The Influence of Age on Soil Quality Bioindicators in Dutch Food Forests

Regional Integration Project (GEO1-2416) - Group 4b

Máté Török – 5107439

Hanna Rotman – 7070640

Lis Reichelt- 7100531

Cornelie Hooft Graafland – 7049404

Daan van Amelsfort - 9490680

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Figure 1 Cover photo: Soil with sprout (Ag week, 2017)

1. Introduction

Agriculture is a key contributor to the Dutch economy, culture, and landscape, being it takes up 54% of the total area of the Netherlands (CBS, 2020). It has intensified considerably over the years, according to the CBS: “production has increased tenfold between 1950 and 2015” (CBS, 2020). This intensification involved the use of pesticides, fertiliser, and plant breeding. Multiple ecosystem services are affected by this intensification, such as soil organic carbon and water uptake by the soil (Barrios et al., 2012).

As a result of this, there is increased attention drawn to nature-inclusive farming techniques, such as food forests, and wider recognition of the importance of soil health in land management. Food forests are a form of permaculture: an agricultural technique that focusses on the principle of self-sufficiency while approaching the natural system as a whole (De Groot & Veen, 2017). Food forests imitate natural ecosystems through a combination of crops and trees and, optionally, livestock. In contrast to conventional monocultural crop fields, it forms a polycultural landscape containing a variety of species and several functional layers (De Groot & Veen, 2017). One of the layers with a high biodiversity is the soil, which contains a variety of organisms such as archaea, fungi and, specifically, earthworms. Earthworms are invertebrates that reside in all layers of the soil, where they decompose organic material and enrich the soil with nutrients that assist plant growth (Maier, 2020).

Food forests are a relatively young and undiscovered concept for temperate regions, such as the Netherlands, on which little scientific research has been done. This report describes an attempt to broaden the knowledge on food forests, with the focus on temporal changes in the ecosystem induced by the transformation to this farming technique. The aim of the paper is to examine the change in earthworm abundance and functional diversity of present earthworms in multiple food forests over time in a temperate climate. The study area of this paper are five different food forests in three locations, namely Leusden (established in 2020), Nijmegen (two forests established in 2020) and Haarzuilens (established in 2015).

The earthworm abundance and functional diversity can be used as bioindicators for soil health (Buckerfield et al., 1997). Using earthworms as a determinant for soil quality is a widely used method, mainly because they are an integral part of the ecosystem dynamics and they are frequent, easy to collect and simple to identify (Fründ et al., 2010).

Thus, this paper will revolve around answering the following research questions:

Is there a significant difference in earthworm abundance between three one-year-old food forests and two six-year-old food forests?

Is there a significant difference in the earthworm species' functional diversity between three one-year-old food forests and two six-year-old food forests?

This paper first gives a brief overview of the current academic debate on food forests and soil science. Secondly, the methodological approaches taken in the study will be explained, followed by the results. Subsequently, there is a discussion of the findings and its limitations. Finally, after drawing a conclusion, the findings will be put into a broader context.

2. Literature review

Food forests are an upcoming trend that might provide a solution to the current exploitative agriculture system. They are based on using an area of land to create an agricultural system consisting of woody, perennial, food producing species (Castro et al., 2018). Food forests fall under the agricultural category agroforestry, which entails a 'land-use system involving trees combined with crops and/or animals on the same unit of land' (Nair, 1991). Agroforestry has three main types: agrisilvicultural system (crops and trees), silvopastoral system (animals and trees) and agrosilvopastoral system (crops, animals, and trees). The subcategory of food forestry falls under the type agrosilvopastoral, which entails that the agricultural area is built up entirely out of crops and trees. These plants and crops are categorized in seven different layers: canopy, lower trees, shrubs, herbaceous (perennial plants without wood stems), rhizosphere (root crops), soil surface and vertically growing plants (vines) (De Groot & Veen, 2017).

There is a body of evidence supporting the hypothesis that agroforestry increases soil health, as trees modify the soil environment in several ways (Dollinger et al., 2018). Research has shown that trees have profound impact on soil properties such as nutrient availability, soil fertility as well as soil fungi and other organisms (Barrios et al., 2012). Resultingly, agroforestry enhances soil organic carbon and soil nutrient availability, and improves soil biota, which are all positively influencing soil health (Dollinger & Jose, 2018). Nonetheless, there is fewer research on the soil health of food forests particularly.

