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Sustainable soil revival with successional agroforestry

Case study of the Lill-Nägel's Model in Kirkkonummi

FLORENTINE CHE NGONG

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Author: Florentine Che Ngong
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Supervisor(s): Joshua Finch.

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Abstract

Successional agroforestry, an environmental conscious approach to land restoration, offers a promising solution to address soil degradation and biodiversity loss in degraded agricultural landscapes. This degree thesis aimed to investigate the efficacy of the Lill-Nägel's model of successional agroforestry in remediating degraded agricultural soil while promoting biodiversity. The implementation of this model involved the deliberate integration of trees, shrubs, and perennial vegetation into agricultural landscapes, fostering biodiversity, improving soil health, and promoting resilience. The primary objectives included promoting biodiversity, generating income through economic crops, and sequestering carbon to mitigate climate change effects.

The study employed various methods, including biodiversity observation, soil analysis, plant sap analysis, horse manure application, introduction of a drip irrigation system, and application of foliar spray. These methods were applied systematically to monitor and enhance soil health and biodiversity within the pilot plot. Results from the analysis revealed a gradual improvement in soil organic matter (SOM), trace elements, and general biodiversity of plants within the pilot plot. Increased microbial activity and nutrient availability in the soil were observed, leading to enhanced productivity while minimizing input costs, thereby making the agricultural system more economically viable and sustainable.

Above all, the implementation of the Lill-Nägel's model of successional agroforestry demonstrated significant potential in restoring degraded agricultural soil, promoting biodiversity, and fostering sustainable agricultural practices. The findings of this study contribute to the growing body of knowledge on agroforestry systems and their role in addressing soil degradation, biodiversity loss, and climate change mitigation. This research underscores the importance of adopting holistic approaches to land restoration and highlights the potential of successional agroforestry as a viable solution for sustainable agriculture and environmental stewardship.

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1 Introduction

In an era marked by escalating environmental challenges, the loss of soil nutrients stands as a silent yet pervasive threat to the delicate balance of our ecosystems. Coupled with the looming specters of eutrophication and climate change, this depletion of vital soil resources underscores the urgent need for transformative solutions in agricultural practices (Malhi et al. 2021). Amidst this backdrop of ecological crisis, successional agroforestry emerges as a guiding light of hope, offering a holistic approach to land management that addresses the root causes of soil degradation while simultaneously mitigating the impacts of eutrophication and climate change ("Lal, 2012). At its core, successional agroforestry embodies a profound understanding of the interconnectedness between land, plants, and people. By integrating trees, shrubs, and crops in a synergistic arrangement, this approach harnesses the regenerative power of natural ecosystems to restore soil health, enhance biodiversity, and promote resilience in the face of environmental stressors (Schreefel et al., 2020).

The loss of soil nutrients, often exacerbated by conventional agricultural practices, lies at the heart of many environmental woes, from declining crop yields to water pollution and beyond. Through successional agroforestry, however, we could reverse this trend, replenishing soil fertility through the strategic planting of nitrogen-fixing trees, nutrient-rich cover crops, and diverse agroforestry system (Favor, 2021). Furthermore, by reducing nutrient runoff and soil erosion, successional agroforestry serves as a defense against eutrophication, safeguarding our waterways and aquatic ecosystems from the harmful effects of nutrient overload.

In the context of climate change, successional agroforestry offers a dual benefit, both mitigating greenhouse gas emissions and enhancing climate resilience. Through carbon sequestration in tree biomass and soil organic matter, as well as the moderation of microclimates and water cycles, successional agroforestry holds immense potential to mitigate the impacts of climate change on agricultural productivity and food security (Joshi et al., 2016).

Aims

The primary goals of the Lill-Nägel's model of successional agroforestry are as follows: The project aims to use successional agroforestry as a holistic approach to address soil degradation, enhance farm profitability, engage the local community with sustainable agriculture, and implement innovative systems to attract new talent to the field. The project envisions a regenerative and economically viable agricultural landscape, with active participation from both farmers and the wider community.

- To promote biodiversity by creating diverse habitats through the cultivation of cover crops, fruits trees, and grapevines.
- To generate income through the cultivation of economic crops, ensuring economic sustainability during the transition towards a fully agroforestry-based system.
- To sequester carbon in the soil and woody biomass, contributing to climate mitigation.
- Implementing natural methods to restore and enhance soil health and fertility through the integration of trees, shrubs, and crops, thereby promoting sustainable agricultural practices.
- Improving water retention and infiltration in the soil, reducing erosion, and enhancing water quality through the establishment of agroforestry systems that optimize water use efficiency.
- Facilitates the exchange of knowledge and expertise among farmers, researchers, and other stakeholders to promote the adoption of successful agroforestry practices and contributes to ongoing learning and innovation.

1.1 Research questions

- Why restore the soil at the Lill-Nägel’s pilot project plot?
- How successful were the restoration measures at the Lill-Nägel’s farm?
- How was the nutrient and trace elements uptake improved by the plants?
- How was the biodiversity improved at the pilot project plot?
- How do agroforestry systems contribute to climate change mitigation and adaptations?

1.2 Theoretical background

Successional agroforestry represents a holistic approach to land management that integrates ecological principles with agricultural practices to restore degraded lands while promoting biodiversity and sustainability. As global concerns over soil degradation, loss of biodiversity, and climate change escalate, successional agroforestry emerges as a promising solution to address these pressing environmental challenges.

For example, the landscape in the middle hills of Nepal provides a touching example of the transitions occurring in traditional farming systems as forests encroach upon once dominant mosaic landscapes (McGunnigle et al., 2023). This shift reflects broader global trends where agricultural practices, such as monoculture and intensive chemical inputs, have led to soil degradation and loss of biodiversity in many regions. In response, successional agroforestry offers a transformative, drawing upon natural ecological processes to rehabilitate degraded areas.

At its core, successional agroforestry involves the deliberate integration of trees, shrubs, and perennial vegetation into agricultural landscapes, mimicking natural succession processes to establish diverse and dynamic plant communities. By harnessing principles of natural succession, this approach initiates with pioneer species and progresses towards a more complex ecosystem, fostering biodiversity, enhancing soil health, and promoting resilience.

The Lill-Nägel’s model of successional agroforestry exemplifies this innovative approach, focusing on the regenerating soil health through natural methods and maximizing photosynthesis to efficiently capture and utilize solar energy. This model underscores the importance of biodiversity management in restoring soil health, mitigating erosion, and promoting ecological balance.

However, despite the potential benefits of successional agroforestry, there exist knowledge and policy gaps that hinder widespread adoption and implementation. In Brazil, for instance, uncertainties regarding regulations and economic considerations have discouraged technicians from making recommendations and farmers from actively engaging in restoration efforts (Miccolis et al.; 2017).

To address these gaps, this study aims to propose agroforestry options suitable for different contexts, particularly in restoring degraded lands while complying with the provisions of forest laws. By examining the suitability of agroforestry systems for conserving Permanent Preservation Areas (PPAs) and Legal Reserves (LRs), identifying management practices and various contexts, this research seeks to contribute to the advancement of successional agroforestry as a viable strategy for sustainable land management.

Through a comprehensive examination of theoretical background knowledge and empirical research, this work explores the potential of successional agroforestry to address environmental degradation while promoting biodiversity conservation and socio-economic resilience.

2 Method

The successional agroforestry project at Lill-Nägel’s pilot plot endeavors to restore degraded soil and establish sustainable land management practices. To achieve this goal, a comprehensive approach incorporating various methods has been employed to enhance soil health and fertility. The 0.8-hectare plot was meticulously selected, fenced to prevent wildlife interference, and structured into alleys (A), margins (M), and tree lines (T) to optimize land use efficiency and facilitate agroforestry integration. The restoration efforts commenced with the ploughing of the entire plot, followed by the strategic implementation of interventions aimed at soil rejuvenation.

