Facilitating development of Food Forest Roggebotstaete - Towards a productive system

June 2019

Jasper Kruse

Roggebotstaete estate | Aeres University of Applied Sciences

LANDGOED& PROEFTUIN ROGGEBOTSTAETE.NL

AERES HOGESCHOOL

Bachelor Thesis Applied Biology

"We must cultivate our own garden. When man was put in the garden of Eden he was put there so that he should work, which proves that man was not born to rest."

Voltaire, 1759

Jasper Kruse | June 2019

Supervisor: Dr. Ir. E.D. Ekkel

Aeres University of Applied Sciences, Almere

Preface

This bachelor thesis concludes a yearlong study of Food Forest Roggebotstaete and the topic of temperate climate food forests. My motivation for this study originated in Australia, where I resided for 12 years. I started my working life Down Under in the commercial kitchen working as a chef. It was here that my love and passion for fresh, flavoursome, regional and organic produce and products began. The expression of flavours in locally grown and organic foods is vastly different to the conventionally farmed and manufactured alternative. Good quality ingredients need but seasoning to let them sing! After the commercial kitchen I worked for 7 years as a ranger for the Department of Parks and Wildlife, in the Kimberley region of Western Australia. In those 7 years I spend most of my time working as a field ecologist designing and executing biodiversity surveys in very remote locations, in collaboration with local traditional owners. This exposure to largely untouched wilderness and Aboriginal culture taught me a lot about the natural processes shaping the environment.

I was introduced to permaculture in the beginning of 2014 through a good friend. Upon concluding my Permaculture Design Certificate, I was most enthusiastic about soil management and the concept of food forests. The concept of a food forest reflected my previous experiences in the kitchen, forest management and observing nature and felt like a perfect match to me. My knowledge of and experience with food forests was gained in tropical and subtropical Australia. On my return to Europe I was keen to understand how food forests grow and function in the temperate climate of my home country the Netherlands.

Food Forest Roggebotstaete is one of the few established food forests in the Netherlands. It is a relatively young forest, providing a great opportunity to monitor the growth and development of a temperate climate food forest. As part of my 6-month company placement I designed and undertook a detailed site analyses and assessment, resulting in the baseline study of the factors influencing vegetation growth in Food Forest Roggebotstaete. Roggebotstaete is one of the original signature holders of the Green Deal Food Forests and a frontrunner under the deal. Valuable lessons can be learned from the challenges faced by Food Forest Roggebotstaete in its development towards a productive system. This information could contribute towards the body of scientific knowledge under the Green Deal and in the establishment and management of other Dutch food forests.

I would like to take this opportunity to thank all the people that have helped and supported me over the past year. My mentor, Dr. Dinand Ekkel from Aeres University of Applied Sciences, for introducing me to Roggebotstaete. Lennard Duijvestijn and Suzanne Miezgiel from Roggebotstaete for taking me on board and challenging my perspectives. The Flevocampus for granting me a “knowledge voucher” to fund my soil research and Karin Blok, my former soils teacher, for her valuable input at critical stages in the writing of both my company assignment and this thesis.

A special thank you goes out to Wormie and Danielle for indirectly starting this journey and helping me along the route. My sister, who gave me oversight when I had lost it. My parents for taking me in and allowing me the space to write. And lastly my beautiful fiancée, who has stood by me, supported me and put up with me in my quest to finish!

Enjoy!

Content

Summary

English

Food forests form an interesting option in the development of a more sustainable form of agriculture. They are rapidly gaining in popularity in the Netherlands, although the uptake of the concept has mainly been on private estates and public land. The Dutch agricultural sector is sceptical of the concept due to a lack of existing research and established productive food forests. Food Forest Roggebotstaete was created to introduce this concept to government agencies, companies and farmers and show its potential.

Food Forest Roggebotstaete could develop naturally, by minimising human interference, with the return of investment estimated to take around 7 to 10 years. A site analyses and assessment Food Forest Roggebotstaete was commissioned to evaluate the factors influencing vegetation growth. The findings of the baseline study brought the adopted management vision into question. It found the soil to be of poor quality and low in fertility. This was reflected by the limited growth, development and general health of the introduced vegetation. An estimated 15% of the total failed to establish and needed to be replanted. The low ground water table and soil capillary action meant that Food Forest Roggebotstaete could struggle with its water supply in times of drought.

For this thesis the theoretical framework of food forests was examined to find possible management strategies that would fit the ecosystem dynamics of Food Forest Roggebotstaete and overcome these identified problems. This could facilitate its progress towards a productive and self-fertilising ecosystem. A comprehensive review of scientific resources and prominent temperate climate food forest literature was performed. It found that food forests develop and mature through the process of ecological succession. The field of restoration ecology has created a conceptual framework for plant community development with useful applications to food forest farming.

Temperate climate food forests should be maintained at mid-successional stage to be most productive. The soil food web and especially mycorrhizal fungi play a crucial role in achieving a self-fertilising system. The ability of a food forest system to conserve and accumulate nutrients are the most important factors contributing to this self-sustaining fertility. The task of a food forest farmer is to create desired ecosystem dynamics within the forest to facilitate the development of a healthy, self-fertilising ecosystem able to produce high and diverse yields. In Food Forest Roggebotstaete this could be achieved by directing succession, active fertility management and minimising competition.

Dutch

Voedselbossen vormen een interessante optie in de ontwikkeling van een duurzamere landbouw. Ze nemen snel in populariteit toe in Nederland, maar deze groei vindt voornamelijk plaats in de particuliere hoek. De Nederlandse landbouwsector staat sceptisch tegenover het concept vanwege een gebrek aan bestaand onderzoek en gevestigde, goed producerende voedselbossen. Voedselbos Roggebotstaete is o.a. aangelegd om het potentieel van dit concept bij overheidsinstanties, bedrijven en boeren te introduceren.

Voedselbos Roggebotstaete heeft zich sinds 2016 op natuurlijke wijze mogen ontwikkelen, waarbij menselijk ingrijpen tot een minimum beperkt is. Het terugwinnen van de investeringskosten zal naar schatting 7 tot 10 jaar bedragen. Als deel van de bedrijfsopdracht is een nulmeting van Voedselbos Roggebotstaete ontworpen en uitgevoerd, om de factoren die de vegetatiegroei beïnvloeden te evalueren. De bevindingen van de nulmeting trekken de huidige visie van het beheer in twijfel. De algemene conclusies zijn dat de bodem van slechte kwaliteit is met een lage vruchtbaarheid. Dit wordt weerspiegeld in de beperkte groei, ontwikkeling en algemene gezondheid van de aangeplante vegetatie, waar naar schatting 15% van is uitgevallen en opnieuw moest worden aangeplant. Daarnaast kan dit voedselbos in tijden van droogte mogelijk met de watervoorziening worstelen.

Voor dit afstudeerwerkstuk is het theoretische kader van voedselbossen onderzocht om mogelijke beheersmaatregelen te vinden die de vastgestelde problemen zouden kunnen oplossen. Hierdoor zou het voedselbos zich makkelijker kunnen ontwikkelen tot een productief en zelfvoorzienend ecosysteem. Middels uitgebreid literatuuronderzoek met betrekking tot voedselbossen kan vastgesteld worden dat voedselbossen zich ontwikkelen volgens ecologische successie. Het vakgebied van “restoration ecology” heeft handvaten ontwikkeld om de processen van successie op landschapsbeheer toe te passen. Deze zouden ook nuttig kunnen zijn voor voedselbos beheer.

Voedselbossen in een gematigd klimaat moeten in een “mid-successie stadium” worden gehouden om het meest productief te zijn. Het bodemleven, maar voornamelijk mycorrhiza-schimmels spelen een cruciale rol in het realiseren van een zelfvoorzienend ecosysteem. Het vermogen van een voedselbossysteem om voedingsstoffen te behouden en te accumuleren zijn de belangrijkste factoren voor een zelfvoorzienende vruchtbaarheid. De taak van een voedselbosboer is het creëren van de gewenste ecosysteemdynamiek binnen het bos. Dit zal de ontwikkeling van een gezond, zelfvoorzienend ecosysteem bevorderen. Voedselbos Roggebotstaete kan dit bereiken door successie te sturen, de bodemvruchtbaarheid actief te beheren en concurrentie te minimaliseren.

Chapter 1: Introduction

1.1 *A look towards the future*

The United Nation's Food and Agriculture Organisation (FAO) estimates the total world population to grow to around 9.8 billion people by 2050. To feed the world population, the total agricultural output will need to increase by 60%. Due to the environmental impact of agriculture the FAO concludes that a 'business as usual approach' is no longer an option (FAO, 2018).

Modern intensive farming methods, growing irrigated monoculture crops with the use of chemical fertilisers and maintaining them by spraying biocides, have led to deforestation, depletion of fresh water sources, soil contamination and loss of biodiversity (FAO, 2018; Foley, 2014). Modern agriculture is one of the world's largest contributors to global warming, due to large quantities of greenhouse gas emissions (Foley, 2014). Climate change is increasingly affecting crop yields (FAO, 2018). With an additional 2 billion mouths to feed, a change to more sustainable methods of agriculture is critical going forward (FAO, 2018).

1.2 *Agriculture in the Netherlands*

The Netherlands is one of the world's most intensive farming countries. It is the world's number two exporter of food as measured by value. This is second only to the United States, which has 270 times the available landmass. The Netherlands is a relatively small but densely populated country, with over 500 inhabitants per square kilometre. More than half of the Netherlands' land mass is used for agricultural or horticultural purposes (Viviano, 2017).

The foundation for this incredible productivity was laid by Sicco Mansholt. He was a farmer and a member of the Dutch resistance during the Second World War. Mansholt experienced the horrors of the Dutch famine at the end of the Second World War first hand. Directly after the war, with a food crisis imminent, Mansholt was offered the post of Minister of Agriculture, Fishery and Food Distribution. Mansholt's plan was to encourage productivity in agriculture by guaranteeing farmers a certain minimum price for their produce and providing incentives for them to grow more. The agricultural policy was very successful in meeting its initial objective of making the Netherlands more self-sufficient with food products (European commission, 2016). By the 1970s the policy had worked so well that there were often surpluses of farm produce such as milk and grain (Mulder, 2014).

The high productivity of Dutch agriculture has come at a significant cost to its environment. The increased use of fertilisers and pesticides have had far reaching consequences on the water quality, biodiversity and even peoples own backyards (Bouma, 2019a; Bouma, 2019b; Bouma, 2019c). Mansholt himself admitted in his autobiography 'Crisis' of the far-reaching consequences of intensive agriculture to the environment (Mulder, 2014). Due to the environmental impacts and the limited amount of space, environmental sustainability has become a big topic in Dutch agriculture (Viviano, 2017).

In 2018, the Dutch Minister for agriculture and environment (LNV) Carola Schouten, made a commitment that all agricultural lands in the Netherlands will be farmed in a sustainable way by 2030; "Sustainable management of soils is the cornerstone of long-term food security, improving biodiversity and achieving the goals set out to combat climate change" (Rijksoverheid, 2018).

1.3 *Sustainable agriculture in the Netherlands*

Minister Schouten has named circular agriculture as the main method of making agriculture more sustainable. In this practice arable farming is combined with dairy farming by utilising each other's residual waste. The manure from dairy farms is combined with green manures to supply nutrients for crop production on arable farms, therefore eliminating the need for large scale use of synthetic fertilisers. About 30% of the biomass of these crops is suitable for human consumption. Residual parts of these crops, such as protein rich foliage of sugar beets gets combined with suitable waste from the food industry to supply fodder for dairy cows. This helps reduce the need for concentrated feed for dairy cows (Smit, 2018; WUR, n.d.).

Other agricultural practices striving for more sustainable forms of agriculture include organic farming (UCSUSA, n.d.). Organic farming is becoming more popular in the Netherlands, especially within the last 10 years (Den Helden, 2019). The International Federation of Organic Agriculture Movements describes organic farming as an integrated farming system that strives for sustainability, the enhancement of soil fertility and biodiversity and relies on ecological processes and cycles adapted to local conditions. Organic farming prohibits the use synthetic pesticides and fertilisers, genetically modified organisms, growth hormones and the prophylactic use of antibiotics (Van Buuren, 2019). These changes in agricultural practices have significant environmental benefits, but do not address the large volumes of green house gas emissions. Profound changes to the agro-food structure are required to achieve a significant reduction in greenhouse gas emissions (Garnier *et al*., 2019). Agroforestry could provide a solution to this desired change.

Agroforestry is a collective name for agricultural systems that use woody perennials next to crops and/or animals. The FAO defines agroforestry as a dynamic, ecologically based, natural resource management system. Through the integration of trees on agricultural land this system diversifies and sustains production for increased social, economic and environmental benefits (FAO, 2015). Agroforestry provides a significant environmental benefit by creating carbon sinks in the agricultural landscape (Abdulai *et al*., 2018; Kay *et al*., 2019; Cole *et al.,* 1997). Agroforestry can be divided in three main categories, summarised in Figure 1:

- Silvopasture: these systems combine tree crops with land where domesticated animals can graze, for instance woodland grazing promoting forestry production.
- Agrosilvopasture: these systems combine tree crops, animals and annual crops. In these systems the animals are used for grazing after harvest, for instance the combination of sheep, cereal crops and rangeland.
- Agrosilviculture: these systems combine tree crops with other beneficial vegetation, for instance by alley cropping or as a food forest (FAO, 2015; Rigueiro-Rodriguez, McAdam & Mosquera-Losada, 2009).