Even though the terms soil health and soil quality are widely used in literature, there is a degree of uncertainty on the precise difference and interchangeability. Nevertheless, soil quality focuses more on the function of soil. It is more clearly defined as to "sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health" (Doran & Zeiss, 2000). On the other hand, the term soil health is widely associated with the measure of the soil to function as a dynamic and living system within its ecosystems boundaries (Andrews et al., 2004) and draws additional focus on "deviation[s] of the soil conditions from an ideal 'healthy' state" (Fründ et al., 2010). In this paper both terms will be used, whereas soil quality displays a description of the specific function of the soil and soil health describes the ecosystem dynamics.

Understanding soil processes is a key element for successful agriculture as it is the very base of food production. As for how soil health can be assessed, earthworms are frequently used as bioindicators of soil quality (Buckerfield et al., 1997). They are an integral part of the dynamics of the soil system, as well as relatively easy to collect and identify (Buckerfield et al., 1997). Other reasons earthworms are a suitable method for assessing the health of the soil are the following: (1) earthworms are sensitive to variations in management; (2) they are correlated to beneficial soil functions; (3) they are useful for elucidating ecosystem processes; (4) they are easy and inexpensive to measure (Fründ et al., 2010).

As it was found by Barrios et al. (2012), agroforestry would increase the abundance of soil biota, which supports the use of earthworm abundance as soil quality indicator by several scholars (Buckerfield et al., 1997; Szilágyi, et al., 2020; Wiesel et al., 2015; Timmermann et al., 2006). Additionally, earthworm species diversity can also be an insightful indicator for soil quality (Fründ et al., 2010). A study by Joshko et al. (2006) connects earthworm diversity to soil properties such as acidity and total nitrogen content. The interpretation of earthworm abundance as an indicator of soil quality can be limited, since it is influenced by several factors such as soil moisture and recovery from the sum of temperatures below 0°C in the preceding winter (Timmermann et al., 2006). Therefore, it has been found to be fluctuating, which suggests that species community might also be an adequate measure (Fründ et al., 2010; Joschko et al., 2006). Further, Valckx at al. (2011) have conducted a sample-based rarefaction curve, which suggests that even a relatively small sample size (about 5-10 samples) is sufficient to capture the 'true' biodiversity due to that fact that earth worm communities are usually relatively species poor.

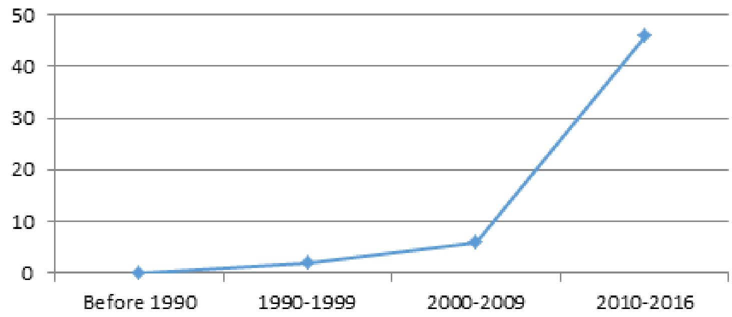

Figure 2. Growth of the number of food forests in the Netherlands (De Groot & Veen, 2017)

This papers' study area, the Netherlands, experiences an increasing interest in food forests which is visible in the increasing number of food forests in the Netherlands (see figure 2). Nevertheless, most research on food forests is based on tropical regions, whereas limited research has been devoted to food forests in temperate regions, including the Netherlands (De Groot & Veen, 2017).

It has been noted that more research needs to be conducted on food forests in temperate climates. To date, little scientific attention has been devoted to the temporal scales of food forests, which is required to gain notable knowledge on changes in soil ecology. (Stewart et al., 2018).

3. Research Methods

To get an integrated view of the quality of the soil in our research areas, the study considered a quantitative approach to investigate earthworm abundance and functional diversity, as well as determining the soil type in our sample locations. After the individual sampling took place, the holes were filled up to minimize the disturbances to the natural environment. Based on the literature review, the expectations for this research are an increase in earthworm abundance and functional diversity in older food forests, indicating an improved soil quality.