These interventions included the creation of tree lines and the application of horse manure compost to enrich soil organic matter and nutrient content. Furthermore, the strategic planting of rhubarb and willow trees along the tree lines not only served as valuable components of the agroforestry system but also contributed to soil stabilization and nutrient cycling.

Additionally, the installation of a drip a drip irrigation system along tree lines ensured efficient water management strategies and plant sap analysis. Collectively, these methods represent an integrated approach to soil restoration at Lill-Nägel’s pilot project, aiming to foster sustainable agricultural practices and promote ecosystem resilience in the face of environmental challenges.

2.1 Soil sampling and analysis

Soil health is the foundation of any successful agroforestry project, and in Lill-Nagel’s, this aspect is meticulously assessed through soil sampling and analysis. Soil samples are collected from various points within the project area, representing different zones of agroforestry development. These samples are then subjected to a battery of tests, including nutrient analysis, pH levels, organic matter content, and microbial activity assessments. The data obtained from these tests offers valuable insights into the soil’s fertility, structure, and overall health. Regular monitoring allows for adaptive management strategies to maintain or enhance soil quality over time.

The state of the soil as it was in 2022 will be used as a reference point for management. Within the scope of Lill-Nägel's agroforestry pilot project, three management zones were identified which are: margins, alleys, and tree lines. Despite variations in soil types, the trees management practices remained consistent across these zones. Due to budget constraints, only two soil types were selected for testing, demonstrating the project's pragmatic approach.

Soil samples were gathered from both shallow and deeper soil regions as outlined in the project's design. This comprehensive approach aims to evaluate soil health at various depths, revealing that the soil types identified were sand-loam and clay-loam, respectively.

On-farm tests were conducted to compare the locations of the 2022 soil tests with the desired soil sampling program. These tests helped confirm the relative homogeneity of the sites, suggesting that the soil characteristics within each sample and profile can serve as a baseline for all management zones.

"Sample #1" represents shallow soil in a polyculture, while "Sample #2" represents deep soil in a polyculture. This indicates that different soil profiles and depths were considered in the assessment.

Soil samples were collected on August 3, 2022, during a period of prolonged drought with warm air temperatures. This time was significant because it can affect the soil's moisture content and overall condition.

During this period, plant growth stopped due to the drought, which had a negative impact on soil aggregates, as they rely on energy delivered by plants. This suggests that the soil was experiencing stress due to the lack of moisture and plant activity.

2.2 Application of horse manure compost

Applying horse manure compost at the initial stage of this successional agroforestry project before planting of trees and garlic on tree lines have several important benefits:

Compost made from horse manure is rich in organic matter, nitrogen, and other essential nutrients. These nutrients can provide valuable fertilization for soil, helping to enhance its fertility. This is important in agroforestry where trees and crops are planted together. The organic matter in compost can improve soil structure, water retention, and nutrient-holding capacity, all of which contribute to better plant growth.

Organic matter in compost serves as a food source for beneficial microorganisms. These microbes play a crucial role in breaking down organic materials, releasing nutrients, and improving soil health. By adding compost, it promotes a thriving soil microbial community, which can lead to improved nutrient cycling and overall soil health.

Choosing horse manure compost, which is deficient in inherent nitrogen richness, was a deliberate decision for its significance in offering negligible or no nitrogen levels to the agroecosystem. The composting process helps in managing nitrogen levels effectively. This choice is crucial to avoid potential issues associated with excessive nitrogen, which can weaken woody shrubs and trees within the system.

Composting by sustaining optimal temperatures over an extended period; effectively eliminates weeds seeds. At Lill-Nägel’s project, the customary practice involves using compost as a mulch on the soil’s surface to achieve the desired outcomes, this facilitates mechanical weeding and shields the underlying mineral soil, with the addition of nutrients and carbon of lesser importance in the project’s goal.

The utilization of compost in the early phase of the successional agroforestry project offers essential nutrients, enhances soil structure, and promotes the overall well-being of the agroecosystem. This positively impacts the health and growth of both the trees and crops planted along the tree lines.

2.3 The planting of rhubarb and willow trees

Planting rhubarb and willow as companion plants in Lill-Nägel’s successional agroforestry project can serve several beneficial purposes for bioremediating degraded soil (Figure 1). We are uncertain about the suitability of the current planting density for willow, as it hinges on how they react to the project’s management.

Figure 1. Integrating Rhubarb plant and Willow tree into agroforestry

Rhubarb plants are indeed known for possessing deep root systems that play a valuable role in breaking up compacted soil, particularly in degraded or densely packed soil conditions. The extensive root system of rhubarb aids in soil aeration and helps alleviate soil composition, contributing to improved soil structure and fertility. This root system can improve soil aeration and drainage, making it more suitable for other crops. Moreso, the organic matter from rhubarb's large biomass can be left as mulch or incorporated into the soil, enriching it with nutrients and improving its overall structure. Additionally, it's worth noting that rhubarb, being edible, has the potential to be sold, contributing to potential financial returns. Rhubarb can provide shelter for soil and other plants, reducing erosion and wind exposure. This shelter can create a more stable microclimate, protecting the soil from extreme temperature fluctuations and helping to retain moisture.

Willow trees are recognized for their capacity to drop leaves and branches, contributing to the formation of a nutrient-rich layer of organic material on the forest ground. As this organic matter breaks down, it releases nutrients that serve to enrich and replenish the soil's organic content. The presence of willows also encourages the growth of other decomposing organisms and beneficial soil microbes, willow hedges and windbreaks act as effective erosion control and soil stabilizers. Their extensive root systems help bind soil particles together, preventing erosion and enhancing soil structure. This is particularly important in agroforestry projects aimed at restoring or improving degraded soil. Willows are one of the first plants to flower in early spring, providing essential nectar and pollen for pollinators. Supporting pollinators can lead to better fruit tree pollination, increasing fruit yield in the agroforestry system.

Therefore, planting rhubarb and willow as companion plants in Lill-Nägel's successional agroforestry project is a well-thought-out strategy for bioremediating degraded soil. Rhubarb's contribution includes soil improvement, shelter, and biomass for soil nourishment, while willow trees offer erosion control, soil stabilization, and pollinator support. These benefits collectively contribute to the overall health and productivity of the agroforestry system, helping to restore and improve the soil for sustainable agriculture.

2.4 Drip irrigation system

The provision of drip irrigation kits at Lill-Nägel's successional agroforestry project is crucial for several reasons to bioremediate the degraded soil (Figure 2).

Figure 2. Netafin water filter and drip lines for water supply.

Drip irrigation provides a consistent and controlled water supply to the plants. In regions prone to drought, like the area where the project is located, consistent moisture is essential for plant growth. This helps in preventing water stress and ensuring the plants receive adequate hydration during dry spells.

Drip irrigation allows for precise water application directly to the root zones of plants. This efficient water distribution method reduces water wastage and minimizes the risk of overwatering or underwatering. It helps in maintaining optimal soil moisture levels, which is vital for bioremediation and plant growth. Drip irrigation significantly improves garlic production, as garlic is particularly sensitive to water stress. Consistent moisture during its growth cycle can lead to better bulb development, increased yield, and improved crop quality.

Drip irrigation kits can enhance the growth rate of fruit trees and grape vines. These are long-term investments in the agroforestry system and ensuring their health and vigor is crucial for the overall success of the project. Drought and irregular weather patterns can negatively affect plant growth and soil health. Drip irrigation acts as a buffer against climate uncertainties, ensuring that the soil and plants receive the necessary moisture, even during dry spells.

Adequate and controlled irrigation helps facilitate the bioremediation process by ensuring that the soil is consistently provided with the right conditions for the restoration of its structure and fertility. This is especially important in degraded soil where water management plays a critical role in soil improvement.

The provision of drip irrigation kits at Lill-Nägel’s s agroforestry project is essential for mitigating the impact of drought, supporting a diverse range of crops, boosting garlic production, and promoting healthy tree and vine growth. It contributes to the overall success of the agroforestry project and helps in the bioremediation of degraded soil by maintaining consistent soil moisture and fostering plant health and productivity.