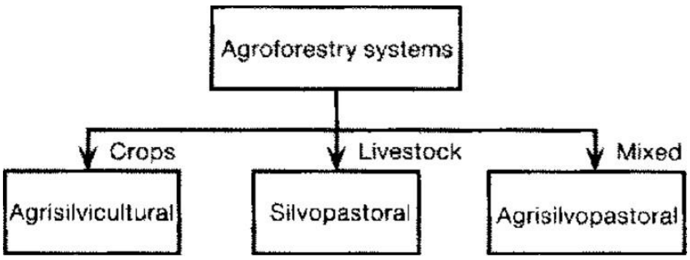

Figure 1. An overview of the various agroforestry systems. Adapted from (Lal, 1995).

The agrosilviculture system of a food forest is currently not well known in the Netherlands, but the concept is rapidly gaining in popularity (Green Deal, 2017; Oostwoud, 2019). Food forests form biologically highly efficient, stable and resilient agricultural systems. They provide biodiverse habitat, sequester carbon and provide a place for education and recreation, whilst yielding highly diverse and nutritious products (Crawford, 2010). They form an interesting choice in sustainable agriculture by being able to address long term food security whilst improving soil health, local biodiversity levels and mitigating the effects of climate change (Breidenbach, Dijkgraaf, Rooduijn, Nijpels-Cieremans & Strijkstra, 2014).

1.4 *What is a food forest?*

Food forests have been compared by some to the religious concept of the garden of Eden (Bell, 2004). The concept originates in the tropical regions of the world and is probably one of the oldest forms of agriculture. In prehistoric times families living in monsoonal regions identified, protected and improved useful plants and vines in their local riparian jungle vegetation. They eliminated undesirable plants and gradually introduced superior species to create a forest garden (McConnell, 1992). Food forests form a significant source of income and food security for local populations in tropical Asia, Africa, Central America and temperate and subtropical China (McConnell, 1973; Crawford, 2010). Robert Hart, a British organic gardener was the first to adopt the concept of food forests from the tropics to the temperate climate of the United Kingdom in the 1980's (Crawford, 2010).

Temperate climate food forests are often referred to as forest gardens. The Dutch term "voedselbos" literally translates to "food forest". Therefore, this term will be applied to describe this type of agroforestry system in this thesis. In its most basic form food forests could be described as edible ecosystems (Jacke & Toensmeier, 2005). They are not ecosystems that occur naturally but consciously designed and orchestrated. Every food forest is unique and reflects the interests and personalities of its creator (Lawton, 2011).

Food forests are polycultures[1] which consist of a high diversity of multipurpose perennial plants, which yields are of direct or indirect benefit to people (Jacke & Toensmeier, 2005; Crawford, 2010). Dave Jacke describes these benefits as the 7 F's; food, fuel, fibre, fodder, fertiliser, pharmaceuticals and fun (Jacke & Toensmeier, 2005).

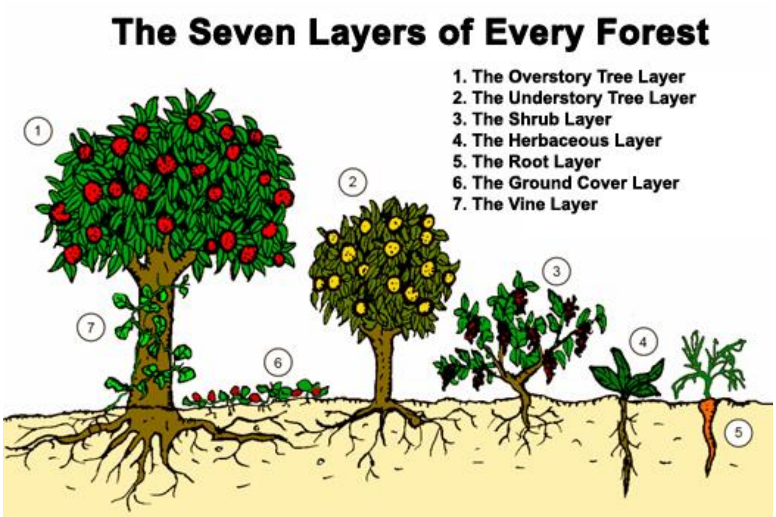

Figure 2. Food forests mimic the seven layers of a natural forest. (Burtner, 2014)

Food forests come in many shapes and sizes, from a small backyard to several hectares and may contain large trees, small trees, shrubs, herbaceous perennials, herbs, annuals, root crops and climbers (Ratay, 2018; Crawford, 2010). Together this vegetation mimics the layered structure and function of a forest ecosystem, as displayed in Figure 2. By doing so, food forests can create high and diverse yields, a healthy ecosystem and are self-maintaining (Jacke & Toensmeier, 2005). The existence of multiple layers differentiates a food forest from both annual vegetable gardens as well as conventional agroforestry systems (Rigueiro-Rodriguez *et al*., 2009).

1.5 *Green Deal # 219 Food Forests*

Food forests are a relatively new concept to the Netherlands. Food forest Ketelbroek, established in 2009 by Wouter van Eck is widely cited to be the first in the Netherlands. At the time of writing this thesis, around 20 food forests have been established in the country, although this number is a rough estimate, as there is no central point of registration (Oostwoud, 2019). Marc Buiter from Voedselbosbouw Nederland (personal communication, 2018) explained to me that although they are gaining in popularity, food forests are currently a niche industry in the Netherlands.

To help expand the number of food forests in the Netherlands the Dutch government nominated the concept for a Green Deal (Figure 3.) Green Deal number 219 Food Forests was signed in 2017 by various estates and local, provincial and federal governments. Under a Green Deal, public and private parties are encouraged to work together to support creating sustainable initiatives (Green Deal, 2017).

Figure 3. A stakeholder signing on during the Green Deal workshop on 13/09/18.

A major topic identified under the Green Deal is the lack of existing research (Green Deal, 2017). Due to their incredible complexity, food forests have rarely been studied by agricultural scientists (Crawford, 2010). They are still a novelty to agriculture in the Netherlands, therefore Dutch farmers are generally not acquainted with the concept. Those who have heard of it are sceptical, partially due to the low numbers of "productive" temperate climate food forests (Graham, 2016).

Four estates with established food forests co-signed the Green Deal and are called the so called "front runners". They will serve as practical examples for other food forest projects by sharing their experiences and undertaking scientific research. One of the original signature holders and a frontrunner under the Green Deal is Roggebotstaete (Green Deal, 2017).

1.6 *An introduction to Food Forest Roggebotstaete*

Roggebotstaete is situated on the northern tip of the reclaimed land of the province of Flevoland on an old sandbank called 'Het Roggebotzand (Figure 4.) Before the establishment of the province of Flevoland this sandbank formed part of the Southern Sea coast of the historical town of Kampen. The estate first served as a large state-owned tree nursery, supplying shrubs and trees for public areas in the newly created province, before being sold to a commercial operator. The total size

Figure 4. Location of Roggebotstaete on Roggebotzand, to the west of a large commercial tree nursery. Het Ketelmeer is the waterbody to the north of the property. Adapted from (www.kaartenenatlassen.nl).

of the estate was too large to be commercially viable and in the early nineties 52 hectares were sold to a private party (Duijvestijn, 2016).

Roggebotstaete is wedged between the two natural areas called ‘het Roggebotsebos’, a natural forest and ‘het Ketelmeer’, a Natura 2000 listed waterbody. The above-mentioned private party in collaboration with state and local government, decided to transform the estate into a natural area, complementing the natural values of its surroundings and making the estate part of ‘Nature Network the Netherlands’. Between 2001 and 2005 Roggebotstaete underwent a transformation with large amounts of the topsoil being removed and several waterbodies being established (Duijvestijn, 2016).

No active management took place on Roggebotstaete between 2005 and 2012, with the intention that nature could restore itself. In 2012 the estate was donated to ‘Stichting Landgoed Roggebotstaete’, which is governed by a board of members and run the estate manager Lennard Duijvestein and natural area manager Suzanne Miezgiel. The estate was developed into a place where people can experience the practice of sustainable living and food production. Part of this sustainable food production experience includes a 1.5-hectare food forest. This food forest was designed by Wouter van Eck and Malika Cieremans and funded by Rich Forests and ‘Stichting Landgoed Roggebotstaete’. It was created in the beginning of 2016 by Roggebotstaete employees and volunteers (Duijvestijn, 2016).

Roos Nijpels- Cieremans from Rich Forests describes the main aim of Food Forest Roggebotstaete to introduce the food forest farming concept to government agencies, companies and farmers and show it’s potential. It creates an educational environment where school children and adult consumers can learn about the importance of natural food production and the benefits on personal health and wellbeing (Nijpels-Cieremans, 2015). Duijvestijn and Miezgiel described that the yields from the food forest will feature in dishes served in the future on-site restaurant and will be processed into value added products, such as chutneys, to be sold in the estate shop.

1.7 *Establishment of Food Forest Roggebotstaete*

Food Forest Roggebotstaete was created in an existing forest (Figure 5.) (Nijpels-Cieremans, 2015). This original forest was planted in 2004 and consisted of two different parts. The northern part was mainly made up of walnut trees (*Juglans regia*), interspersed with wild cherry (*Prunus avium*) and sweet chestnut trees (*Castanea sativa*). The southern part was dominated by European ash (*Fraxinus excelsior*). Undergrowth was sparse in large parts of the forest and was made up of ash seedlings, field-forget-me-not (*Myosotis arvensis*), bushgrass (*Calamagrostis epigejos)*, cleavers (*Galium aparine)* and bitter dock (*Rumex obtusifolius).* The forest mantle was predominantly made up of common hazel (*Corylus avellana*) and common medlar (*Mespilus germanica*), with hairy willowherb (*Epilobium hirsutum*) and common nettle (*Urtica dioical)* dominating the herbaceous layer (Van der Goes & Thijssen, 2009; Egberts, 2017).

Miezgiel explained that most of the original vegetation, save for the forest mantle and some larger fruit trees, was cut down. The branches were chipped and used as mulch, but the large trunks were taken away. Roughly 90% of the original vegetation gave way for edible plant varieties (Figure 6.) (Miezgiel, personal communication, 2018). These were planted in rows running east to west, increasing in height from south to north for maximum sunlight exposure, a method van Eck calls a rational food forest (Oostwoud, 2019). These rows were planted in between the original forest edges, which served as a windbreak (Nijpels-Cieremans, 2015). Miezgiel estimated the total effort took around 1000-man hours to complete (Miezgiel, personal communication, 2018).

Figure 5. The original forest site in 2016, before its transformation (Google Earth, 2018).

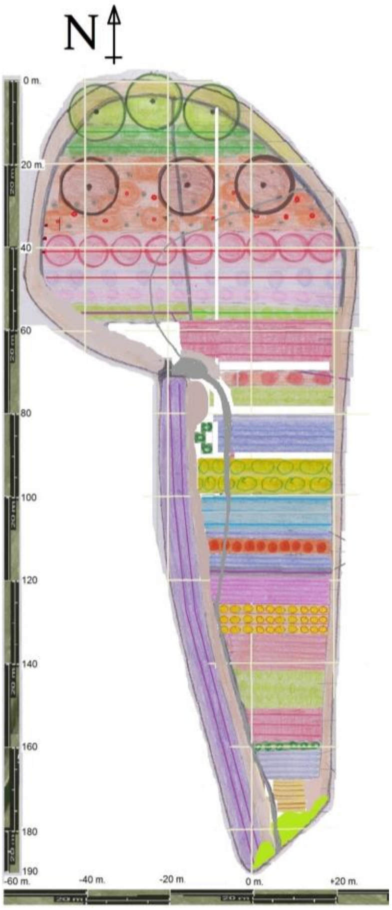

Figure 6. An overview sketch of food Forest Roggebotstaete (Kruse, 2018).

1.8 *Development of Food Forest Roggebotstaete*

After its creation in early 2016, it was ensured this food forest could establish itself at its own pace, with as little human interference as possible. Food Forest Roggebotstaete was predicted to make a return on investment (ROI) in about 7 to 10 years from the date of establishment. The ROI was described as the net worth of products matching the price of establishment (Nijpels-Cieremans, 2015; Nijpels-Cieremans, personal communication, 2018; Van Eck, personal communication, 2018).

Van Eck explained that in general terms this food forest should not have any issues developing into a productive ecosystem. As the development of a food forest is governed by ecological succession, nature would find the required solutions to achieve a state of equilibrium. Over the course of time fungi should develop mycorrhizal symbiosis with plant roots. This symbiotic relationship is the driving force behind the development and productivity of this food forest and should therefore not be disrupted. Therefore, no site assessment and analyses of the site was necessary, and no compost was required in its establishment (Van Eck, personal communication, 2018).

According to van Eck pioneer species, vegetation illness and death are part of the same natural processes by which nature finds its balance and these developments should not be disturbed. The total amount of nutrients lost to harvesting should be compensated by the total biomass of organic litter falling on the forest floor, which is converted to available nutrients by the soil food web. The food forest therefore needs no extra fertilisation as mycorrhizal fungi can extract all the required plant nutrients, even from a barren soil (Van Eck, personal communication, 2018).

1.9 *The commission of a site analyses and assessment*

Three years on Miezgiel, as well as many of the visiting farmers believed the predicted ROI time of 7 to 10 years required reviewing. Food Forest Roggebotstaete had grown in appearance akin to a wild natural area. In parts of the forest pioneer species had formed dominant and well-defined clusters. Especially bramble (*Rubus caesius)* and bushgrass (*Calamagrotis epigejos)* had grown into thickets, such as the area seen in Figure 7, smothering the newly planted vegetation (Kruse, 2018).