3.1 Earthworms as bioindicators for soil quality

During the fieldwork, samples were taken from the soil in each food forest for the assessment of earthworm abundance and species diversity. To extract the earthworms from the soil, soil cubes of 20 x 20 x 20 cm were excavated using a shovel. The soil samples were removed in one piece to preserve its structure and to minimise the cutting of earthworms. Then the sample was transferred to a plastic tarp to count the number of worms by hand-sorting the sample and the worms were laid out so photos could be taken.

The photos were then visually assessed to identify the worm species by comparing them to pictures of commonly occurring species in the Netherlands (n.d., 2021). The species were categorised in accordance with their ecological group of species that are based on function: anecic, endogeic and epigeic (Huang et al., 2020). Following, an index such as used in Joschko et al. (2006) was assigned to the strata. This index is evaluating the ecological groups and the number of species (types) within each group. However, the index by Joschko et al. (2006) did not include the epigeic group. Therefore, we used the score of the Ecomorphological Index (EMI), which is indicating the adaptation of the species to the soil environment (Gardi et al., 2019). As epigeic and endogeic group have similar EMI scores, namely 3 and 3,2 (Fusaro et al., 2018), they are treated with the same value in our index (Fusaro et al., 2018). This index is ranking the strata to display the increasing complexity of the earthworm's functional diversity. To see whether there is a significant difference in this functional diversity between three one-year-old food forests and two six-year-old food forests, a Mann-Whitney U test was performed.

Lastly, the soil type and structure of the topsoil plays a vital role in the functioning and the ecology of ecosystems such as the earthworm activity (Doube & Brown, 1998). Therefore, determining the soil type of the samples is key for the interpretation of the findings. The type and structure of the topsoil was determined by a visual and manual assessment method of the extracted soil cross-sections. The manual method can be seen in the appendix A.

3.3 Sample sites and statistical analysis

The samples' locations were assigned on-site using the stratified random sampling design by categorizing the study area according to its age and differences in vegetation communities. This allowed to estimate the statistical measures for each stratum group. In each stratum, exact sampling locations were chosen by the simple random sampling method, by generating a distance using a random number generator. The possible numbers to be generated is estimated by the maximum number of steps that can be taken along the present footpath, starting from the side of the stratum.

Hence, a number in that range was produced and the according steps were taken along the paths of the stratum. Next, another number was generated to determine the distance to walk into the food forest. This number will be in a positive (go to right) and negative (go to left) direction according to the estimated possible distance. The degree to which it was possible to walk in the food forest was limited by restrictions of owners or new plantings.

The samples were taken over the course of three days and all collected data was inserted in Microsoft Excel. All statistical analyses were performed using SPSS software, version 26. The collected data was tested for normality with the Shapiro-Wilk test. The test resulted that the measured data was not normally distributed, therefore the Mann-Whitney U test was used for the analysis. The Mann-Whitney U test compared the number of earthworms and functional diversity found per two age groups to identify if there is a statistically significant difference between the means in the different food forest ages. The statistical test allows to determine whether age might be a factor that affects size and composition of the earthworm population, and thus the soil quality, significantly.

4. Results

Following, the results of the two statistical tests are presented, which indicate whether there is a significant difference in abundance and functional diversity of earthworms between the two age groups. The diversity index was assigned to each stratus (see appendix C) as it was specified in the methodology. The specific average abundance and the ranking via the diversity index of each stratus is further specified in the following table (figure 3). Further, the analysis of the soil type suggests that all strata are comparable, as they are all clay soil.

Stratus	Age	Mean Abundance (individuals)	Diversity Index
Haarzuilens A	1	13,8	5
Nijmegen	1	7,2	4
Leusden	1	3	1
Haarzuilens B	6	20,4	3
Haarzuilens C	6	3,6	2

Figure 3. Specification of mean abundance and diversity index for earthworm species community of each stratus.