2.5 Application of foliar spray

The application of foliar spray consisting of seaweed extract, fish hydrolysate, and compost extract may serve as a strategic approach to enhance plant growth and metabolic uptake of nutrients for several reasons (Figure 3).

Figure 3. Tractor applying foliar spray on plants at Lill-Nägel's pilot project.

Seaweed extract, fish hydrolysate, and compost extract are rich sources of essential nutrients such as nitrogen, phosphorus, potassium, and micronutrients. By applying these extracts directly onto the leaves of plants, nutrients are readily absorbed by the foliage and transported to various parts of the plant, supporting overall growth and development.

Figure 4. Seaweed extract and fish hydrolysate for foliar application.

Seaweed extract contains bioactive compounds such as cytokinin's, auxins, and betaines, which can help mitigate the negative effects of environmental stressors such as drought, salinity, and temperature extremes. Fish hydrolysate also contains amino acids and peptides that act as natural growth promoters and stress alleviators. By applying these extracts foliarly, plants are better equipped to withstand adverse conditions, allowing them to allocate more resources towards growth and nutrient uptake.

Seaweed extract contains compounds that can stimulate plant metabolism and hormone production, leading to increased photosynthesis, nutrient assimilation, and overall metabolic activity. Fish hydrolysate also contains growth-promoting substances that can enhance metabolic processes within the plant. By applying these extracts foliarly, plants are encouraged to allocate more energy towards growth and nutrient utilization, resulting in improved vigor and productivity.

The combination of seaweed extract, fish hydrolysate, and compost extract in a foliar spray provides a synergistic approach to promote plant growth and enhance the metabolic uptake of nutrients, contributing to improved plant health, vigor, and productivity at Lill-Nägle’s pilot project plot.

2.6 Near infrared spectroscopy, (NIR)

Near Infrared Spectroscopy (NIR) is a non-destructive analytical technique used for soil analysis, which can provide valuable information about the composition and characteristics of soil samples. In the context of Lill-Nägels soil analysis, NIR was used to assess various soil properties, and the results were compared to conventional soil tests.

NIR can determine the reserves of major macro and micronutrients in the soil. In this case, it showed that Sample 2 had higher nutrient reserves across the board, but this did not necessarily indicate better soil health. For example, the total nitrogen reserves were high in both samples, but the soil lacked the capacity to release this nitrogen to plants effectively.

2.7 Plant sap analysis

Plant sap analysis is a scientific technique used to assess the nutrient status and overall health of plants by analyzing the liquid sap extracted from plant tissues, typically from leaves or stems (Figure 5). This analysis involves measuring the concentrations of various essential nutrients, such as macronutrients (e.g., nitrogen, phosphorus, and potassium) and some micronutrients (e.g., iron, zinc), as well as other important compounds like sugars and ions. Plant sap analysis provides valuable insights into a plant’s nutrient uptake, nutrient deficiencies, and imbalances, helping growers and agronomists make informed decisions about fertilization and crop management to optimize plant growth and yield.

Figure 5. Plant samples processing for sap analysis.

In the realm of regenerative agriculture, the quest for sustainable nutrient-rich crops has given rise to innovative techniques that harmonize with nature’s processes. One such method is plant sap analysis, a tool that has gained attention for its ability to fine-tune agricultural practices and boost soil health.

Plant sap analysis involves testing plant sap to gauge nutrient levels and identify deficiencies. By scrutinizing nutrient mobility within plants, particularly mobile nutrients like nitrogen (N), phosphorus (P), potassium (K), and magnesium (Mg), this technique unveils a plant’s nutritional status in a highly detailed manner. The process revolves around assessing the oldest yet viable leaves and the youngest fully mature leaves.

In this section of my thesis, I incorporate insights from my blog post on plant sap analysis, which has become an integral component of my research at Lill-Nägel’s project. The blog post, originally published on Regenerative Agriculture with Plant Sap Analysis (Che Ngong & Finch, 2023). Lill-Nägel’s case delves into the nuances of plant sap analysis. It is important to note that certain sections have been recopied and rephrased from the blog post with the author’s permission. For further details and the original content, please refer to blog post (Novia University of Applied Science, 2023)

At Lill-Nägel’s, plant sap analysis is being used as cornerstone for sustainable growth. This technique, intended to be performed every two weeks, serves as a navigational tool, providing insight into the impact of agricultural interventions. Representative samples are ideally collected and analyzed before and after the application of a foliar spray.

The collected data from Lill-Nägels will highlight the foliar spray had a notable impact on plant health and nutrient content. Initially, soil samples were gathered from both shallow and deeper soil regions for laboratory analysis. Additionally, on-farm tests were carried out along an axis approximately 30 meters from the starting point in each direction. On the 3rd of August 2022, soil profiles were excavated at four separate locations, revealing signs of insufficient natural soil processes.

3 Results

The implementation of successional agroforestry at Lill-Nägel's pilot project represents a concerted effort to address soil degradation and promote sustainable land management practices. Through the integration of various methodologies aimed at enhancing soil health and ecosystem resilience, the project seeks to yield tangible outcomes that not only demonstrate the efficacy of agroforestry but also provide valuable insights for future agricultural endeavors.

This section presents an overview of the results obtained from the implementation of key methods at Lill-Nägel's pilot project, shedding light on the project's achievements in soil rehabilitation, crop productivity, and environmental sustainability. From soil nutrient replenishment to crop growth dynamics and ecological interactions, the findings elucidate the transformative potential of successional agroforestry in mitigating the adverse effects of conventional farming practices.

Through soil sampling and analysis, the project gained critical insights into the baseline soil conditions and nutrient deficiencies, laying the foundation for targeted interventions. The application of horse manure compost facilitated the replenishment of organic matter and essential nutrients, leading to noticeable improvements in soil structure and fertility over time. Also, the strategic planting of rhubarb and willow trees served as dynamic components of the agroecosystem, contributing to biodiversity enhancement, erosion control, and microclimate regulation.

The deployment of a drip irrigation system proved instrumental in optimizing water use efficiency and mitigating drought stress, ensuring sustained crop growth and productivity throughout the growing season. Complementing this, the application of foliar organic spray provided natural nutrients and pest management solutions while minimizing environmental impact, fostering a balanced agroecosystem conducive to crop health and vitality.

Moreso, the utilization of plant sap analysis offered valuable insights into plant nutrient status and physiological responses, facilitating timely adjustment strategies for optimal growth and yield. Together, these results underscore the synergistic effects of integrating diverse practices within a successional agroforestry framework, culminating in improved soil health, increased crop yields, and enhanced environmental sustainability at Lill-Nägel's pilot project.

The findings presented in this work not only validate the efficacy of successional agroforestry as a viable solution for soil rehabilitation but also underscore its potential to revolutionize modern agricultural practices towards a more regenerative and resilient future.

3.1.1 The initial state of the pilot plot at Lill-Nägel's farm

The farm has been practicing long-term monoculture, primarily cultivating cash crops like wheat and peas. Monoculture involves the cultivation of a single crop in the same area, which over extended periods of time can lead to a reduction in biodiversity. In this case, growing wheat with herbicides and ploughing prevents the growth of other plants in the area.

The farm has been heavily reliant on chemical fertilizers for crop production. While these fertilizers can boost crop yields, they can also have adverse effects on soil health and microbial diversity. The excessive use of chemical fertilizers may have contributed to nutrient imbalance in the soil.

Ploughing has been a frequent practice on this farm, it disrupts the natural structure of the soil, harming beneficial organisms like earthworms, and can lead to a decrease in soil biodiversity.

The topography of the project's site provides efficient drainage, which may reduce water retention in the soil. This could affect the availability of moisture and nutrients for different plant species, further impacting biodiversity.