While some of the newly planted vegetation has managed to become established, other vegetation has displayed minimal growth or did not survive. Some vegetation display signs of malnutrition in their leaves and growing patterns. Foliar disease is prolific in most of the regrown walnut trees (Figure 8.) and the planted blackcurrants are displaying signs of rust (Figure 9.). Miezgiel explained that of all the original fruit and nut trees, planted in 2004 to form the original forest, only the Walnut trees produce a small yield (Kruse, 2018).

Figure 7. Bramble and bushgrass forming thickets, smothering planted vegetation.

Figure 8. Vegetation disease in the walnut trees.

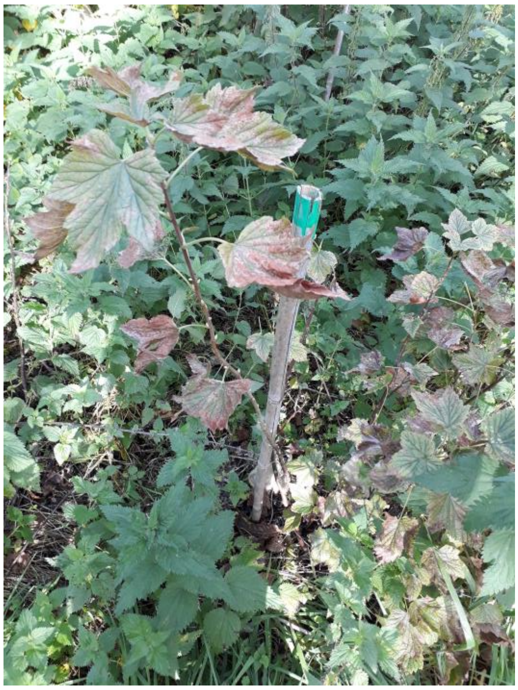

Figure 9. Rust on the planted black current bushes.

The main question raised by Suzanne Miezgiel and many of the visiting farmers focuses on whether this food forest will be able to develop itself into a productive ecosystem without outside input, and if so, how long it would take for this food forest to give a return on investment? There was no definitive answer to these questions. Part of the reason for this was the absence of a formal site assessment and analysis prior to the establishment of the food forest along with no monitoring and evaluation plan. Duijvestein and Miezgiel from Roggebotstaete expressed the need for a detailed site analysis and assessment, to understand the ecosystem dynamics of the site. This led to the commission of the baseline study of the factors influencing vegetation growth in Food Forest Roggebotstaete (Kruse, 2018).

For the setup of this study the food forest was divided into four subplots based on the differences in existing pioneer vegetation, indicating differences in the local growing conditions, with emphasis on the soil. On these four subplots quadrants of 7 x 7 meters were established. In these quadrants the vegetation was examined on composition, variety and density per vegetation layer. Soil samples were analysed on their physical and chemical aspects and soil profiles were determined (Kruse, 2018).

The main conclusions of the site analyses and assessment of Food Forest Roggebotstaete were as follows: The soil is of poor quality, low in fertility and largely made up of calcareous sand. This soil quality reflects directly in the limited growth and development of the planted vegetation and on the general health of the food forest flora. An estimated 15% of the total planted vegetation has died. The low ground water table and the low capillary action of the sand means the food forest may struggle with its water supply in times of drought (Kruse, 2018).

1.10 *Sketching the problem*

The current vision on the development of Food Forest Roggebotstaete is minimising human interference and letting nature take its course. This would allow the food forest to develop into a healthy and productive ecosystem and give a return on investment within 7 to 10 years (Nijpels-Cieremans, 2015). The findings of the baseline study bring this vision into question (Kruse, 2018). The soil is of poor quality three years after the food forest was created. The introduced vegetation has shown minimal growth and a significant amount has died out. This vegetation had to be replanted, adding to the investment cost and resetting the timeline for a ROI. 15 years after the original production trees were planted only the walnut trees currently produce a small yield (Kruse, 2018).

International literature on the topic of food forests describes a different, more (pro)active approach than has been applied to Food Forest Roggebotstaete thus far. Dave Jacke and Eric Toensmeier, writers of the “Edible Food Gardens volume 1 and 2”, describe site analysis and assessment to be a critical factor in developing a good design. It will help decide whether to leave the site and adapt the design to it (adaptive design) or to modify it to create better growing conditions for the desired plant species (site preparations) (Jacke & Toensmeier, 2005).

Martin Crawford, author of “Creating a Forest Garden”, mentions that although food forests are modelled on natural forests and their ability to self-fertilise through natural mineralisation processes, we usually want a greater yield from a food forest than available from natural forests. Therefore, some plants will require extra nutrients to replace those harvested (Crawford, 2010).

Geoff Lawton describes in many of his publications the use of nitrogen fixing support species in the establishment of a food forest. These support species help build soil fertility and can feed the productive trees, thereby speeding up the growth of a food forest (Figure 10.). In the video “How to create a food forest, the permaculture way” Lawton describes that by purposely feeding the soil and fungi and improving soil fertility we can speed up succession in a human designed and orchestrated ecosystem (Lawton, 2011).

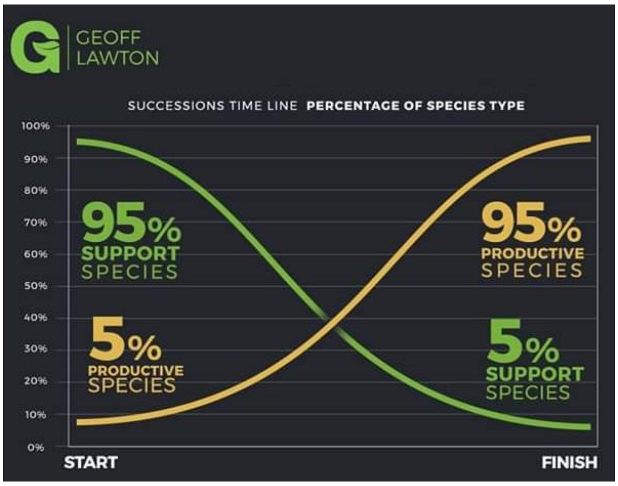

Figure 10. Speeding up food forest growth by using N-fixing support species. Adapted from (Lawton, 2019)

Albeit gaining in popularity, food forests are currently a niche sector in the Netherlands, especially in the agricultural sector (Green Deal, 2017). More collaboration is required between stakeholders in this field about the role of a food forest farmer and active management within these agro-ecological systems (Jacobi *et al*., 2017)

The objective of this thesis is to use international literature on temperate climate food forests to determine appropriate management strategies to address the identified problems in Food Forest Roggebotstaete. This could help facilitate its development towards a healthy, self-fertilising ecosystem able to produce high and diverse yields and thus achieving the goals, set out by its financiers and Roggebotstaete.

The information gathered in this thesis could be applied to the development and management of established and future food forest projects in the Netherlands, giving farmers and managers the ability to steer and accelerate natural processes to achieve abundant yields. Additionally, this thesis will add to the body of research under the Green Deal, giving Dutch farmers and policy makers valuable information regarding active management in a food forest, an option currently not discussed under the Green Deal Food Forests.

This thesis will answer the following research question:

> *What management strategies are applicable to overcome the identified problems in the development of Food Forest Roggebotstaete and facilitate its progress towards a productive and self-fertilising ecosystem?*

This research question will be answered by covering the following sub questions:

1. *What is the theoretical framework of a food forests?*
2. *What is the role of a food forest farmer?*

3. *What are the ecosystem dynamics of Food Forest Roggebotstaete?*

Readers guide: Chapter 2 describes how information for this literature review was collected, assessed and processed. Chapter 3 contains the results of the literature study and answers each sub-question. Chapter 4 contains the interpretation and discussion of the results. Chapter 5 answers the research question in form of the conclusion. The numbered* words in the text can be found in the Glossary.

Chapter 2: Literature search methodology

2.1 *Methodology gathering information*

The first step of this literature study was to investigate what information is available on the topic of management strategies in temperate climate food forests. As mentioned in the introduction food forests have rarely been studied by agricultural scientists which has resulted in the lack of existing scientific research (Crawford, 2010; Green Deal, 2017). Thus, a conventional search for specific scientific articles on temperate climate food forest management didn't yield desired outcomes.

Taking this into account a different approach was required. The first step of this approach was to find literature written by authorities in the field of food forest farming, with the emphasis on management strategies for temperate climate food forests. The second step was to examine any scientific literature that was used in compiling these works, also known as backwards literature searching. Additionally, specific management strategies mentioned by the authors were used as search terms on the various search platforms, such as 'Google Scholar', 'Springer', 'Wiley' and 'Science Direct'. Most scientific articles were open to public viewing, those with no access were not able to be used in the writing of this thesis. Furthermore, by studying the bibliographies of relevant scientific articles, additional scientific papers were found to complement the information.

The first draft of the preliminary research phase revealed the initial demarcation of the topic to be too broad. An open-minded approach to valuable constructive criticism resulted in reconsideration of the presentation of the research and thus redrafting of the thesis to make it applicable to Food Forest Roggebotstaete.

2.2 *Criteria for information use*

The literature search yielded both practical information based on experience, as well as scientific material on the application of specific management strategies. Sufficient depth of the retrieved information was ensured by adhering to a set of selection criteria:

- Practical and theoretical information based on experience of leading temperate climate food forest farmers, derived from officially published sources;
- Scientific articles including:
  - Current knowledge
  - Most up to date
  - Peer reviewed and sourced from reputable sources.

Peer reviewed sources considered to be very reliable included: refereed journal articles, reports from research institutes, essays and books with multiple authors and a source list. The relevance of the source was determined by the SCImago Journal Rank Indicator (SJR), by using https://www.scimagojr.com/journalrank.php. This score is a measurement for determining the prestige, importance and relevance of the source from which the article originates. The website gave access to the SJR indicator of scientific literature. As the research topic of this thesis was a specific field of expertise, SJR ratings were expected to be on the lower end of the scale. An SJR score above 1.0 was preferred for inclusion in this literature search.

Listed below are the main international literature works that were used to study the topic of a temperate climate food forest and utilised in each sub question, listed in order of relevance and importance:

- Jacke , D. and Toensmeier, E. (2005). *Edible forest gardens. Volume 1. Ecological vision and theory for temperate climate permaculture. Volume 2. Ecological design and practice for temperate climate permaculture*. White River Junction, Vermont: Chelsea Green Publishing.
- Crawford, M. (2010) *Creating a Forest Garden. Working with Nature to Grow Edible Crops*. Cambridge: Green Books.
- Lowenfels, J. (2003). *Teaming with nutrients. The Organic Gardener's Guide to Optimizing Plant Nutrition.* Portland, London: Timber Press.
- Lowenfels, J., Lewis, W. (2010). *Teaming with Microbes. The Organic Gardener's Guide to the Soil Food Web*. Portland, London: Timber Press
- Lowenfels, J. (2017). *Teaming with Fungi. The Organic Grower's Guide to Mycorrhizae.* Portland, London: Timber Press
- Oostwoud, M. (2019) *Voedselbos. Inspiratie voor ontwerp en beheer.* Zeist: KNNV

Information from news sites and food forest practitioners, either written, communicated verbally or captured on video was used to compliment the above-mentioned information sources if it held relevance to answer the research and sub questions.

2.3 *Methodology per sub question*

In addition to the information from the main international literature works mentioned above, the following methodology was used to answer the sub questions, listed in chronological order:

2.3.1 What is the theoretical framework of a food forests?

This chapter starts by addressing the ecological forces that govern the development of a food forest. The various types of ecological succession theories are discussed, leading towards the theory behind the preferred successional stage of a food forest.

Terms used to search peer reviewed, and other relevant information in both scientific and regular search engines included: “Mechanisms of succession”,” Secondary succession”, “Ecology of secondary succession”, “Forest establishment”, “Forests succession”,

Terms used to search scientific articles investigating the overall fertility in food forests, nutrient cycles and the nutrient requirements of introduced vegetation and the mechanisms behind self-sustaining fertility included:

Fertility: “Soil nutrient budget”, “nutrient pools”, “limiting factors”, “guild structure”, “biogeochemical cycling”, “temperate climate nutrient cycling”, “nutrient loss”.

Soil food web: “Soil microbial community structure”, “mycorrhizal fungi”, “benefits of the soil food web”, “benefits of mycorrhizal fungi”, “forest microbial function”.

Self-renewing fertility: “Guild structures”, “nutrient retention”, “nutrient accumulation”.

2.3.2 What is the role of a food forest farmer?

This chapter describes the role of a farmer in various agricultural systems. The benefits of food forest farming are explored along with the role of management within a food forest. Ecosystem dynamics are introduced as well as how they facilitate food forests development towards a healthy, self-fertilising ecosystem, producing high and diverse yields (Jacke & Toensmeier, 2005).

Development of Food Forest Roggebotstaete only commenced in early 2016, therefore the design elements pertaining site preparation were outside the scope of this thesis. This thesis is focussed on the management activities that can be used to generate the desired ecosystem dynamics. Which provide the practical framework to put the issues identified in the site analysis and assessment into an ecological context. This creates the context for the proposed management actions.

Peer reviewed, and other relevant information was searched in both scientific and regular search engines under the terms: “forest ecosystem dynamics”, “holistic agriculture”, “agricultural robustness”, “Sustainable paradigm shift agricultural systems”.

2.3.3 What are the ecosystem dynamics of Food Forest Roggebotstaete?

The results of the site analyses and assessment of Food Forest Roggebotstaete are summarised and projected onto the ecosystem dynamic model making a case for directing succession, working towards a self-fertilising capacity and minimising competition in Food Forest Roggebotstaete.