4.1 Earthworm abundance

The Mann-Whitney U test results lead to a significance value of p=0,894 for worm abundance. This significance value falls above 0,05. Therefore, we cannot conclude a significant difference between the earthworm abundance between three one-year-old food forests and two six-year-old food forests. However, the average earthworm abundance does have a slight increase over time, as visible in the graph below (see figure 4).

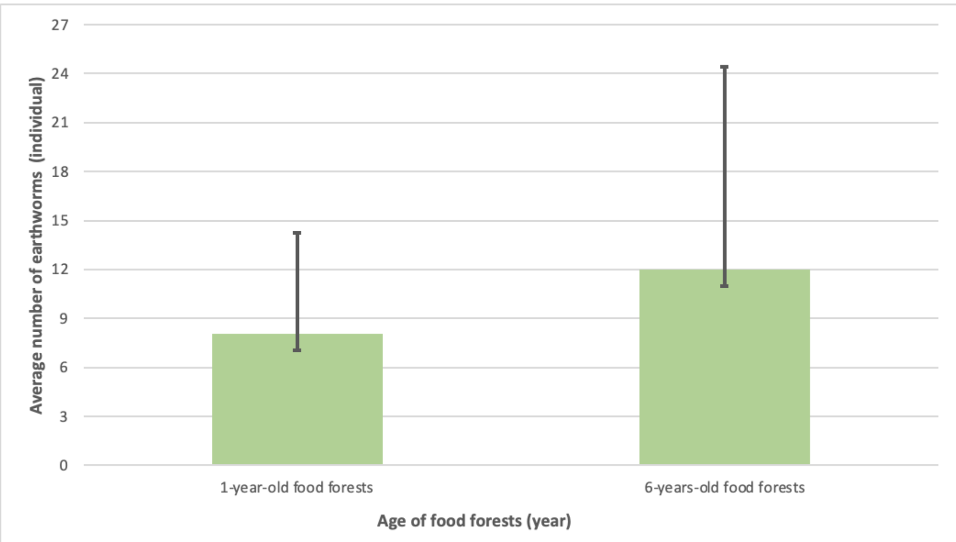

Figure 4. The bar depicts the average number of earthworms found in the two differently aged food forests and the error bar shows the standard deviation of the samples found on-site.

4.2 Earthworm functional diversity

The Mann-Whitney U test results lead to a significance value of p=0,564 for earthworm functional diversity. This significance value falls above 0,05. Therefore, we cannot conclude a significant difference between the earthworm functional diversity between three one-year-old food forests and two six-year-old food forests. Furthermore, the average earthworm functional diversity does not signify an increase over time, as visible in the graph below (see figure 5).

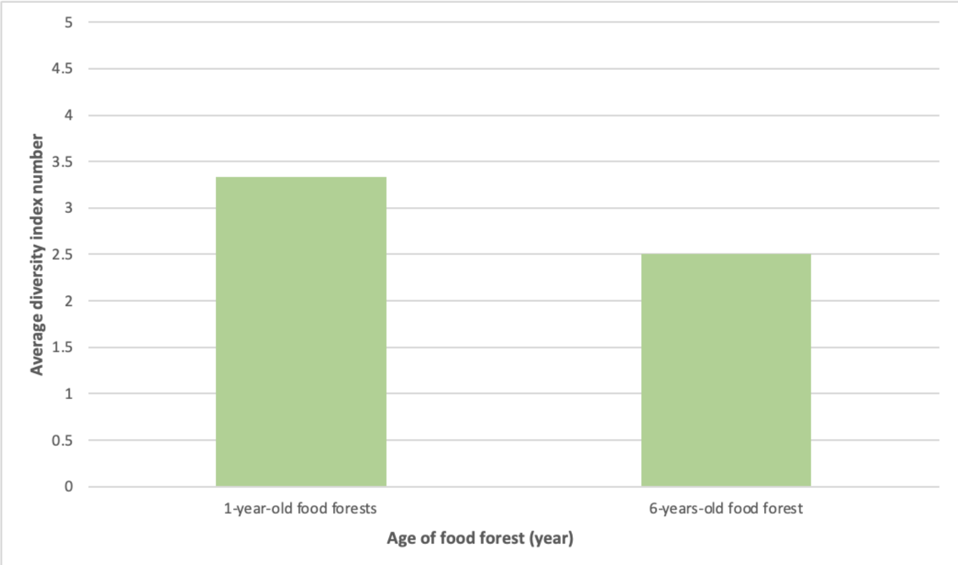

Figure 5. Average Diversity Indices for earthworm species community for the two age groups.