To tackle soil depletion, the farmer takes breaks by leaving the land fallow and uses natural management practices at Lill-Nägel's farm. The farmer also transforms some arable land into grass, avoids using chemical fertilizers, and in return receives subsidies from the government. However, this grass species did not effectively restore the soil's health. The choice of a non-flowering plant suggests that there may have been limited consideration for attracting pollinators like insects and honeybees.

The overall biodiversity on the farm is described as poor, this applies to both the plant species (flora) and the animal species (fauna) present. Monoculture, chemical use, and lack of diverse plant types contributed to the absence of flowering plants that can attract pollinators and support a variety of wildlife.

The Lill-Nägels farm's initial state showed an apparent lack of biodiversity, both in terms of plant species and the fauna that rely on them. The farm's heavy reliance on monoculture, chemical fertilizers, and disruptive agricultural practices had led to soil nutrient depletion and a less hospitable environment for a diverse range of flora and fauna. Addressing these issues is essential for restoring and promoting biodiversity on the farm and improving its overall ecological health.

3.1.2 Soil health and biodiversity at Lill-Nägel's farm

The soil biology for Lill-Nägel's Pilot Project, conducted during the summer of 2022, provides valuable insights into the initial state of the soil and its intricate food web. The soil food web analysis unveils a varied ecosystem with fluctuations in the populations of different soil organisms in both shallow and deep baselines. In the shallow baseline, the count of beneficial organisms was 8168.4 µg, and in the deep baseline, it was slightly less at 7337.7 µg. These organisms play a crucial role in promoting soil health and fertility.

The decomposer community showed variations between the shallow and deep baselines. The shallow baseline had 39 fungi, 8129 bacteria, and 0.4 actinobacteria. In contrast, the deep baseline exhibited higher numbers, with 88 fungi, 7249 bacteria, and 0.7 actinobacteria. Also, the analysis of predators, such as flagellates, showed zero counts in both shallow and deep baselines. Amoeba were not detected in the shallow baseline, while a recorded presence of 32,608 microgram (µg) in the deep baseline is considered insignificant. Moreso, bacterial feeding nematodes were absent in both shallow and deep baseline. Fungi-feeding nematodes were present in the shallow baseline (200) but absent in the deep baseline, while predatory nematodes showed zero counts in both baselines.

Detrimental organisms, including Oomycetes, were present in the shallow baseline (62) but absent in the deep baseline. Root-feeding nematodes were found in the shallow baseline (200) but not in the deep baseline. Anaerobic protozoans, such as ciliates, were absent in both shallow and deep baselines.

The initial state of the soil at Lill-Nägel's Pilot Project in the summer of 2022 reflects a soil ecosystem heavily skewed in favor of bacteria. The variations in the populations of beneficial organisms, decomposers, predators, nematodes, and detrimental organisms underscore the complexity of the soil-food web. Understanding these dynamics is crucial for implementing effective soil management practices and ensuring the overall health and sustainability of the soil ecosystem in the pilot project.

3.1.3 Soil sampling analysis

The soil samples consistently exhibited water infiltration rates of less than one minute per half-liter of water, which is noteworthy considering the unfavorable condition of the soil which is attributed to prevailing drought conditions. It is noteworthy that, in comparison with Rikard's other fields exhibit significantly longer infiltration times, exceeding 1 to 2 hours, particularly in clay and clay-loam soils. Even though the plants have a shallow and weak root system, the results indicate that perennial grass, pre-existing in the agroforestry project, surpasses bare soil in performance compared to traditional soil management with tillage and herbicides when it comes to holding and soaking up water. The composition of the Lill-Nägel's soil in 2022 seems to have been shaped primarily by decades of management practices, with the prolonged summer drought playing a lesser role. The soil was characterized by stable conditions in some management zones, while others were affected by the drought's impact on soil aggregates and water infiltration rates. Continued monitoring and data collection will be important for understanding and managing the soil's composition and health in the future.

Sample #1 Soil Profile at T1during summer of 2022.

The following text is a paraphrased rendition of information obtained from the soil profile at T1 during the summer of 2022 (Figure 6). sourced from the recent soil analysis at Lill-Nägel's farm indicated significant findings in soil health (Novia University of Applied Sciences, 2023).

Figure 6. T1: Shallow Soil 1

Surface Characteristics

The surface layer of soil exhibits a poor decomposition rate, this could be attributed to monoculture, specifically the continuous growth of grass, and suboptimal carbon-nitrogen ratio. This suggests that the organic matter in this layer is breaking down slowly.

The mulch might not be in direct contact with the soil surface, this can affect organic matter decomposition and moisture retention in the topsoil.

Grass roots are present and extend to the bottom of the soil profile, reaching up to 50cm in depth. Additionally, there are small tunnels and burrows present, which may indicate the activity of soil-dwelling organisms.

Root Distribution

The highest root density is observed at the surface, particularly in the top 20cm layer. This suggests that the most active root system is concentrated in this upper portion of the soil.

The most active topsoil is found within the 10cm depth, where grass rhizomes and mowing residues have been deposited. This is the area where the most active microbial decomposition and nutrient cycling are occurring.

Despite the uniform root system observed, the root population decreases rapidly after the 20cm depth. This is attributed to the prolonged monoculture, indicating that there is limited root diversity and depth beyond this point.

Aggregates and Soil Composition

Root aggregates are evident until a depth of 20cm from the surface. These aggregates tend to grow and decrease in number as you move deeper into the soil profile.

The soil is compact and rocky, with some areas containing a considerable proportion of sand in addition to clay. This suggests variability in soil texture within the profile.

Subsoil and Below

Root Absence: Below the active root zone (20-25cm), approaching the subsoil, root aggregates almost disappear, and there is no indication of soil coloration. This suggests a lack of root activity and organic matter in this region.

Soil Organisms: While root activity diminishes below 20cm, there are still traces of earthworm burrows and some soil insects. This indicates the presence of soil organisms even in deeper layers.

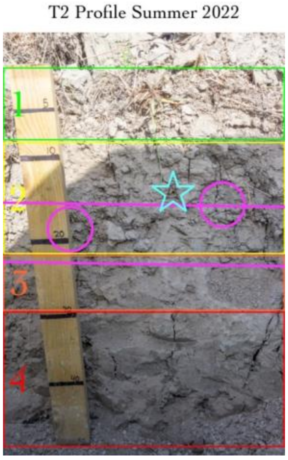
Rooting Depth and Diversity

The maximum rooting depth is observed at 20cm, which is low. This limited rooting depth may be a consequence of residues from ploughing or the presence of crop stubble that has not yet fully decomposed.

The lack of plant diversity is highlighted, with all roots belonging to the same species. This monoculture condition restricts root diversity and potentially limits soil health.

I think if the ecosystem is improved by diversifying plant species and enhancing organic matter decomposition, the soil can recover faster. This implies that interventions aimed at increasing plant diversity and enhancing soil biological activity may be beneficial for restoring soil health in this profile.

The soil profile at T1 in the summer of 2022 shows signs of poor decomposition at the surface, a concentrated root system in the upper layer, limited root diversity and depth, variability in soil texture, and potential for improvement through ecosystem enhancement measures.



T2 Profile Summer 2022

Figure 7. T2 deeper soil in the upper-mid slope

The soil profile at T2 which represents deep soil in the upper-mid slope, can be described as follows:

Surface Characteristics

Like T1, the soil surface at T2 exhibits characteristics of grass cover (Figure 7), however in T2, the grasses are described as dark green, due to the presence of deeper soils.

Grass roots are present in the soil profile, and there are small tunnels and burrows observed, indicating activity of soil-dwelling organisms.

Root Distribution

The densest root system at T2 is found in the top 10cm of the soil profile. Root density decreases more rapidly compared to T1, which suggests that the concentration of roots is in the uppermost layer.

Like T1, the root system in T2 is uniform due to monoculture, indicating a lack of root diversity.