Peer reviewed, and other relevant information was searched in both scientific and regular search engines under the terms:

Directing succession: “ecosystem recovery”, “successional age”, “shifting soil organism constitution”, “creating stable plant communities”, “directing succession”, “facilitating fungal dominance”, “cover crops”

Self-sustaining fertility: “nutrient pool”, “ecosystem nutrient budget”, “temperate climate forestry practices”, “ecosystem nutrient conservation”, “ecosystem nutrient accumulation”, “nutrient availability”.

Minimising competition: “plant competition”, ”community niche availability”, “plant establishment”, “plant resources”, “minimising competition in agroforestry systems”.

Chapter 3: Results of the literature review

3.1 *What is the theoretical framework of a food forests?*

In its most basic definition a food forest could be described as 'an edible ecosystem'. They are conscientiously designed to mimic the layered structure and complexity of a natural forest (Jacke & Toensmeier, 2005). Food forests are not ecosystems that occur naturally, but rather are made up of vegetation communities purposely chosen to maximise positive species interactions (Lawton, 2011). This is achieved by using a large variety of plants, including non-native vegetation with the aim to increase the diversity (Crawford, 2010). Mature food forests mostly generate and maintain their own fertility as an inherent community function (Jacke & Toensmeier, 2005).

As food forests are designed to emulate forest conditions they are governed by rules of forest ecology (Crawford, 2010). This makes them incredibly complex systems to study and understand. There are four important forest ecology aspects that summarize the complexity of a food forest (Jacke & Toensmeier, 2005). These include:

1. Community architecture: The community architecture of a food forest is established by the layering, patterning, density and the diversity of the vegetation community, as well as the soil horizon structure. The combination and interaction of these factors determine overall yields, plant health, the dynamics of pest and diseases and maintenance requirements in food forest systems (Jacke & Toensmeier, 2005; Crawford, 2010).
2. Ecosystem social structure: All organisms, living in a food forest, interact with each other and their direct (non-living) environment. Their behavior, adaptive strategies, living requirements and physical characteristics influence the way in which they interact. Together they form the ecosystem social structure (Jacke & Toensmeier, 2005).
3. Soil interactions: Food forests are designed so that organisms can form beneficial associations with each other. This creates networks of mutual support to minimize competition and to share resources. The interaction between plant roots with the non-living environment and the soil food web is a critical component in the self-renewing fertility of a food forests (Jacke & Toensmeier, 2005).
4. Ecological succession: The growth and development of a food forest is governed by the natural forces that shape the land, better known as ecological succession (Jacke & Toensmeier, 2005). This process can be described as a directional and predictable change in vegetation community structure over time, caused by shifts in the occurrence and abundance of species diversity (Huston & Smith, 1987). Primary succession is the process of ecosystem development when there are no organisms or vegetation present and the environment is absent of soil, for example after volcanic activity (Emery, 2010). Secondary succession begins when an area is cleared of preexisting vegetation by a disturbance, such as plowing, burning or clearing (Connell & Slayter, 1977; Crawford, 2010).

Readers guide: The introduction of the theoretical framework of a food forest allows for a more detailed understanding of the complexity of Food Forest Roggebotstaete. It will help to find and combine appropriate maintenance solutions to fix the problems identified in the site assessment and analyses. This section will delve deeper into the ecological aspects that guide food forest development and the mechanisms of productivity and fertility of a temperate climate food forest.

3.1.1 A closer look at classic forest succession

The growth and development of plant communities in a food forest is governed by ecological succession (Jacke & Toensmeier, 2005). This process is a directional and sometimes predictable change in vegetation community structure over time (Huston & Smith, 1987). The first types of vegetation that spontaneously appear on cleared soils are the pioneer species, sometimes described as weeds. They are either transported to the site by wind or animals or grow from the seedbank present in the soil (Oostwoud, 2019). These pioneering species are typified by high rates of photosynthesis, respiration and net primary productivity[2]. They rapidly absorb soil nutrients, grow quickly and typically contain high concentrations of minerals (Emery, 2010; Jacke & Toensmeier, 2005). Their lifespans are short, they are mostly annual or biannual (Oostwoud, 2019).

Early successional systems have little plant biomass and diversity, consequently, there is a reduced role for decomposer organisms. There is a greater amount of biogeochemical cycling[3] and lower stability compared to late successional systems (Emery, 2010). Early successional soils support only small amounts of fungi due to the absence of root exudates and the limited availability of decomposable organic matter. The biomass of bacteria is therefore greater than fungi in early successional soils (Jacke & Toensmeier, 2005).

Bacteria secrete slimy alkaline substances in order to attach to soil particles. Large concentrations of bacteria can alter soil pH, resulting in a predominantly alkaline soil. The high numbers of bacteria in turn support large numbers of bacteria consumers, such as protozoa (Lowenfels & Lewis, 2010; Jacke & Toensmeier, 2005). Bacteria consumers release excess nitrogen as a waste product in the form of ammonium (NH_4^+). Nitrifying bacteria that thrive in the alkaline environment, convert the ammonium to nitrate (NO_3^-) (Lowenfels & Lewis, 2010). This makes nitrates the dominant form of nitrogen available to plants in early successional soils. Most annuals and grasses prefer nitrogen in this form, whilst most perennials and woody plants do not thrive in nitrate rich environments allowing pioneer plants to outcompete perennials and woody plants at this stage of succession (Lowenfels & Lewis, 2010; Jacke & Toensmeier, 2005).

When pioneer species come to the end of their lifespan they turn into organic litter. This litter accumulates on the soil surface and feeds the soil food web. Over time this organic matter changes the makeup of the soil allowing more permanent perennial plants to replace the short-lived annual vegetation. These plants in turn produce more complex and a higher variety of organic litter. At this stage the accumulated organic litter provides enough nutrients for fungi to grow and their spores start to germinate (Lowenfels & Lewis, 2010; Jacke & Toensmeier, 2005).

Fungal communities play an important role during successional shifts. How exactly soil microbial community structure responds to changing plant communities and soil chemistry associated with ecological succession is not known (Shao, Liang, Rubert-Nason, Li, Xie, & Bao, 2019). However, the general understanding is that shrubs and pioneer trees tolerate bacterially dominated soils and facilitate the conversion to a fungal dominated soil by the production of ever more complex organic litter (Lowenfels & Lewis, 2010; Jacke & Toensmeier, 2005; Seitera, Ingham & William, 1999). Bacteria are still present but are limited to digesting simple carbohydrates (Lowenfels & Lewis, 2010; Jacke & Toensmeier, 2005).

In the long term this environment will support climax community species. The shrubs and sun loving pioneer trees will be shaded out and start to disappear. The forest will the enter its climax stage (Jacke & Toensmeier, 2005). In late successional systems most of the nutrients are locked up in organic biomass. Consequently, biogeochemical cycling is slowed down, and most nutrients are internally available through the natural decomposition processes (Emery, 2010; Jacke & Toensmeier, 2005). The fungal bacterial ratio of the soil has shifted in favour of fungi (Lowenfels & Lewis, 2010).

Mycorrhizal fungi play a critical role in several key ecosystem functions in climax communities (Jacke & Toensmeier, 2005). As the main decomposers they are responsible for carbon cycling, nutrient mobilization from soil organic matter and from soil minerals (Courty *et al.,* 2010). Fungi produce organic acids to decompose organic matter for nutrients. When enough fungal acids are created they can offset the bacterial slimes and the pH of the soil becomes more acidic. Consequently, less nitrate is mineralised, leaving most of the nitrogen in ammonium form (NH_4^+). This allows trees, shrubs and other perennials that prefer nitrogen in ammonium form to outcompete the nitrate loving pioneer species (Lowenfels & Lewis, 2010; Jacke & Toensmeier, 2005). Figure 11 summarises the process of classic forest succession.

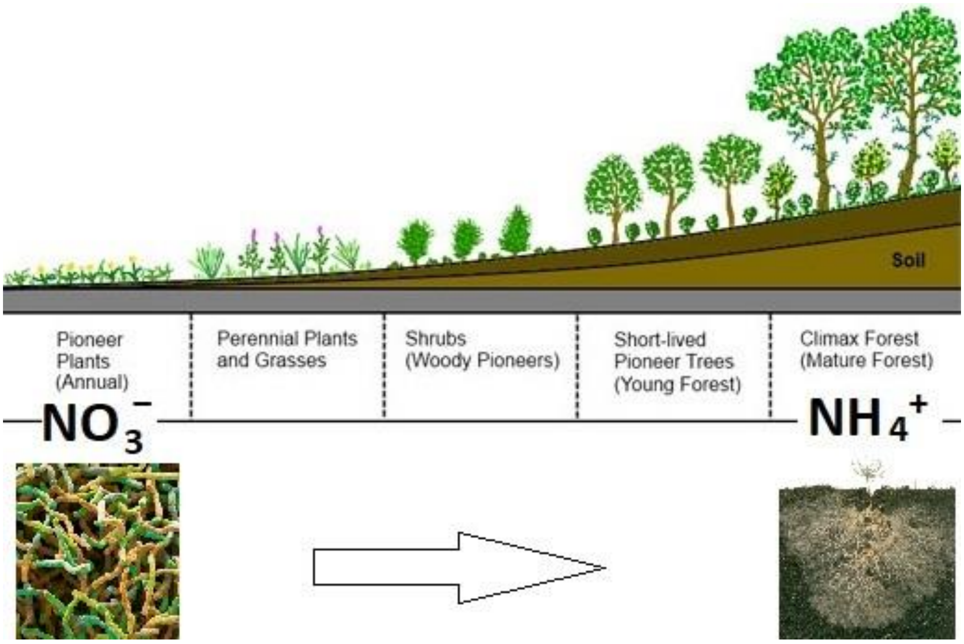

Figure 11. The progression of classic forest succession, Bacteria dominated early successional soils have nitrate as available nitrogen, in fungal dominated late succession soils this is ammonium. Adapted from (Eliades, 2009).

3.1.2 Succession theory and its application over time

Ecological succession has captivated ecologists for centuries and has been studied by ecologists since the end of the 19th century (Emery, 2010). In natural ecosystems, the process theoretically described above is more complex and localised, due to natural disruptions, variations in local microclimates, soil types and interspecies interactions (Jacke & Toensmeier, 2005).

Frederick Clements was the first to offer a comprehensive theory of plant community development at the beginning of the 20th century (Emery, 2010). The "Clementian succession theory" dominated the field of ecology for the first half of the 20th century (Glenn-Lewin, Peet & Veblen, 1992). Clements proposed that an ecosystem was able to self-form or self-renew towards a stable and permanent climax vegetation community and would follow a predictable pattern to achieve this (Emery, 2010). Clement described these steps as:

1. Migrating: The process of the arrival of organisms at a disturbed site.
2. Ecesis: The establishment of new organisms at the site.
3. Competition: The process of interaction of organisms at the site.
4. Reaction: The process of modification of the site by the organisms, changing the relative abilities of species to establish and survive.
5. Stabilization: The end point of the previous processes and the development of a stable climax community (Clements, 1916).

Clements proposed that the climax community was always made up of characteristic species that defined the local climate and ecosystem (Clements, 1916). For example, in most parts of the Netherlands this end stage climax community would be characterized by common beech forests (*Fagus sylvatica*) (Mohren, 2006).

Clements was convinced that after a disturbance this system would go through the same successional communities and automatically return to the characteristic climax community assemblage as before. He thought that this predictability was the result of all climax community species collaborating as a type of super-organism to maintain a stable structure (Emery, 2010).

Clements contemporary Henry Gleason opposed the super-organism concept and argued that there was no such thing as one stable climax vegetation community. The assembly of species was something that happened purely by chance and was regulated by the environment and species movement (Gleason, 1926; Emery, 2010). This made it possible for more than one climax community to form. This laid the foundation for the poly-climax theory currently supported by most ecologists (Young, Petersen & Clary, 2005).

Over time this theory became more refined. In the early 1970's ecologists agreed that plant succession contained predictable patterns, most notably the increase in species diversity and complexity with the successional age of an ecosystem. There was however no definitive endpoint to succession (Glenn-Lewin *et al.,* 1992).

It was in the late 1970's that Connell & Slayter proposed three different mechanisms by which vegetation communities progressed through predictable successional sequences (Emery, 2010). It was acknowledged that these processes often acted simultaneously and that the balance between them was a major factor determining the makeup of subsequent vegetation communities (Bellingham, Walker & Wardle, 2001). The distinguishing factor between these three mechanisms was the effects pioneer species had on the relative success of later-successional communities (Emery, 2010).

1. Facilitation: early successional species colonize a disturbed area and alter the environment. This alteration facilitates the invasion of later-successional species, while simultaneously making the habitat less hospitable for its own ecological demands.
2. Tolerance: early successional species neither inhibit nor facilitate the growth and success of other species. The climax community in this case is made up of the most tolerant vegetation

able to co-exist with others. Eventually, dominant species replace or reduce early successional species through competition.

3. Inhibition: early successional species inhibit the growth of later successional species. They simultaneously reduce the growth of existing vegetation and make the environment less hospitable to other potential colonizing species. The only possibility for new vegetation to grow or colonise the inhibited area is when a disturbance leads to the dominating species to be destroyed, damaged, or removed. (Connell & Slayter, 1977).

In 1989 Steward Pickett and Mark McDonnel expanded on that theory by proposing three causes for plant succession: Site or niche availability, differential species availability and deferential species performance (Jacke & Toensmeier, 2005).

The scientific field of restoration ecology has developed since the early 1990's (Perring *et al.,* 2015). It is particularly focussed on how vegetation communities are constructed and recover after disturbances (Van Andel & Aronso, 2005). As such restoration ecology studies the facilitating interactions between species, network dynamics and the interaction between above- and belowground associations and has provided the ideal setting to test successional theories in ecology (Perring *et al.,* 2015).