5. Discussion

The main findings of this study deviate from prior expectations, wherein there would be an increase in earthworm abundance and functional diversity in food forests over time, indicating an improved soil quality. The literature review done prior to this research contradicts the results of this study. Earlier studies state that agroforestry has shown evidence of its role in improving soil quality based on data gathered worldwide (Dollinger & Jose, 2018).

The findings of this study suggest that there is no significant difference in earthworm abundance between three one-year-old food forests and two six-year-old food forests. Additionally, the second test indicates that there is no significant difference in earthworm's functional diversity between the three one-year-old food forests and the two six-year-old food forests.

The high standard deviation in earthworm abundance could also be influenced by measurements done in stratus Haarzuilens C (see figure 5) in the food forest in Haarzuilens. As the findings in Haarzuilens C seem to differ considerably from the other measurements in Haarzuilens A and B (see figure 3), the measurements might have been influenced by a hidden variable or factor not accounted for in this study. Overall, there were two sites originating from 2015 having a varying worm abundance, namely a mean in stratus B of 20,4 worms in comparison to 3,6 worms in plot C. It is notable that the highest abundance has been found in the 6-year-old stratus Haarzuilens B. The reason for the deviating results gathered from plot Haarzuilens C could be that these measurements were taken relatively close to a path, as the vegetation was dense, and the owner requested not to harm the vegetation. In these locations the soil was relatively dry compared to plot B with the same age and location. This might have had a significant impact on the findings in this plot. Hence, the statistical tests were run a second time, now excluding the measurements of plot Haarzuilens C. The functional diversity does not change significantly when neglecting Haarzuilens C. However, the test on worm abundance resulted in a significance of p=0,026 instead of p=0,894 indicating a significant difference between the one-year-old food forests and the six-year-old in earthworm abundance.

This finding would complement current research stating that soil health is increasing due to the several beneficial effects that permaculture, and trees in particular, have on the soil. This was proven by a study done by Szilágyi, et al. (2020), in which earthworm density was compared between 5 conventional, 5 organic and 5 permaculture farms in Hungary. The research concluded that the permaculture farms, similar in composition to the food forests in this study, had a higher earthworm density and compaction of the soil than the conventional and organic farms. These findings contradict the findings of this study. Research done by Richard, et al. (2008), compared the earthworm abundance, species composition, and species richness in agricultural fields in Michigan in the USA. This study concluded that the species richness and community composition appeared to be reflective of the qualitative differences in land-use intensity along the gradient of the research areas.

Nevertheless, the average worm abundance does indeed increase, even though there is a high standard deviation, resulting in an insignificant difference. This could be the case due to high variance of the variable and the small sample size. It could be the case that when the sample size is larger, the dataset will be more robust, resulting in a greater significancy in the statistical results and thus confirming the prior expectations. For the analysis of the species community, however, the sample size was sufficient according to Valckx at al. (2011).

Another reason for the insignificant findings could be the limits of the approach of using solely earthworms as indicators for soil quality. As mentioned by Fründ et al. (2010), earthworms and their populations are regulated by numerous factors, reacting not only to soil conditions but also to climate and agricultural management. This notion applies in this research as well, insinuating that there are many factors influencing the earthworm population, without necessarily implying that the soil quality is different in this location. Future studies may want to include other soil quality assessment tools.

Furthermore, the unexpected findings could partly be due to notable differences in between the food forests, which might have limited the comparison more than expected. Firstly, the food forests differ in management type, being distributed from only performing sporadic planting and mowing paths to more intensive human intervention such as lavish planting, using compost and removing specific plant species (appendix B). Secondly, the food forests had different starting conditions when the food forests were established, namely grassland, an orchard and monocultural cropland. In younger ages, this might still have high influence on the soil processes and soil health as the response of an ecosystem to different management types can vary over several years (Barrios et al., 2012). Therefore, an age difference of 5 years might not be sufficient for the bioindicator to show substantial differences. Thirdly, vegetation types and cover differed in the food forests. This influences the provision of shade and moisture degree. For example, the strata Haarzuilens C and Leusden both had less shade and drier soil. This might be a reason for the low average abundance and functional diversity for the two plots. Next, the strata Haarzuilens A had a water ditch right next to it and wet soil (appendix B). This might be one of the reasons for the high average abundance for a one-year-old food forest and the high diversity index (see figure 3).