Aggregates and Soil Composition

The finest aggregates are located right under the soil surface where the densest root system is present. In this area, aggregates are less compacted compared to T1. However, aggregates in general are poor.

The soil at T2 has a higher clay content, this higher clay content may influence soil properties and behavior.

Transition Zone to Subsoil

The transition zone between the topsoil and subsoil at T2 is less obvious but can be determined by shifts in root density and the presence of residues from ploughing. The transition zone is characterized by larger rocks, and the color shift is less dramatic, occurring at a depth of 25cm.

Subsoil and Below

Below the transition zone, the soil profile still exhibits some signs of biological activity. Earthworm burrows are present, and a few soil-borne insects are observed. The soil smells earthy, indicating some level of soil organic matter and microbial activity.

Soil Health and Management

The soil at T2 benefits from perennial grass cover, which makes it easier to work despite having a higher clay content. However, the root systems are described as less developed, and strong root depth is reported to be poorer at 10-15cm. This suggests that the soil may not be in optimal health.

Note that T2 soil represents deep soil on the upper-mid slope and shares some similarities with T1, such as a uniform root type due to monoculture. However, T2 has a higher clay content, exhibits a less compacted transition zone, and is benefiting from perennial grass cover. Despite these positive aspects, there are still signs of soil health issues, including poor root development at certain depths, indicating that further soil management practices may be necessary to improve its overall health.

The Soil Profile at T4

Representing deeper soil in the Low-mid Slope (Figure 8), is characterized by several noteworthy features:

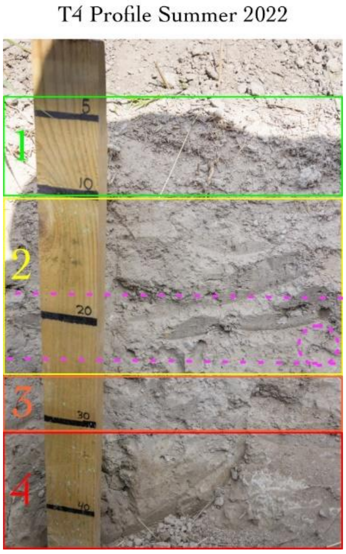

T4 Profile Summer 2022

Figure 8. The soil profile at T4.

Surface characteristics

Unlike T1 and T2, the soil at T4 exhibits increased diversity, in addition to grasses, clover plants are growing, suggesting a more diverse ecosystem.

The soil profile at T4 contains grass and clover roots, as well as small tunnels and burrows extending to a depth of 50cm. This indicates active soil-dwelling organisms and root penetrating to significant depths.

Residues from ploughing are present in the soil, suggesting past cultivation practices.

Root Distribution

The densest root system is found near the surface, particularly in the top 10cm. This dense root system is associated with the finest aggregates in this area.

Direct soil observation reveals both grass and nodulated clover roots, indicating that nitrogen is actively being fixed. This suggests a more sustainable nutrient cycle within the soil.

Soil Aggregates and Composition

The finest aggregates are found right under the soil surface where the densest root is present. The aggregates contribute to a loose and friable soil structure.

Soil Texture: The soil is easy to work, with few stones or large rocks, despite compaction, it retains an earthy smell, indicating the presence of organic matter and microbial activity.

Soil Fauna and Biological Activity

While there are no earthworms observed, a few soil-borne insects are present, although not in significant numbers. The presence of soil-dwelling organisms is an indicator of soil health.

Burrows are not evident in this soil, suggesting that soil fauna activity may be limited compared to other profiles.

Subsoil and Residues

The subsoil at T4 shows signs of the presence of oxygen, which is contributing to the overall health of the soil.

Residues from past ploughing practices are still evident in the soil, even years later. This indicates that natural soil processes are not functioning at an optimal level. Biologically active soil should break down these residues quickly.

The soil profile at T4 reflects a more diverse and biologically active ecosystem compared to T1, and T2. The presence of clover (Figure 9), and the associated nitrogen fixation, along with increased plant diversity, contribute to a healthier soil ecosystem. The soil is easier to work with, has better aggregation, and retains moisture well.

Figure 9. Red clover plant at T4

However, despite these positive attributes, the presence of residues from past ploughing practices suggests that conventional farming methods, including monocultures and chemical use, may have discouraged healthy soil development. The goal should be to continue promoting diverse plant communities and soil biological activity to enhance the soil’s natural processes and nutrient cycling, leading to improved soil health and sustainability.

3.1.4 Conventional soil test for Lill-Nägel’s project

The content below is a rephrased representation of information retrieved from the source at “The conventional soil analysis at Lill-Nägel’s farm that provided detailed insights into the soil’s condition” (Novia University of Applied Sciences, 2023).

Soil Organic Matter (SOM)

In Sample 1, the conventional test indicated a soil organic matter content of 3.3%, falling within the range of 3-5.9%.

While in Sample 2, the conventional test indicated a soil organic content of 6-11.9%.

The NIR test for Sample 2’s organic matter percentage was found to be 3.7%, while sample 1 had a lower value of 3.3%. Sample 2’s conventional soil organic matter (SOM) range deviates from the near-infrared (NIR) results. The lower limit indicated by the conventional test is 1.6 times higher than the corresponding value obtained through the NIR and suggests that both samples have a low soil organic matter content. Thus suggests a need for soil ecosystem improvement.

a. pH

Both samples returned a pH measurement of 5.3, indicating that the soil is acidic. To improve soil pH, increasing biodiversity in the soil is recommended, as it can help buffer the plants against the acidic state of the soil. Therefore, liming may not be necessary if soil ecosystem is improved.

b. Calcium (Ca)

Both samples had low levels of available calcium, with 630 and 1000mg/L. The reserve of calcium as indicated by the conventional test was 1500 and 1800mg/L, well above the available pools. These levels suggest that there is a substantial reserve of calcium in the soil.

c. Phosphorus (P)

The available phosphorus levels in both samples were quite low. The conventional report indicates that the phosphorus reserve is 50-80 times larger than the available pools, and the NIR test results suggest that the reserve is even higher. This implies that there is a significant amount of phosphorus stored in the soil, but it is not readily available to plants. Proper management practices are needed to make this phosphorus more accessible to crops.

d. Sulphur (S)

Sulphur levels in both samples were low, with 9.2 and 5.9mg/L. This indicates a deficiency of Sulphur in the soil, which may need to be addressed through appropriate fertilization, but remember we do not need any artificial fertilizer.

e. Cation Exchange Capacity (CEC)

CEC is a measure of the soil's ability to bind and supply nutrients. In this case, the soil samples are under-saturated with calcium (Ca), and over-saturated with magnesium (Mg). Given the substantial clay fraction in the soil (approximately 30%), the CEC should naturally average. This suggests a need for balanced nutrient management to address the CEC imbalance.

However, the conventional soil test results at Lill-Nägels farm shows a need for improving soil organic matter content, increasing pH, addressing calcium, phosphorus, and Sulphur deficiencies, and balancing the cation exchange capacity. These improvements will help make the soil more fertile and better suited for crop growth. Proper soil management practices should be implemented to address these issues effectively.

3.1.5 Near infrared spectroscopy (NIR)

The subsequent text has been rephrased from information found in the source regarding Near Infrared Spectroscopy (NIR), available at (Novia University of Applied Sciences, 2023). NIR can determine the reserves of major macro and micronutrients in the soil (Pereira et al, 2007). In this case, it showed that Sample 2 had higher nutrient reserves across the board, but this did not necessarily indicate better soil health. For example, the total nitrogen reserves were high in both samples, but the soil lacked the capacity to release this nitrogen to plants effectively. NIR provided information about soil organic matter (SOM) and the carbon-to-SOM ratio. The near-infrared spectroscopy (NIR) analysis indicated that the soil had a low organic matter content, ranging from 3,3% to 3,7%. The pH level was measured at 5.3, indicating a distinctly acidic nature. Furthermore, the samples displayed limited availability of calcium, with concentrations ranging between 630 and 1000 mg/L. Phosphorus, sulfur, and nitrogen levels were also found to be deficient.