Restoration ecology operates from the successional theory of non-equilibrium alternative climax communities (Perring *et al*., 2015). It has drawn from established ecological principles and concepts to create a conceptual framework for plant community development that can be applied at a landscape level (Young *et al.,*2005; Van Andel & Aronso, 2005). Some of the restoration ecology principles share common ground with food forest farming and could have useful applications (Young *et al*., 2005; Jacke & Toensmeier, 2005):

- The presence of ecological guilds[4] can facilitate and enhance natural regeneration. These guild species include nitrogen fixing vegetation and overstorey plants (Bruno, Stachowicz & Bertness, 2003).
- The role of disturbances, both spatially and temporally is a natural and essential component of many vegetation communities (White & Jentsch, 2004).
- Nutrient and energy fluxes are crucial components of ecosystem function and stability (Peterson & Lipcius 2003).

Due to the endless possibilities of succession it is now generally accepted that ecosystem populations and communities change constantly. Either in a directional or a random, chaotic fashion (Van Bruggen *et al.,* 2019). It is clear that the conceptual framework, and the application of plant community development is still evolving (Young *et al*., 2005).

3.1.3 Temperate climate food forests are most productive at mid successional stage

The term food "forest" can be misleading in a temperate climate setting (Strouts, 2016). Temperate climate food forests need to be maintained in a state that resembles a young to mid succession stage forest. This is because temperate climate woodland systems are most productive in the mid succession stage (Jacke & Toensmeier, 2005).

In tropical climates the energy from the sun reaching the vegetation is up to eight times higher than in temperate climates (Crawford, 2010). This allows some tropical food forest species (e.g. coffee) to be productive, even in the shade (Craves, 2006). In contrast, temperate climate food forests require a very open canopy structure to allow enough sunlight to reach plants beneath the trees to increase productivity (Jacke & Toensmeier, 2005; Crawford, 2010). This has prompted prominent temperate climate food forest designers and practitioners to adopt the term "forest gardens" instead of food forests (Jacke & Toensmeier, 2005; Crawford, 2010).

While early successional systems are typified by rapid biogeochemical cycling, climax successional systems have most of the nutrients locked up in organic biomass. Consequently, biogeochemical cycling slows down in climax successional systems, reducing its productivity (Emery, 2010; Jacke & Toensmeier, 2005). A stable climax community is also commonly accompanied by a decrease in biodiversity (Jacke & Toensmeier, 2005). At this stage in succession the abundance of mycorrhizal fungi in the soil decreases while the total amount of saprobic fungi[5] increase (Castillo, Lucas, Le Moine, James & Nadelhoffer, 2018). Additionally, soil food web activity slows down, as it becomes more organised and efficient (Zhao *et al*., 2019).

Temperate climate food forest farming is about finding the balance within the spectrum of ecological succession (Jacke & Toensmeier, 2005; Crawford, 2010). Incorporating disturbances and plant guild structures in the development of a food forest, both spatially and temporally, facilitates a temperate climate food forest productivity and can help direct the desired vegetation (Young *et al.,* 2005; Jacke & Toensmeier, 2005). This insight can offer useful applications for the development of Food Forest Roggebotstaete.

<u>Readers guide:</u> This concludes the theoretical framework of food forest development. The next sections delve into the ecological aspects guiding the mechanisms of productivity and fertility of a temperate climate food forest.

3.1.4 The underground economy of a food forest

Forest nutrient cycling is the exchange of elements between living and nonliving components in the ecosystem. This cycle starts with nutrient uptake by vegetation from the soil. Nutrients are incorporated into biomass by the vegetation. When the vegetation sheds its leaves or branches, or it dies it produces organic litter that falls on the forest floor. The soil food web decomposes this organic litter, unlocks and transforms the nutrients back into forms which plants can utelise (Foster & Bhatti, 2006).

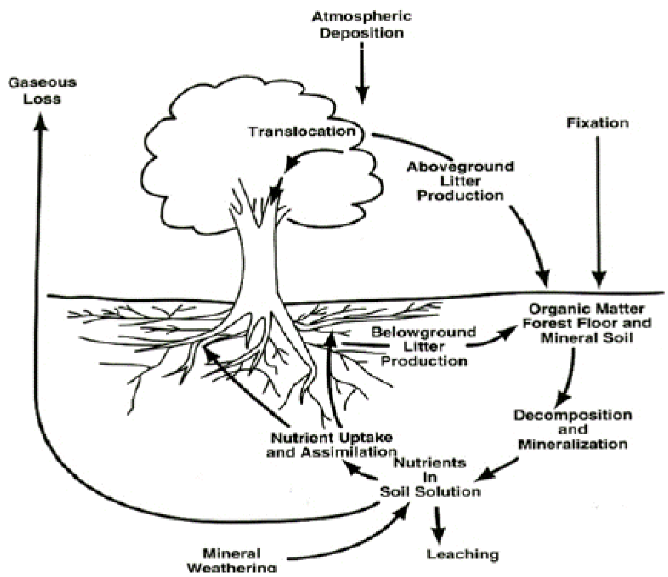

Figure 12. Forest nutrient cycling (Rahman & Tokumoto, 2013)

Nutrient sources in a temperate climate forest consist of animal excreta, nitrogen fixing bacteria, atmospheric deposition[6], decomposition and mineralisation of organic matter and the weathering of primary minerals in the soil. Nutrients are lost from a forest by leaching and by gaseous transfers, Figure 12 (Foster & Bhatti, 2006; Crawford, 2010). More than half of the annual nutrient uptake by temperate forest vegetation is returned to the forest floor and soil (Foster & Bhatti, 2006). Nutrient availability is strongly influenced by the quantity and quality of litter produced in a forest (Maes *et al.,* 2019).

Food forests are designed to function as a natural forest, this includes the process of nutrient cycling (Crawford, 2010). Much like a natural forest, the fertility in a mature food forest is largely maintained by its own vegetation. The majority of the nutrient demand of its vegetation are met through internal cycling (Jacke & Toensmeier, 2005).

Harvesting removes nutrients from a food forests and interrupts biogeochemical cycling. The recovery of those cycles after harvesting depends on the ability of the soil to supply nutrients to the plant roots (Foster & Bhatti, 2006; Crawford, 2010). Plant species vary widely in their demand for nutrients (Crawford, 2010). If the soil is unable to supply nutrients at a sufficient rate to maintain productivity, then additional fertilization is necessary to feed plants with extra nutrients to replace harvested nutrients (Foster & Bhatti, 2006; Crawford, 2010).

3.1.5 Nutrient availability in the soil

There are eighteen nutrients that are essential for the growth and development of plants (Sahu *et al*., 2018; Jacke & Toensmeier, 2005). The elements carbon, oxygen and hydrogen form the primary framework for all organic molecules and together make up around 95% of plant biomass (Campbell, 2018; Jacke & Toensmeier, 2005). Plants require large amounts of the macro nutrients nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), sulfur (S) and magnesium (Mg), as they are involved in fundamental metabolic processes. Plants need only small amounts of the micro nutrients such as boron (B), manganese (Mn), iron (Fe), copper (Cu), zinc (Zn), Cobalt (Co), Molybdenum (Mb), Nickel (Ni), Silicon (Si) and chlorine (Cl) (Foster & Bhatti, 2006; Campbell, 2018; Jacke & Toensmeier, 2005).

Each nutrient has its own unique biogeochemical cycle (Foster & Bhatti, 2006). Most of these nutrients are primarily derived from the soil (Campbell, 2018; Jacke & Toensmeier, 2005). Limitation in the supply of a single nutrient restricts plant survival, growth and production, even when all other growing conditions of the plant are being met (Campbell, 2018; Jacke & Toensmeier, 2005). Therefore, maintaining soil nutrient content is crucial for plant health, crop productivity and assuring a sustainable agro-ecology (Sahu *et al*., 2018; Jacke & Toensmeier, 2005).

Factors that influence nutrient availability are temperature, soil pH, soil aeration, soil moisture and the mineral and organic composition of the soil (Lowenfels, 2003). The most common limitation to plant growth and development are deficiencies of macronutrients (Campbell, 2018; Jacke & Toensmeier, 2005). Knowing which nutrients tend to limit plant growth and addressing these is an important step to increased survival, growth and productivity of food forest vegetation (Jacke & Toensmeier, 2005; Crawford, 2010). The following nutrients are the most common cause for mineral deficiencies in plants. Their origins and biochemical cycles are listed below (Campbell, 2018; Jacke & Toensmeier, 2005):

Nitrogen is the most common limiting factor to ecosystem productivity, as it's demand often exceeds supply (Lebauer & Treseder, 2017). Nitrogen naturally enters a food forest by deposition from the atmosphere or by nitrogen fixing bacteria, both in the soil and in association with plants. It is stored in organic matter. Decomposition by soil organisms makes nitrogen available for plants by mineralisation (Lowenfels, 2003).

Phosphorous deficiencies are the second most common limiting factor for plant growth (Jacke & Toensmeier, 2005). It has a very complex soil chemistry, therefore phosphorous deficiency in a plant is usually occurs due to the phosphorous not being available for uptake by the plant, rather than a lack of phosphorous in the soil. Phosphorous is almost exclusively derived from parent materials, although some deposition from the atmosphere does take place. Soil organisms are extremely important in converting phosphorous to an available form for the plant (Lowenfels, 2003).

Potassium deficiencies are the third most common limiting factor in plant growth (Jacke & Toensmeier, 2005). Potassium originates from rocks and is slowly released to the ecosystem by the process of weathering. Small amounts enter the ecosystem by atmospheric deposition (Perrenoud, 1990). Potassium is a cation and water soluble, which makes it rapidly leach out of organic material and the soil (Lowenfels, 2003). The positive charge of potassium allows it to be captured by negatively charged particles such as clay and organic matter in the soil, in an action called the Cation Exchange Capacity[7] (CEC). Sandy soils that lack organic matter have few negatively charged particles to bind potassium. This makes potassium the most limiting factor in these soils as it naturally leaches out. Soil organisms, such as mycorrhizal fungi play an important role in making potassium available for plants (Lowenfels, 2003; Perrenoud, 1990; Portela, Fernando, Fonseca & Abreu, 2019).

3.1.6 The importance of the soil food web

The decomposition and recycling of organic matter by the soil food web is a critical biological process through which soil regains nutrients that have been taken up by the plants (Sahu *et al*., 2018). The speed in which this process occurs is dependent on the composition of soil organisms, the physical environment and the quality of the organic material (Lowenfels & Lewis, 2010).

The soil food web is made up of an incredible diversity of organisms. There are micro-organisms (e.g. bacteria, fungi, protozoa and algae), macro-organisms such as insects, nematodes and earthworms and also larger animals, for example moles and mice and finally the roots of plants (Figure 13.) (Lowenfels & Lewis, 2010).

The composition of the soil food web is directed by the availability of food sources (Bot & Benites, 2005). In a temperate climate food forest this is season dependent (Jacke & Toensmeier, 2005). Soil organisms are therefore not uniformly distributed and their presence fluctuates throughout the year (Bot & Benites, 2005; Lowenfels & Lewis, 2010).

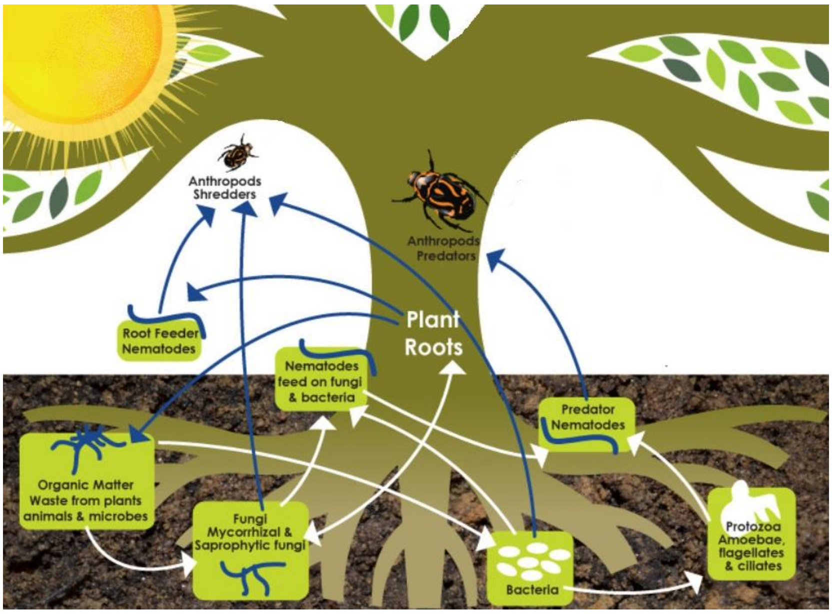

Figure 13. Soil food web interactions. Adapted from (https://preservationtree.com)

Food forests sustain large and diverse soil food webs, due to the accumulation of large amounts of highly diverse biomass on the forest floor (Bot & Benites, 2005; Jacke & Toensmeier, 2005). Soil organisms are present wherever organic matter is available (Ingham, Moldenke & Edwards, 2000). They are mostly concentrated in surface litter, as well as on the surfaces and in between the spaces of soil aggregates[8] and around plant roots (Ingham *et al.,* 2000; Lowenfels & Lewis, 2010). The rhizosphere[9] sustains a large amount of microbial diversity (Sahu *et al*., 2018). Each plant supports a specific micro-organism community with root exudates[10]. Plant diversity therefore directly effects the diversity of the soil food web (Jacke & Toensmeier, 2005). This interaction greatly contributes to plant and soil health (Sahu *et al*., 2018; Lowenfels & Lewis, 2010).