Therefore, the differences in management type, starting conditions and moisture degree might have had a notably high influence on the earthworm abundance and diversity. Additional research could compare food forest in the temperate region regarding these aspects. In order to investigate the temporal patterns with a minimum of differences between the sample locations, a longitudinal study could take yearly measurements over a period of several years. However, due to the time limit of this research project, this was not possible.

6. Conclusion

In this paper the relation between soil quality bioindicators, namely earthworms, and the age of food forests has been researched. The statistical tests suggest that there is no significant difference in earthworm abundance between three one-year-old food forests and one six-year-old food forest. Additionally, the earthworm diversity does not insinuate a relation to the different aged food forests. This in return means that the correlation between the age of the food forest and the quality of the soil has not been proven based on this research.

However, the worm abundance and functional diversity have been influenced by many factors, mainly by the difference in management types, different starting conditions, and other features of the food forests, such as varying soil moisture levels and the deviating plot Haarzuilens C. If that plot is taken out, the findings on earthworm abundance would indeed be significant to conclude a difference between the age groups. It is notable that the highest abundance has been found in the 6-year-old stratus Haarzuilens B.

Nevertheless, this research still provides useful insights for the agricultural sector. These insights can be that the dissimilarities between the food forests make them difficult to compare, and, therefore, generalising would be challenging. Furthermore, our findings might suggest that other factors, such as management type or moisture level, are also influential and therefore should be regarded with further consideration.

A suggestion for future studies is research that has less differences between the study areas, ideally a longitudinal study on one particular food forest. Moreover, more research on the above-mentioned factors is needed as they could be more influential than simply the time span of 5 years. Additionally, a suggestion for future research is to investigate whether solely earthworms are an adequate indicator for soil quality in the temperate region or if other indicators are necessary to create a more complete overview.

Although our results do not directly lead to a significant conclusion of the positive impacts of age of food forests on soil quality, it has been proven that food forests improve soil quality (Dollinger & Jose, 2018; Szilágyi, et al., 2020). Thus, food forests provide a promising agricultural form to keep soil quality on an elevated level. How influential the factor of time is on soil health in contrast to other factors remains to be specified. This research indicates that small spatial differences in measurements (e.g., measuring close to the path) and overall dissimilarities of food forests make comparisons difficult and should be regarded in future research. Nonetheless, this study contributes to further research towards food forests in temperate regions, which is an area where extended research is lacking.

7. Relevance

This research contributes to identify the challenges and opportunities for sustainable food production and consumption on the Utrecht Heuvelrug and surrounding area. The findings suggest that there is no clear correlation between the age of a food forest and its soil quality. However, by comparing food forests on temporal aspects, a broader view of the phenomenon has been created. This results in a better assessment of possible effects of the implementation and maintenance of food forests and might raise confidence for the realisation of food forests in the future.

Furthermore, these findings suggest the importance to owners of food forests to consider other influential factors such as a suitable management type. Additionally, when starting a food forest, it has to be kept in mind that response of the ecosystem might take more than 5 years before seeing significant changes in e.g., earthworm presence. This could imply that it takes many years until the full profit from the food forest can be exploited. This adds to the critique that is brought forward on food forests, that states that food forests would not be profitable enough for many farmers to transit to from other forms of agriculture (De Groot & Veen, 2017). Hence, monoculture will still be an attractive form of agriculture during these years, especially for high-demand species (Deelder, 2020). Due to the slow increase in return of investment and the fact that food forests are smaller and more intensive to harvest due to its high variability of species, owners might rely on the contribution of labour by volunteers or self-picking by residents and visitors. Therefore, in the current models the scalability of food forests differs from large-scale farming. Nevertheless, food forests are an adequate provider of food and biodiversity and could partially replace unsustainable conventional agriculture (De Groot & Veen, 2017).