The original schedule called for sampling every 2-3 weeks, but because of a drought, we faced a shortage of materials to gather. Consequently, the samples could not be collected until after the spray had already been administered to the plants. Before the spray, measurement in some key parameters such as nitrogen (N), phosphorus (P), and potassium (K) were all sufficient in the soil but was not readily available for plant uptake, meanwhile some trace elements were found to be deficient from plant samples with deficiencies in Fe, Zn, and Mo as compared to conventional standard listed by Novacropcontrol.

Significant improvements in these measurements coincided with the introduction of foliar spray, underscoring the effectiveness of the treatment in addressing nutrient imbalances. The composition of foliar spray, a concoction of natural ingredients including fish hydrolysate, seaweed extract, and compost extract, played the pivotal role in the observed changes. This cocktail of organic elements not only contributed to nutrient replenishment but also fostered a holistic approach to plant health, aligning with the principles of regenerative agriculture. There was excess of both Nitrogen (N), Phosphorus(P), and potassium (K), while there was a significant increase in trace elements like Fe, Zn, and Mo.

The NIR analysis in Lill-Nägels soil assessment is a valuable tool for quickly assessing various soil properties. It can provide insights into nutrient reserves, organic matter, microbial communities, and the soil food web. However, it is important to interpret the results in conjunction with other soil tests and consider the specific needs of the soil and crops in question to make informed agricultural decisions.

3.1.6 Plant sap analysis at Lill-Nägel’s farm may prove valuable

1. By pinpointing specific nutrient imbalances, farmers could tailor their interventions and reduce input wastage, resulting in cost savings.
2. The bi-weekly analysis may provide a real-time snapshot of plant health and soil quality, enabling farmers to make informed decisions and track the efficacy of their interventions.
3. With a focus on both the macro and micronutrients, the analysis shed light on the complex interplay between plant nutrient and soil quality. This knowledge will guide farmers towards practices that progressively improve soil health.

Table 1. Alleys sap analysis of some major and trace elements before foliar applications.

Sampling date	Cultivar	N-ppm	P-ppm	K-ppm	Fe-ppm	Zn-ppm	Mo-ppm	Ca-ppm
24.07.2023	CC-A1	2376	910	7356	2.29	0.85	0.03	520
24.07.2023	CC-A2	2537	491	7149	1.43	0.74	0	644
24.07.2023	CC-A3	1308	632	5357	0.74	1.53	0.08	991
24.07.2023	CC-A4	1998	746	6790	0.74	1.53	0.05	915

Table 2. Alleys sap analysis after foliar fertilizer application.

Sampling date	Cultivar	N-ppm	P-ppm	K-ppm	Fe-ppm	Zn-ppm	Mo-ppm	Ca-ppm
31.07.2023	CC-A1	2615	933	7767	1.90	1.60	0.05	476
31.07.2023	CC-A2	1681	736	6335	2.94	3.36	0.05	869
31.07.2023	CC-A3	2122	831	7131	2.27	1.62	0.12	1379
31.07.2023	CC-A4	2386	959	7885	7.24	1.40	0.12	1041

Table 3. Difference in sap analysis before and after foliar fertilizer application.

Cultivar	N-ppm	P-ppm	K-ppm	Fe-ppm	Zn-ppm	Mo-ppm	Ca-ppm
CC-A1	239	23	411	-0.39	0.75	0.02	-44
CC-A2	-856	245	-814	1.41	2.62	0.05	225
CC-A3	814	199	1774	1.53	0.09	0.04	1288
CC-A4	388	213	1095	6.5	-0.13	0.07	247

The analysis of sap, both prior (Table 1), to and following the implementation of foliar spraying (Table 2). Reveals that certain elements have exceeded their optimal levels, including phosphorus and nitrogen. Additionally, trace elements like zinc and molybdenum have shown significant enhancements. However, there remains an observable calcium deficiency in alleys and the difference in nutrients both before and after foliar application (Table 3).

In conclusion, the Lill-Nägels case study illuminates the potential of plant sap analysis as a transformative tool in regenerative agriculture. By offering a nuanced understanding of nutrient mobility and deficiencies, this technique may empower farmers to make timely and targeted interventions. The story of Lill-Nägels may demonstrate how plant sap analysis can harmonize with regenerative practices, contributing to a future where agricultural sustainability is delicately balanced with ecological vitality.

3.1.7 Present state of the soil at the Lill-Nägel's pilot project plot

The initiation of the management system in Lill-Nägel's successional agroforestry project has shown promising early signs of enhancing biology and overall soil health. Thes positive developments can be linked to several factors and practices introduced in the project.

1. Increased flora and fauna diversity

By planting a wide variety of cover crops and fruit trees, the project has created a more diverse plant community. This diversity provides numerous benefits:

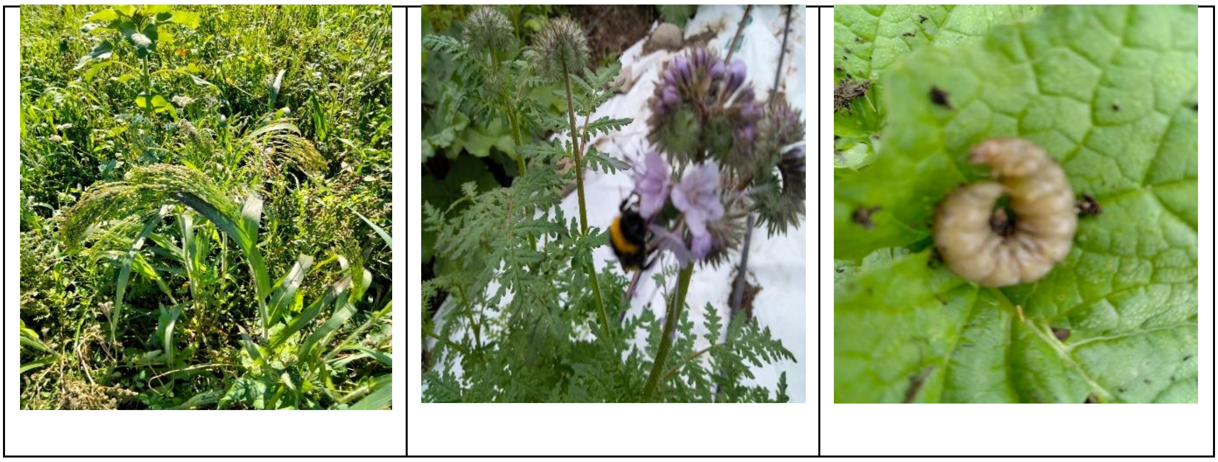


Figure 10. Increased plant diversity (left), honey flower with bees (middle), increased insects' diversity on plants (right).

The introduction of cover crops like clovers, radish, millet, honey flowers, and sunflowers, along with fruit trees such as pear, cherry, plum, and currants, has significantly increased plant biodiversity in the area. This is essential for soil health because different plants contribute various organic materials and nutrients to soil, preventing soil exhaustion.

Flowering cover crops such as honey and sunflowers have bright, attractive flowers that draw in a variety of insects, including bees and butterflies. These insects play a vital role in pollinating both the cover crops and fruit trees, promoting their growth and reproduction.

2. Soil structural improvement

The soil samples analyzed from the pilot project as from 29.08.2022- 30.10.2023 using the NIR spectroscopy analysis shows positive signs of enhanced nutrient dynamics, microbial activity, and soil structure. Fluctuations in nutrient levels and microbial activity are natural in transitional stages and may signify dynamic ecological processes. The data provided through NIR spectroscopy offers valuable insight for sustainable land management practices in successional agroforestry. Sustained monitoring and responsive management, informed by laboratory analysis, will play a crucial role in continuously improving soil health and ensuring the success of the agroforestry endeavors.