Soil organisms contribute to the functioning of a food forest by regulating the physical and chemical soil functions (Jacke & Toensmeier, 2005). A healthy and diverse soil food web benefits a food forest in various of ways:

<u>Nutrient retention:</u> Micro-organisms assimilate, sequester or adsorb mineral nutrients, ensuring that they are retained in the soil and preventing them from leaching out. These nutrients are returned to the soils in the form of organic matter, which slowly and continuously releases them (Sahu *et al*., 2018).

<u>Improving soil structure:</u> Bacteria attach themselves to soil particles by excreting a form of slime which aggregates soil particles. Fungal hyphae, nematodes, worms and insects burrow through the soil increasing its porosity (Jeffery *et al*., 2010).

<u>Increasing pest resistance:</u> The constant interaction between micro-organisms controls the populations of harmful pests and pathogens. This is done by competing for niche space, blocking access of pests to plant roots, preventing pathogens from getting to food recourses, producing chemicals that inhibit or kill them or by directly consuming them (Lowenfels & Lewis, 2010).

<u>Humus production:</u> Micro-organisms create humus by breaking down organic matter in a process called humification. Humus increases soil aggregation and stability, thereby increasing the capacity to store water. Humus increases the ability to attract and retain nutrients by raising the CEC. And it contributes to the availability of nitrogen, phosphorous and other nutrients. Some humus substances can function as natural plant hormones and can improve seed germination and root initiation (Bot & Benites, 2005).

Microorganisms can respond quickly to any physical, chemical or biological changes happening in the soil (Sahu *et al*., 2018). An increase in nutrient availability leads to increased productivity at the base of the food web, which in turn enhances the productivity of intermediate and top consumers. This significantly increases the microbial biomass, the nutrient content of organic matter and the leaf decomposition rates (Cross, Wallace, Rosemond & Eggert, 2006).

3.1.7 Mycorrhizal fungi are the secret to a healthy food forest

Mycorrhizal fungi have had symbiotic associations with plants since they first evolved to live on land, about 450 million years ago. They form symbiotic relationships with the roots of host plants (Amaranthus, 2000; Lowenfels, 2017). Mycorrhizal fungi are divided into two distinct types:

1. Endomycorrhizae: the hyphae[11] of these fungi completely penetrate the cell wall of the roots of the host plants, but not further than the plasma membrane. These fungi are generally associated with the roots of grasses, vegetables, shrubs and fruit trees. Endomycorrhizae are divided into three subgroups, of which the arbuscular mycorrhizae (AM) are the most common and important to food forest farmers.
2. Ectomycorrhizae: the hyphae of these fungi do not penetrate plant cell walls completely. These fungi form an exterior sheath covering the roots of plants. This group has more recently evolved and is about 200 million years younger than the endomycorrhizae. As a result fewer terrestrial plants form ectomycorrhizal relationships (Amaranthus, 2000; Lowenfels, 2017).

Both the host plant and the fungi benefit from these associations. Mycorrhizal fungi depend on the carbon supply from the host plant, in fact, up to 20% of a plant's photosynthesised carbon can be transferred to a fungal partner (Lowenfels, 2017). The hosts plants benefits in multiple ways:

Nutrient supply: Mycorrhizal fungi increase the nutrient supply by adding to the plant root surface area and therefore increase absorption of nutrients (Lowenfels, 2017). The fungi achieve this by creating extensive hyphal networks in the soil, in search for phosphorous, nitrogen, zinc, copper, iron and nickel. Their extracellular digestion releases nutrients, especially nitrogen, into the soil, which indirectly increases plant's nutrient supply. These nutrients are then absorbed and transported to the host plant in exchange for carbon (Köhl & Van der Heijden, 2016; Lowenfels, 2017). Furthermore, mycorrhizal fungi obtain nutrients and metabolites by interacting with the soil food web. In turn mycorrhizal fungi themselves are a food source for other soil organisms (Lowenfels, 2003). Mycorrhizal fungi can also retain nutrients in the soil (Köhl & Van der Heijden, 2016).

Water conservation: The fungal hyphae are extremely fine, allowing them to extend into soil spaces and draw up water which plant roots are unable to reach. The total hyphae network acts like a water reservoir. In addition, mycorrhizal fungi can form water storage structures in the host plant's roots. The combination of these factors allows plants in mycorrhizal associations to better withstand environmental stresses such as drought (Lowenfels, 2017).

Protection against pathogens: Mycorrhizal fungi are powerful competitors of soil pathogens by limiting their access to vital recourses. They achieve this by excreting specific chemicals, to inhibit foraging of pathogens. Some of these fungi can even mimic the chemicals produced by pathogen's natural predators. Mycorrhizal fungi also prevent pathogens from accessing hosts plant's roots by physically blocking them internally, as well as externally. The combination of all these factors allows these fungi to protect their host plant from root pathogens, as well as foliar diseases (Lowenfels, 2017).

Plant community structure: Mycorrhizal fungi can affect plant species behaviours, such as colonization and competitive ability, and therefore play a significant role in shaping plant community structure. They can increase plant species diversity, alter plant species composition and influence the rate and trajectories of community succession (Hartnett & Wilson, 2002).

Underground communication: Mycelial networks composed of different mycorrhizae have the extraordinary ability to communicate. Mycorrhizal fungi can associate with more than one host plant at a time, sharing their hyphal networks between plants, including plants of different species (Lowenfels, 2017; Courty *et al.*, 2010). Plants can literally nourish and protect other plants by the interconnectedness of the mycelial network (Figure 14.) (Babikova *et al.,* 2013; Song, Zeng, Xu, Li & Shen, 2010).

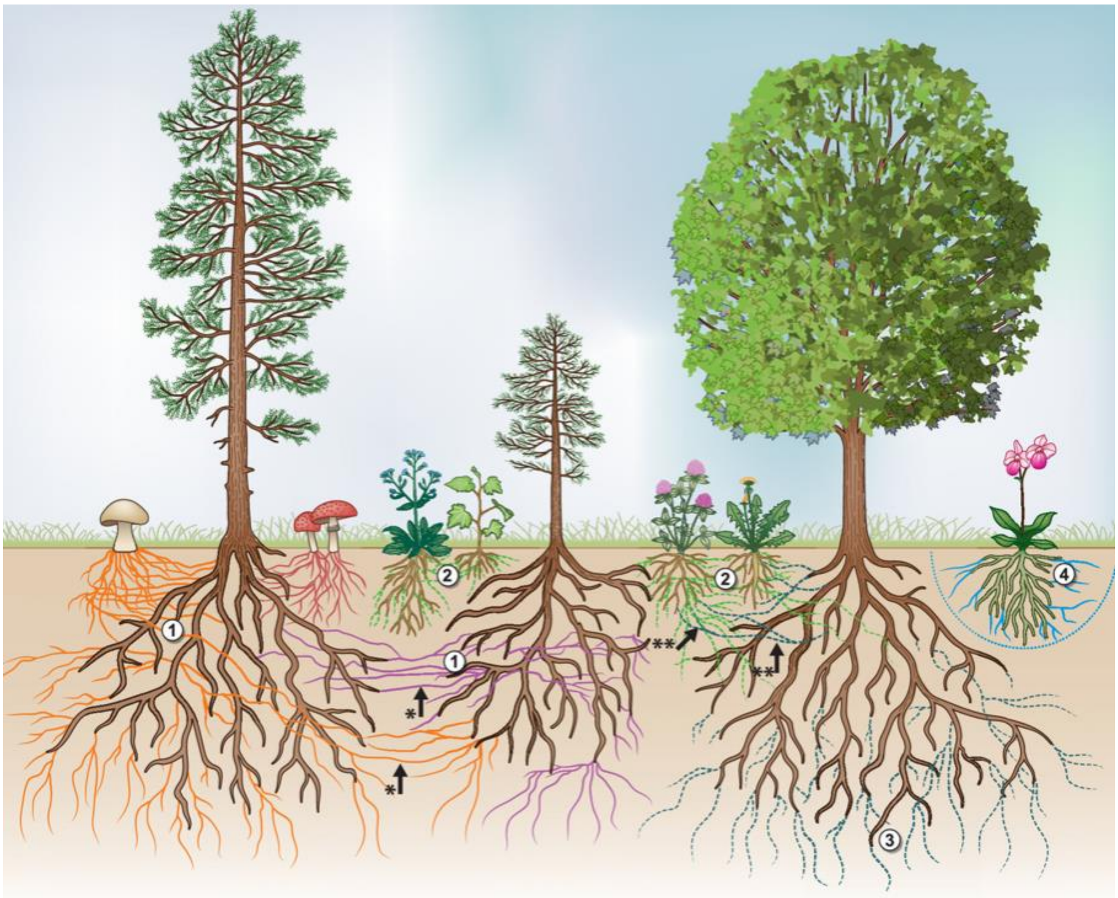

Figure 14. Trees forming networks with EM fungi (1) (solid thin lines) are interconnected*. Various plant species (2) and a tree (3) form interconnected AM networks **. The different colours represent different mycorrhizal fungal species for EM fungi (solid thin lines) and AM fungi (dashed thin lines. (Van der Heijden, Martin, Selosse & Sanders, 2015)

Mycorrhizal fungi have major beneficial effects on the total food forest ecosystem. Food forest health is directly related to the presence, abundance and variety of mycorrhizal associations. The importance of mycorrhizae to a healthy food forest function cannot be overstated (Jacke & Toensmeier, 2005).

3.1.8 Achieving self-sustaining fertility

The anatomy of self-renewing fertility in a forest ecosystem consists of uninterrupted, continuous biochemical cycles of plant nutrients. Nutrient conservation and accumulation are the most important factors contributing to this self-sustaining fertility. Just like a natural forest, a mature food forests can meet a large amount of its nutrient demand through internal cycling. The interconnected system of vegetation, organic matter and the soil food web creates a nutrient conserving system.

Plants energise this system and can alter its composition, structure and dynamics. (Jacke & Toensmeier, 2005).

Figure 15 summarizes this theory. It represents nutrient and waterflows in a mature and healthy food forest. These dynamics can be achieved by first accumulating an adequate nutrient pool in the food forest system to sustain ecosystem functioning. This is achieved by the natural processes of succession. Secondly, by creating a healthy soil food web, supporting large varieties of mycorrhizal fungi, uninterrupted and continuous nutrient cycling can be ensured. Succession can be accelerated to enable an ecosystem to reach a desired vegetation community (Jacke & Toensmeier, 2005). The emerging field of restoration ecology gives useful theoretical and practical insights into this practice (Young *et al*., 2005).

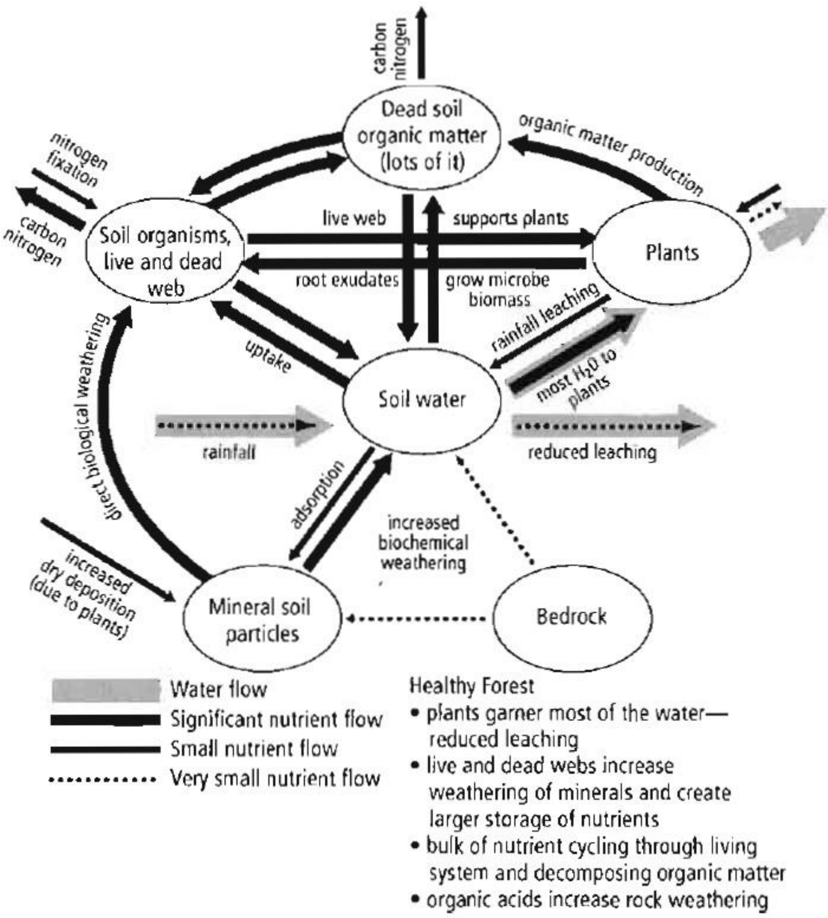

Figure 15. Nutrient flows in a healthy and mature food forest are self-renewing. Plants energise the system, control water flow, add organic matter and control the soil food web. (Jacke & Toensmeier, 2005)

Positive interactions are common phenomenon in natural plant communities and may have significant effects on the constitution of the plant community structure (Hartnett & Wilson, 2002). These interactions affect plant distribution, productivity, diversity and reproduction, see 3.1.2 (Callaway & Walker, 1997). Support species, such as nitrogen fixers, can influence the growth and spatial associations of vegetation (Tewksbury & Lloyd, 2001).