Our findings can contribute to a larger understanding of food forests when comparing them to other social studies, such as the community's opinion of food forests. Since funding and workforce are necessary to start and maintain such initiatives, public opinion plays a key role. The public opinion can be influenced by involving the community. Therefore, food forests function as recreational areas that are open to visitors, suggesting that consumers can see exactly where their food comes from. This close involvement can help reconnect humans to nature, which could lead to more sustainable behaviour (Castro et al., 2018). Food forests also help economies shift to a local scale, short cutting food miles because of locally produced and consumed food, which is connected to the resident's perception and current access to local, environmental-friendly food. Connecting these different topics is essential for effectively transitioning to a sustainable form of food production and consumption.

To conclude, it is vital to consider an interdisciplinary approach to decision-making from both social and natural sciences, as food forests combine features from both spheres. Thus, different fields of science need to be interconnected to give a complete overview of the challenges and opportunities of sustainable food production and consumption on the Utrecht Heuvelrug and surrounding area.

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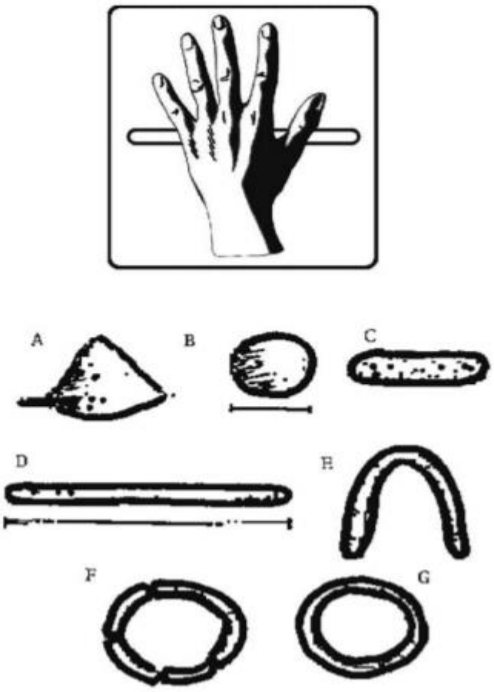
9. Appendices

9.1 Appendix A

Illustration of the hand assessment method and a description of the soil texture (Bunning, et al., 2016).



A **Sandy**	The soils stays loose and separated and can be accumulated only in the form of a pyramid
B **Sandy loam**	The soil contains enough silt and clay to become sticky, and can be given the shape of an easy-to-take-apart ball
C **Silty loam**	Similar to a sandy loam, but the soil can be shaped by rolling it into a small short cylinder
D **Loam**	Contains almost equal amounts of sand, silt and clay. Can be rolled into approx. 14 cm long cylinder that breaks when bent.
E **Clayey loam**	Similar to the loam, but the rolled cylinder can be bent and given a Ū” shape (without forcing it) without breaking
F **Fine clay**	The soil cylinder can be bent into a circle, but shows some cracks
G **Heavy clay**	The soil can be shaped as a circle without any cracks

9.2 Appendix B

Distinction between each food forest based on soil type, management type, mean abundance and mean diversity index.

Location of Food Forest	Age	Soil type	Management Type	Mean Abundance (In individuals)	Diversity Index
Haarzuilens A	1	Clay (near water ditch)	Planting + Mowing paths	13,8	5
Nijmegen	1	Clay (10% sand + 20% gravel)	Planting (Rewilding an Orchard)	7,2	4
Leusden	1	30% Sand, 70% Clay (dry)	Planting + Compost + Mowing paths	3	1
Haarzuilens B	6	Clay	Planting + Mowing paths	20,4	3
Haarzuilens C	6	Heavy clay (dry)	Planting + Mowing paths	3,6	2

9.3 Appendix C

Earthworm species diversity index per age plot per food forest including index average.

Index number	Plot	Age	Endogeic	Epigeic	Anecic
2	B, 1	6	1	1	1
3	C, 2	6	1	1	2
5	D, 3	1	4	1	2
4	E – H, 4	1	3	1	2
1	I,	1	1	0	1
Average: 1 year old	3,3				
Average:6-year-old	2,5				