The findings underscore the importance of informed decision-making, on sustainability, and adaptability in achieving long-term success in agroforestry initiatives.

3. Enhancing soil organic matter (SOM)

The observed patterns in soil organic matter levels can be explained by a combination of seasonal dynamics, agricultural practices such as tillage, and the inherent processes within the agroforestry system. The overall increase in soil organic matter during summer 2023 suggests that the agroforestry practices and ecological processes in place are contributing to the enhancement of soil health and organic matter content in the project area. This is pivotal for soil health because soil organic matter serves as a reservoir of essential nutrients. As it breaks down, it releases these nutrients back into the soil, making them available for plant uptake.

Organic matter helps the soil retain moisture, reducing the risk of drought stress for plants. Soil organic matter provides a food source for soil microorganisms. These microorganisms play a critical role in breaking down organic matter, further enriching the soil.

4. Microbial activity and earthworms

The observed increase in earthworm numbers(Figure 11), from summer 2022 to summer 2023 is likely a result of the positive impact of agroforestry practices on soil health, organic matter input, reduced tillage impact, and the creation of a balanced and diverse ecosystem. These factors collectively contribute to a more hospitable environment for earthworms to thrive and multiply. This has numerous benefits:

Figure 11. Evidence of the presence of earthworms

Soil microorganisms break down organic matter, converting it into nutrients that plants can readily use. Earthworms' population increased, improving soil structure by creating channels as they burrow. This enhances soil aeration and water infiltration. Earthworms, as well as other microorganisms, consume organic matter and excrete nutrient-rich castings. This not only enriches the soil but also enhances its microbial population.

The management system at Lill-Nägel's successional agroforestry project will be fostering a harmonious ecosystem where diverse plant life, pollinators, soil microorganisms, and earthworms work together to improve soil structure, nutrient availability, and overall soil health. The combination of increasing flora and fauna diversity, organic matter accumulation, and enhancing microbial activity is rejuvenating the soil, ensuring its long-term sustainability and productivity. This approach not only benefits the current agricultural practices but also lays a solid foundation for the future success of the project area.

5. Plant sap analysis

Plant sap analysis provides valuable insights into the nutritional status of plants and can be a powerful tool for assessing the effectiveness of soil improvement methods (Table 3). In the case of Lill-Nägel's pilot project, the sap analysis results offer a glimpse into the positive impact of natural means on soil fertility. Here plant sap analysis can be used to evaluate the improvement in degraded soil as follows.

Analysis of plant sap revealed abundant levels of nitrogen in plants, deemed suitable or even excessive before the foliar spray application (Table 1). Additionally, cover crops such as vetch and clovers failed to establish well due to drought conditions, resulting in minimal contributions of new nitrogen from these cover crops. While nitrogen is essential for plant growth, excess can lead to increased susceptibility to pests, as indicated in the diagram.

The elevated levels of micronutrients, such as calcium, iron, zinc, and molybdenum, are probably due to the use of an organic foliar spray that incorporates fish hydrolysate, seaweed extract, and compost extract. Foliar spray containing these elements has played a crucial role in supplementing the micronutrient content of the plants (Table 2). Fish hydrolysate provides essential amino acids and micronutrients, while seaweed extract contributed to overall plant health. Compost extract adds microbial diversity, further enhancing nutrient availability.

The correlation between increased nitrogen levels and heightened pest pressure aligns with well-established ecological principles (Panda et al, 2013). Plants with high nitrogen content are often more attractive to pests. This observation emphasizes the need for a balanced nutrient management approach to avoid unintended consequences (see Figure 12).

Figure 12. Increased in pest pressure on radish plants

Plant sap analysis at Lill-Nägel's pilot project provides a snapshot of the positive outcomes of the implemented natural means for soil improvement. The observed changes in nutrient levels, plant health, and pest pressure strongly suggest that the holistic and sustainable practices applied in the project have indeed contributed to the enhancement of soil fertility and overall ecosystem health.

3.1.8 Comparative analysis

a. Plough pan and soil health

The initial assessment revealed the presence of a plough pan at a consistent depth in the soil, including soil composition. This suggested that soil natural processes cannot function optimally. The project recognized that ploughing, monoculture, and chemical use had discouraged healthy soil development. This understanding led to aa shift in soil management practices.

b. Soil compaction and soil biodiversity

Soil compaction from ploughing can negatively impact soil biodiversity. The presence of few earthworm traces and some soil insects suggested a decline in soil health and diversity. The transition to planting perennial grasses has already begun to repair the damage. The provision of an irrigation system in Lill-Nägel's agroforestry project likely contributes to the increment in earthworm numbers by creating favorable soil conditions, improving soil structure, and providing a diverse and abundant food source through healthier plant growth. Evidence of earth burrows and healthy large worms indicates an improvement in soil health and biodiversity.

c. Plants and insect biodiversity

The initial state showed limited diversity in both plant and insect species, likely due to monoculture practices. The notable increase in the presence of a diverse array of plant species such as honey flower, radish, willows, sunflower, clovers, and various insect species including honey bees, caterpillars, butterflies, and earthworms is a positive indication of significant biodiversity improvement within the agroecosystem. This diversity is crucial for a thriving agroecosystem, which the successional agroforestry project aims to promote.

d. Long-Term Sustainability

The initial findings highlighted a potentially unsustainable agroecosystem due to soil degradation and limited biodiversity. The shift towards perennial grasses and other perennials, followed by annual crops, helps improve soil condition at Lill-Nägel's pilot project by promoting better soil structure, increasing organic matter content, controlling erosion, mitigating drought impacts, and optimizing nutrient cycling through a well-designed crop rotation system.

e. Ecosystem resilience

The initial conditions suggested a lack of resilience in the agroecosystem, making it susceptible to environmental stressors. The presence of earthworms, diverse plants, and insects indicates improved ecosystem resilience. Agroforestry practices can enhance the system's ability to withstand disturbances and adapt to changing conditions.

The Lill-Nägel's successional agroforestry project has made notable strides in improving soil health, increasing biodiversity, and fostering a more sustainable and resilient agricultural ecosystem. The shift away from detrimental practices and the adoption of agroforestry techniques have played a pivotal role in these positive changes. This comparative analysis demonstrates the project's success in transitioning toward a more ecologically sound and productive agroecosystem.

4 Discussion

The successional agroforestry pilot project at Lill-Nägel's farm will stand as an innovative endeavor to remediate degraded soil resulting from prolonged monoculture and intensive synthetic fertilizer use. Through a holistic approach encompassing various natural methods, this project strives to restore soil health and enhance overall ecosystem resilience. The implications of the findings from site selection to the application of foliar spray could be significant, a noteworthy contribution to the fields of agroforestry and soil rehabilitation.

The transition from monoculture to a diverse agroforestry system will signal a departure from conventional agriculture practices. This shift is crucial for breaking the cycle of soil degradation often associated with monocropping. The emphasis on natural methods, such as the application of horse manure compost and diverse cover crops, has led to a reduction in the reliance on synthetic fertilizers. This not only minimizes environmental impacts but also promotes sustainable soil fertility management.

Moreso, the observed increase in earthworm population is indicative of improved soil health. The project's practices fostering an increase in soil microorganisms further contribute to enhanced nutrient cycling, disease suppression, and soil ecosystem services. This microbial diversity is vital for long-term soil fertility.

More to this, the introduction of diverse plant species, including trees, cover crops, and economic crops like garlic, has led to an upsurge in plant biodiversity. This in turn, has attracted a diverse array of pollinators and foraging insects, contributing to a more resilient and balanced agroecosystem. Applying horse manure compost along tree lines could be effective in boosting the soil's organic matter content. This organic matter serves as a reservoir for nutrients, enhances water retention, and provides a conducive environment for soil organisms.