Food forest farmers can make use of these interactions by creating beneficial guilds. These guilds mimic ecosystem social structures and are designed to maximise the beneficial interactions between species and influence their relationships. For example, by mixing plants with different root patterns competition can be decreased, as nutrients are accesses at different soil levels, thus more ecological niches are exploited, and recourses are used more efficiently. This can lead to increased productivity (Jacke & Toensmeier, 2005).

<u>Readers guide:</u> this concludes the theoretical framework on the ecological aspects guiding the development, and mechanisms of productivity and fertility of temperate climate food forests. The role of the food forest farmer in managing a food forest system is discussed in the following section.

3.2 *The role of the food forest farmer*

Farmers, practicing conventional agriculture, control and manipulate their crops to attain maximum yields. This is achieved by growing monocultures which require frequent and intensive human involvement to eradicate threats and disturbances. The system balance is maintained using technologies enabling continuous monitoring and intervention (Ten Napel, Bianchi & Bestman, 2006).

While this farming model has vastly increased productivity it has contributed to air pollution, global warming and the depletion of petroleum reserves. Synthetic fertilizers and pesticides have a negative effect on human health, soil health and the quality of air and water (Erisman *et al*., 2008; Sutton *et al*., 2011; Udeigwe *et al*., 2015). They both leach into the groundwater table and run off into surface water (Oelsner *et al*., 2017).

Additionally, farmers are increasingly faced with the negative effects of climate change, weakening crop responses to agrochemicals and depleting soil nutrition (Sahu *et al*., 2018). The loss of soil organic matter has contributed to carbon releases into the atmosphere (Erisman *et al*., 2011). The combination of all these factors has led to a decrease in public support for this system of agriculture (Ten Napel *et al*., 2006).

Current strategies to improve agricultural sustainability are still largely based on solutions aimed at reducing "disturbances" such as weeds, insect herbivory and drought, that can alter the growing conditions and the yield of the crop (Rijksoverheid, 2018; Ten Napel *et al*., 2006). These strategies require intensive external recourses (e.g. fertilisation, crop protection and irrigation). They fail to reflect natural processes making it more difficult to achieve a sustainable system (Lewis, Lenteren, Phatak & Tumlinson, 1997).

Readers guide: This section researches a model of achieving agricultural sustainability in a food forest. It focusses on the benefits of food forest farming and discusses the role of management.

3.2.1 *A paradigm shift to a sustainable system*

Sustainable agriculture works in harmony with nature and can cope with naturally occurring disturbances, while being beneficial to both the ecosystem and humans (Lewis *et al*., 1997). To achieve this a shift in paradigm in agriculture is required (Ten Napel *et al*., 2006).

Modern farming techniques can be summarised under the 'Control Model'. Agriculture practiced under the 'Adaptation Model' considers local and naturally occurring variations. This enables a more diverse and context-based type of agriculture. An integral part of a more context-based agriculture is the ability of a farmer to learn by observing the conditions of the land and applying this experience to develop a productive production system (Figure 16.) (Ten Napel *et al*., 2006).

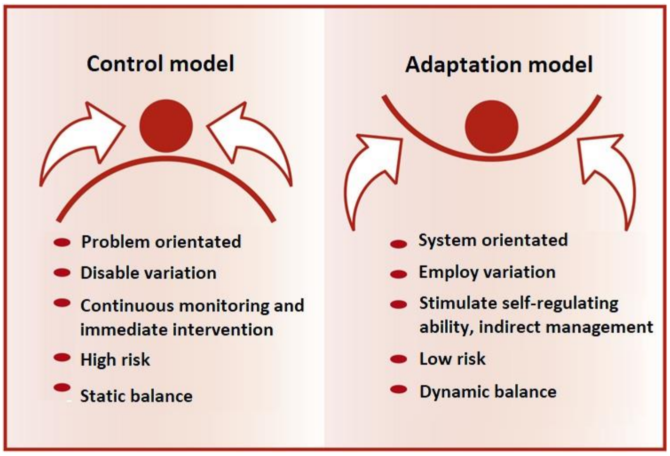

Figure 16. The control model versus the adaptation model. Adapted from (Ten Napel et al., 2006).

Food forests represent an extreme interpretation of this paradigm shift. Food forest farming encompasses the full range of ecological succession, from a bare field to a climax forest and all that occurs in between (see paragraph 3.1.3). In contrast to this, conventional agricultural techniques are aimed at holding back succession. Working the land by mowing, ploughing, weeding and spraying (Jacke & Toensmeier, 2005). The further an agricultural system is distanced from a natural forest ecosystem, the more energy input is required to maintain it. Consequently, arable agriculture needs the most input, while natural forests can look after themselves (Figure 17.) (Crawford, 2010).

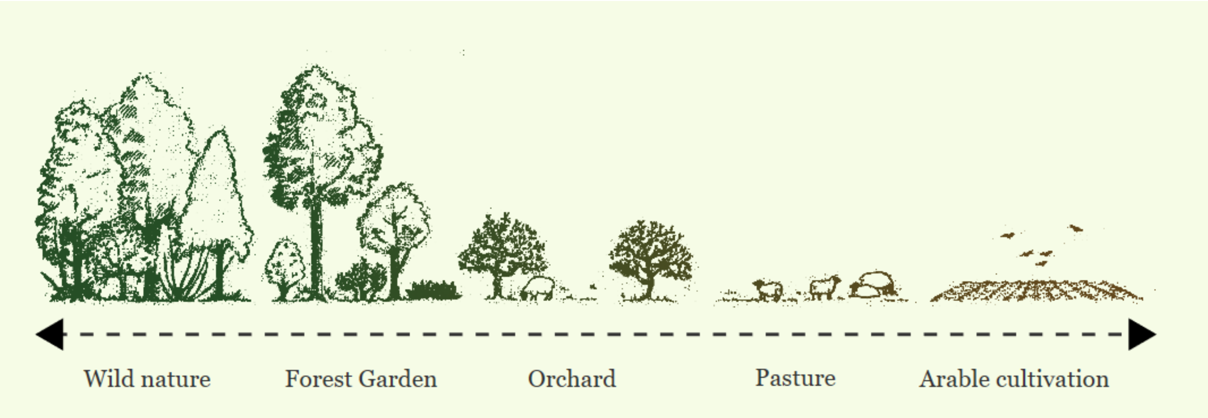

Figure 17. Wild nature needs no outside inputs to sustain itself, they form the most biologically stable systems. Arable cultivated land needs a lot of outside input and are the least biologically stable. (Crawford, 2010)

Food forests farming is inherently different to conventional farming. A food forest farmer must be more system orientated, understand the dynamics within the ecosystem and view naturally occurring variations as opportunities. The emphasis of food forest farming thus relies more on the ability of the farmer to read the landscape and understand the functions of the different species within the ecosystem (Deelder, 2016; Oostwoud, 2019; Jack & Toensmeier, 2005). Ecological knowledge is essential when interacting with a food forest (Deelder, 2016). A food forest farmer spends a lot of time observing things like plant health and interactions. While insect and animal populations are screened for potential pests and diseases, soil conditions are frequently monitored to maintain fertility and development (Jack & Toensmeier, 2005; Crawford, 2010).

3.2.2 The additional benefits of food forest farming

Food forests can provide food security in the form of high and diverse yields, while simultaneously moderating critical greenhouse gas emissions and impacts on soil, water and biodiversity. Food forests are therefore multipurpose by design (Falconer & Arnold, 1991; Jacke & Toensmeier, 2005). Specific end goals of individual food forests can differ, depending on the needs and desires of the creator (McConnell, 1992; Jacke & Toensmeier, 2005). Besides the production of food, food forest farming has additional benefits for a farmer:

> <u>Food forests are low maintenance.</u>
> Food forest vegetation is largely made up of perennial plants, which require little maintenance. They require low energy input and depending on design, the energy output can be much higher, making them biologically efficient agricultural systems (Crawford 2010). Food forests don't yield as much per plant as traditional agricultural systems, but because

food grows in multiple layers the yield can be as high as those of arable fields (McConnell, 1973; Eldredge, 2017).

Food forests form stable and resilient systems.
The diversity of vegetation and interconnectedness make food forests very stable systems. They sequester carbon and contribute to mitigating climate change (Oostwoud, 2019; Crawford 2010). High organic matter content of the soil contributes to nutrient immobilisation and acts like a sponge to retain water, allowing retention of large amounts of water during wet conditions. The combination of water retention and reduced evaporation rates, due to the layered vegetation structure, makes food forests drought resistant systems (Crawford, 2010; Jacke & Toensmeier, 2005).

Food forests provide high biodiversity habitat.
Food forests are dependent on the interactions between plants, animals and soil organisms to grow and function. They complement local environmental values and increase the biodiversity by providing habitat and stimulating the soil food web (Oostwoud 2019; De Waard & Van der Kamp, 2015).

3.2.3 Working with ecosystem dynamics

The establishment and development of a food forest is an ecological and evolutionary process. As the food forest matures plant communities grow, stabilise and decline as part of ecological succession and species evolve and adapt to the site's changing conditions through natural selection. Polycultures are designed to follow a desired successional direction and largely maintain themselves. A good design, site preparation and establishment of a food forest will allow nature to do most of the hard work, limiting the amount of work a food forest farmer will need to undertake (Jack & Toensmeier, 2005).

The magnitude and complexity of species' interactions with their environment makes it almost impossible to predict how a food forest will mature. A food forest farmer's goal is to produce high and diverse yields from a self-maintaining system that creates maximum ecosystem health. Food forest farming can be described as the shaping of ecological forces (Jack & Toensmeier, 2005).

The task of the farmer is to create specific desired ecosystem dynamics within the food forest. Ecosystem dynamics can be described as system behaviours associated with interactions between ecosystem components. These interactions and characteristics arise in the food forest through mimicking natural ecosystem structure and function. By respecting and embracing the local ecological site conditions and stimulating the self-regulating ability of the system, the farmer can facilitate the desired dynamics (Ten Napel *et al.,* 2006; Jacke & Toensmeier, 2005; Crawford, 2010).

A vital resource to successfully guide food forest development, is insight into successional processes (Buiter & de Waard, 2017). Apart from understanding these processes, food forest farmers need to design and manage them. Pruning, fertilising, mulching, weeding and pest control can shift a food forest towards its desired goal. However, these maintenance strategies need careful consideration as injudicious application can push succession and evolution in unintended directions (Deelder, 2016; Jack & Toensmeier, 2005; Crawford, 2010).

Conventional farming looks at issues such as fertility and weed control as separate issues. By introducing ecosystem dynamics food forest farming puts these issues into an ecological context and relates them to each other, like in a natural ecosystem. These ecosystem dynamics arise from the developing communities and interactions between all the elements present in the food forest. There are seven fundamental ecosystem dynamics that control the environmental conditions enabling a food forest farmer to establish a successful system. For more detailed theory behind them, see Section *3.1*. Figure 18 illustrates the interactions that create these ecosystem dynamics (Jacke & Toensmeier, 2005).

1. Healthy plants: ideal growing conditions meet all the plant's needs, creating healthy vegetation which can better resist herbivory, diseases and the negative effects of competition.
2. Self-renewing fertility: the process of succession ensures the accumulation of more complex organic litter. This litter protects and feeds the organisms of the soil food web, which in turn creates the biological infrastructure the ecosystem needs to function properly.
3. Sustainable water cycle: organic matter and humus in the soil act like a sponge to absorb and retain large amounts of water.
4. Minimal herbivory: by understanding the life cycles, the habitat needs and the natural enemies of pest organisms, strategies can be devised to combat them.
5. Minimal competition: competition increases plant stress, pests and diseases and yield reduction in desired vegetation. By minimising competition, plants can use a maximum amount of energy on growth, defence against herbivory and production.
6. Directed succession: a food forest farmer's aim is to create the conditions in which succession is self-directed, to produce desired vegetation communities and to develop a healthy, self-maintaining ecosystem.
7. Overyielding polycultures: all six ecosystem dynamics combined, create the desired conditions, producing healthy and diverse yields.