Furthermore, the cultivation of cover crops and economic crops like rhubarb/currants/fruit trees contribute organic matter to the soil. The diverse root systems of these plants improve soil structure, prevent erosion, and enhance nutrient availability. The foliar spray may have a positive impact on nutrient levels, particularly the increase in calcium (Ca), iron (Fe), zinc (Ze), and molybdenum (Mo), underscores the effectiveness of this organic input in addressing specific nutrient needs of the plants. The Observed positive impact on trace elements demonstrates its potential to significantly contribute to the success of our endeavor.

In addition to the above listed facts, sap analysis post-foliar spray serves as a valuable tool for monitoring the nutritional status of plants. The documented increment in essential elements signifies an improvement in plant health and resilience. The identified excess nitrogen, correlated with increased pest pressure, highlights the importance of balanced nutrient management. This finding contributes to my understanding of the intricate relationships between nutrient levels, pest susceptibility, and plant health.

The successional agroforestry pilot project at Lill-Nägel's farm will represent an excellent effort in sustainable agriculture, providing valuable insights into the holistic rehabilitation of degraded soil. The multifaceted approach, combining diverse plantings, organic inputs, and careful nutrient management, may result in improved soil health, increase biodiversity, and enhance ecosystem services. The project's findings may contribute significantly to the fields of agroforestry and soil rehabilitation, offering a blueprint for sustainable and resilient agricultural practices that prioritize environmental health and long-term productivity.

4.1 Critical review

The successional agroforestry project at Lill-Nägel's farm presents a promising approach to sustainable land management. However, several challenges have been identified that could potentially hinder its effectiveness.

The irregular interval for soil sample collection poses a significant obstacle to accurately assessing soil health and nutrient levels. Consistent and timely soil sampling is crucial for understanding soil dynamics and implementing appropriate management strategies.

Adverse weather conditions delaying the collection of plant samples for sap analysis disrupts the project's ability to monitor the health and nutrient status of vegetation. Addressing this challenge may require the development of alternative sampling protocols or the integration of weather-resistant sampling techniques.

Variations in moisture content within collected samples can introduce bias and inaccuracies in data analysis. Ensuring standardized sampling procedures and implementing quality control measures are essential for obtaining reliable results.

Also, the fluctuating atmospheric temperature during sample transportation for analysis in the Netherlands may affect the integrity of collected samples and compromise the accuracy of analytical results. Proper handling and transportation protocols, such as using insulated containers or refrigeration, may mitigate this challenge.

Despite these challenges, the successional agroforestry project at Lill-Nägel's farm holds great potential for promoting biodiversity, enhancing soil fertility, and improving overall farm resilience. Therefore, addressing the identified challenges through robust monitoring and adaptation strategies will be crucial for maximizing the project's long-term success and scalability.

5 Recommendations

Farmers and agricultural practitioners should encourage the adoption of agroforestry practices by providing educational resources and training programs. Highlighting the benefits of diverse plantings, cover cropping, and organic inputs in improving soil health and overall sustainability. Moreso, policy makers should advocate for policies that support and incentivize agroforestry practices, recognizing their potential in mitigating soil degradation, enhancing biodiversity, and promoting climate resilience.

Furthermore, farmers should be encouraged to diversify their crops and plant species, incorporating a mix of trees, cover crops, and economy crops. This diversity enhances ecosystem services, reduces pest pressure, and contributes to a more resilient agroecosystem.

Moreso, seed companies should develop seed varieties suitable for agroforestry systems, emphasizing resilience, nutrient cycling, and compatibility with diverse plant communities. In addition to this, farmers and extension services should provide guidance on balanced nutrient management, considering the sap analysis findings. Emphasize the importance of avoiding excessive nitrogen levels to mitigate pest pressures and promote overall plant health. Researchers should conduct further studies on nutrient dynamics in agroforestry systems to refine nutrient management recommendations based on specific crops and environmental conditions. In addition to this, the local communities should be actively engaged.

More to these, the local communities should be actively engaged in the benefits of agroforestry, emphasizing not only environmental advantages but also potential economic gains through diversified produce and improved soil fertility. Also, educational institutions should integrate agroforestry principles into agricultural curricula to ensure the next generation of farmers is well-equipped with the knowledge and skills needed for sustainable practices.

Farmers and researchers should implement continuous monitoring of soil health, biodiversity, and crop performance. Utilizing adaptive management strategies to fine-tune agroforestry practices based on ongoing observations and scientific assessments. In addition to this, they should explore the use of technology, such as remote sensing and soil sensors, to enhance real-time monitoring and decision-making for agroforestry systems.

Farmers should form cooperatives and associations to facilitate knowledge-sharing platforms where farmers can exchange experiences and insights on successional agroforestry practices. This explains why farmers should foster collaboration between research institutions, agricultural extension services, and farmers to bridge the gap between scientific knowledge and practical application. Policy makers should advocate for policies supporting sustainable water management practices, including the promotion of efficient irrigation systems like drip irrigation. This is crucial for maintaining crop resilience during periods of drought. Farmers should implement water-saving technologies and practices, aligning with local water management regulations and conservation efforts.

Government agencies should integrate agroforestry practices into national and regional climate change mitigation and adaptation strategies. Agencies should highlight the role of agroforestry in sequestering carbon, enhancing biodiversity, and building climate-resilient agricultural systems. Furthermore, international organizations should provide supportive initiatives that promote agroforestry as a climate-smart agriculture solution, providing financial and technical assistance to farmers transitioning to sustainable practices.

These recommendations aim to translate the successional agroforestry project findings into actionable steps for farmers, policymakers, researchers, and other stakeholders. By implementing these suggestions, there is potential for widespread adoption of sustainable agroforestry practices, contributing to the restoration of soil health, biodiversity conservation, and the overall resilience of agricultural systems.

6 Conclusion

The successional agroforestry pilot project at Lill-Nägel’s farm will stand as a commendable initiative in addressing soil degradation resulting from monoculture and synthetic fertilizer use. The research question guiding this endeavor was centered on remediating degraded soil through natural methods in agroforestry. Employing a holistic approach, system and implemented diverse strategies, including the application of horse manure compost, planting cover crops and trees, introducing economic crops like garlic, implementing a drip irrigation system, and employing a foliar spray.

The methods employed showcased a commitment to sustainable agriculture, moving away from monoculture and synthetic inputs towards a more diverse, organic, and ecosystem-center approach. The findings from the project are manifold and promising. Notable outcomes include the observed increase in earthworm populations and soil microorganisms, heightened plant and insect biodiversity, and improvements in soil organic matter and nutrient levels, as evidenced by sap analysis post-foliar spray. The excess nitrogen correlated with heightened pest pressure emphasizes the importance of balanced nutrient management in agroforestry systems. These findings contribute to the fields of agroforestry and soil rehabilitation by providing tangible evidence for the effectiveness of natural methods in restoring soil health and fostering sustainable agricultural practices. The success of the project demonstrates the feasibility of transitioning towards regenerative agroecosystems that prioritize biodiversity, soil health, and long-term productivity.

The significance of this work will extend beyond Lill-Nägel's farm, offering a model for farmers and researchers grappling with soil degradation challenges. It emphasizes the interconnectedness of diverse plantings, organic inputs, and careful nutrient management in fostering resilient agroecosystems.

As for potential areas for research, investigations into long-term impacts of the successional agroforestry model would provide valuable insights. Exploring variations in this model across different climates, soil types, and crops could yield nuanced understandings applicable to diverse agricultural settings. Additionally, delving into the socio-economic aspects of implementing agroforestry systems and their implications for local communities would contribute to a more comprehensive understanding of the broader impacts of such initiatives.

In essence, the successional agroforestry pilot project at Lill-Nägel's farm will serve as a beacon of sustainable agricultural practices, showcasing the transformative potential of natural methods in soil rehabilitation. Its findings resonate with the growing global need for environmentally conscious farming practices, emphasizing the importance of balancing productivity with ecological stewardship for a resilient and sustainable future in agriculture.

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