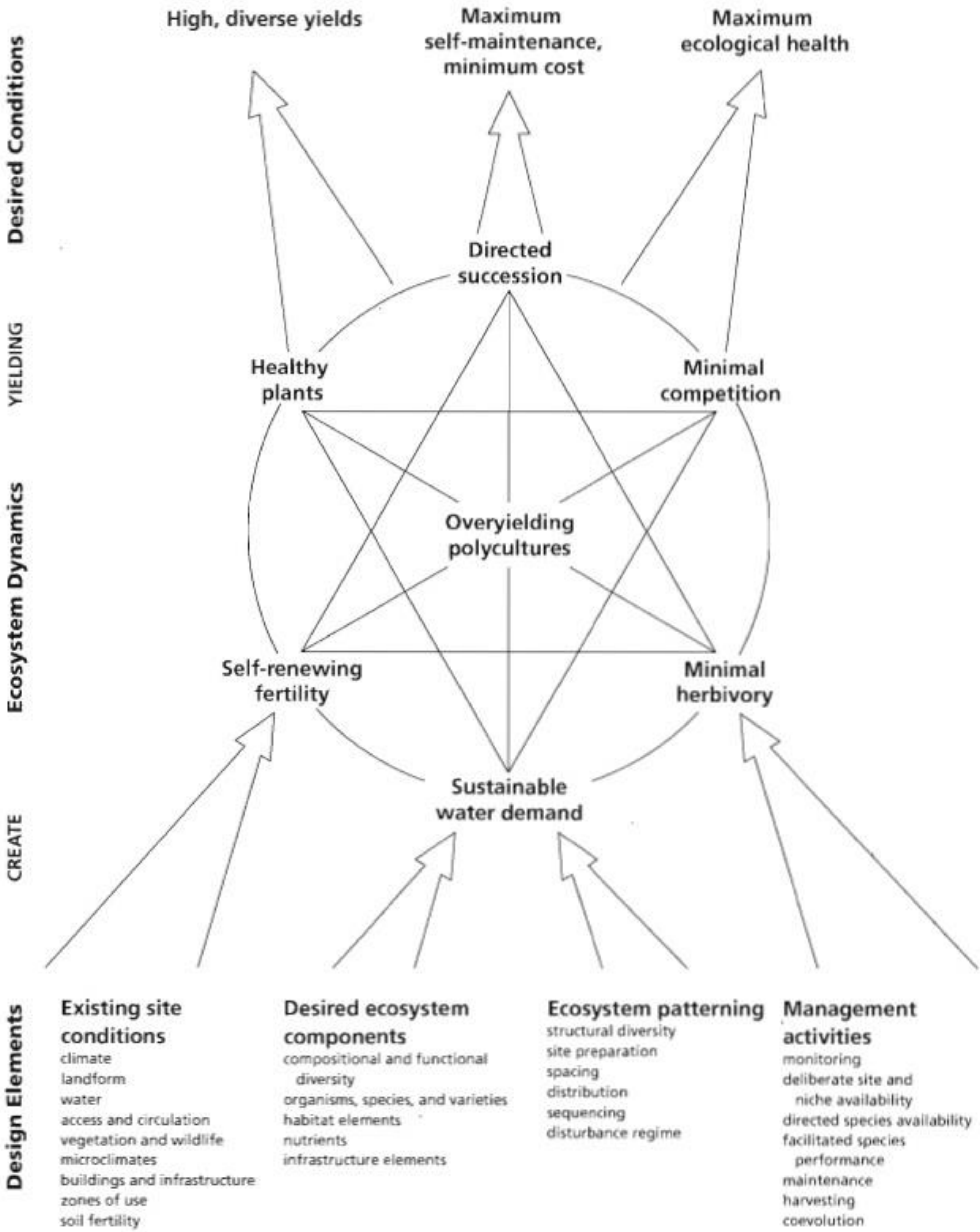

Figure 18. Design elements create ecosystem dynamics yielding desired conditions (Jacke & Toensmeier, 2005).

3.3 *What are the ecosystem dynamics of Food Forest Roggebotstaete?*

Applying the details of the site analyses and assessment of Food Forest Roggebotstaete to **figure 18** gives an overview of the interactions of each element (Kruse, 2018). This gives an ecological context to the identified problems. Furthermore, it provides the practical framework to solve these issues systematically by applying ecosystem design strategies to both directly and indirectly influence the ecosystem dynamics (Jacke & Toensmeier, 2005).

As Food Forest Roggebotstaete was created in early 2016, the design elements pertaining site preparation are not relevant for this thesis. What remains are management activities to generate the desired ecosystem dynamics. The facilitation of the desired ecosystem dynamics will enable Food Forest Roggebotstaete to realise higher yields, maximise self-maintenance and ecological health (Jacke & Toensmeier, 2005).

3.3.1 The findings of the site analyses and assessment of Food Forest Roggebotstaete

The site analyses and assessment of Food Forest Roggebotstaete focused on the factors influencing and contributing to vegetation growth. An overview of the size and constitution of the dominant vegetation communities was determined and plotted on a survey map by using a GPS to walk the vegetation borders. These vegetation communities had been allowed to grow since the creation of the food forest as part of natural succession (Kruse, 2018).

Four inherently different locations within the food forest were identified, chosen for their variances of vegetation communities. Quadrants were set up in all four locations and in each of the quadrants the factors influencing vegetation growth were analysed in detail. This included the composition and structure of the vegetation community, the physical and chemical properties of the soil and the make up of the soil food web, see Section *1.9* (Kruse, 2018).

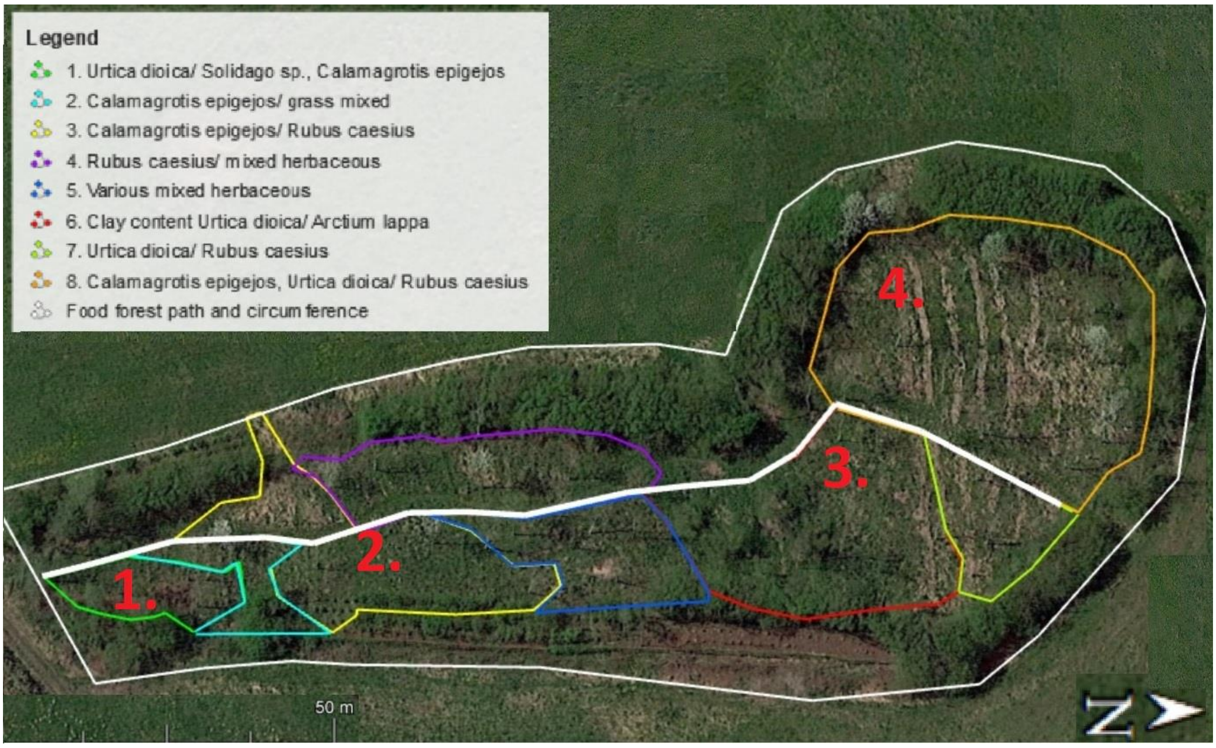

Figure 19. Spatial distribution and composition of succession communities in Food Forest Roggebotstaete. Adapted from Google Earth.

Figure 19 provides an overview of Food Forest Roggebotstaete, the locations of each quadrant and the constitution and distribution of the succession communities.

Analysis of the factors influencing vegetation growth made it possible to draw conclusions on the state of the vegetation, as well as the soil quality and water availability in the food forest. The main conclusions of the site analysis and assessment can be summarised as follows:

<u>The general soil quality is poor.</u>

- The soil on which Food Forest Roggebotstaete is planted is largely made up of calcareous sand with a low clay content (4-5 %). Although quadrant 3 has slightly better values than the other three quadrants, due to a higher clay content.
- The pH is alkaline, with values between 7.2 and 7.3. The concentration of humus and organic matter is low. For example, the organic matter percentage in quadrant 4 is only 1.8%. This also translates in a low CEC.
- The availability of plant essential macro and micro elements is poor. The chemical analyses showed insufficient plant available nitrogen, potassium, sulphur, magnesium, borium, nickel and chromium. While on the other hand concentrations of calcium, iron and manganese are considered too high for optimal plant health.
- The available nitrogen is predominantly in nitrate form in relation to ammonium. For example, on site 4 the amount of NO_3^- was 44 kg/ha, while NH_4^+ was 3 kg/ha.
- The fungal/bacteria ratio is not beneficial. Only a small amount of beneficial fungi is present, while the number of yeasts is very high (Kruse, 2018).

<u>The availability of water in times of drought could be problematic.</u>

Due to a lack of hydrological data it was difficult to draw accurate conclusions about the water availability. However, a good indication is given by the publicly available data from the website www.bodem.nl, in combination with the soil profiles taken in each quadrant.

In general, the food forest is dependent on precipitation for water supply. The low groundwater table and the low capillary action[12] of the sandy soil, in combination with low concentrations of organic matter and clay means Food Forest Roggebotstaete is vulnerable to drought conditions (Kruse, 2018).

<u>Vegetation growth and development is poor.</u>

The poor soil quality translates directly to the growth and development of the desired vegetation and the general health of the food forest flora.

- Pioneer vegetation has grown into local thickets, smothering the introduced vegetation. In particular communities of bushgrass (*Calamagrotis epigejos)*, bramble bushes (*Rubus caesius)* and in lesser amounts stinging nettles (*Urtica dioica)* are abundant.
- The desired vegetation has displayed limited growth in some parts of the food forest and an estimated 15% has died since being planted. A large amount of the walnut trees displays signs of walnut black spot *(Gnomonia leptostyla)* while some of the blackberry shrubs are showing signs of rust (*Pucciniomycetes*) (Kruse, 2018).

When these findings are put into the context of **figure 18** the following conclusions can be drawn of the current ecosystem dynamics of Food Forest Roggebotstaete:

- The food forest is in an early stage of succession, with small amounts of beneficial fungi and plant available ammonium.
- It currently has no self-renewing fertility and a small available nutrient pool.
- Introduced vegetation is struggling to become established, displaying limited growth while some species have failed altogether.
- Competition between introduced and pioneer vegetation is too high in some areas.
- The food forest could struggle with water supply in times of drought, such as the summer of 2018.

Readers guide: The findings of the literature review in Section *3.1* detail the theoretical framework of the development, productivity and fertility of temperate climate food forests. The role of a food forest farmer and active management are deliberated in Section *3.2*. Section *3.3* has provided the practical framework to systematically solve the issues identified in the site analyses and assessment by applying ecosystem design strategies. Chapter 4 will discuss the findings of the literature study and the site analyses and assessment in relation to the research question.

Chapter 4: Discussion

The main goal of this research project was to develop solutions to issues identified during the site analyses and assessment of Food Forest Roggebotstaete. To facilitate this, background theory on temperate climate food forests was gathered by performing a comprehensive literature review of scientific resources. Additionally, news articles, video material and food forestry websites were evaluated, and input was sought from teachers, farmers and food forest practitioners.

<u>Summary of the literature review:</u>
Food forests develop and mature through the process of ecological succession. The theory on plant community development is complex and still evolving. The field of restoration ecology draws from established ecological principles and concepts creating a conceptual framework for plant community development that has useful applications to food forest farming. Temperate climate food forests should be maintained at mid-successional stage to be most productive. The soil food web and especially mycorrhizal fungi play a crucial role in achieving a self-fertilising system, which consists of uninterrupted, continuous biochemical cycles of plant nutrients. The ability of a food forest system to conserve and accumulate nutrients are the most important factors contributing to this self-sustaining fertility.

Food forest farming can be described as the shaping of ecological forces and the task of a food forest farmer is to create desired ecosystem dynamics within the forest. The ecosystem dynamics model was applied to the site analyses and assessment of Food Forest Roggebotstaete to determine a practical framework to systematically address the identified issues in the development of this system. It is hoped that applying systematic solutions to positively influence the ecosystem dynamics of Food Forest Roggebotstaete will facilitate the development of a healthy, self-fertilising ecosystem able to produce high and diverse yields and thereby achieve the goals set out by financiers and Roggebotstaete.

4.1.1 A case for directing succession in Food Forest Roggebotstaete

The current vision for Food Forest Roggebotstaete is minimising human intervention to allow natural succession to develop this food forest into a healthy, productive and stable climax community ecosystem. It was estimated that five to seven years of accumulation and succession would be sufficient to reach a mature and stable system that would coincide with the predicted ROI anticipated for this food forest (Buiter, 2017; Nijpels-Cieremans, 2015; Nijpels-Cieremans, personal communication, 2018; Van Eck, personal communication, 2018).

The site analysis and assessment of Food Forest Roggebotstaete was performed in 2018, with the food forest in its 3rd year of development. The soil fungal/bacteria ratio and the dominance of bushgrass (*Calamagrostis epigejos)* revealed Food Forest Roggebotstaete to be in an early stage of succession (Lowenfeld & Lewis, 2010; Rebele & Lehmann, 2016).

Natural ecosystems have the ability to recover after a disturbance, however, Food Forest Roggebotstaete is not a natural ecosystem (Haeussler, Bartemucci & Bedford, 2004; Lawton, 2011). The conceptual framework of plant community development is still being established (Young *et al*., 2005). By allowing natural pioneer species to grow unchecked, assuming "nature knows best", arguably puts the current adopted vision of this food forest ecosystem in the context of the "Clementian successional theory" (Strouts, 2016). This fails to take in account the inhibiting ability of early successional species, limiting growth of later successional species and outcompeting vegetation already present (Connell & Slayter, 1977).

Pioneer vegetation communities of bushgrass (*Calamagrotis epigejos)* and bramble bush (*Rubus caesius)* have grown into local thickets, smothering introduced vegetation. This has led to the demise of fig tree seedlings, planted around quadrant 2 (Kruse, 2018). Allowing these vegetation dynamics to continue could lead to a very different climax community than originally intended (Young *et al*., 2005; Kruse, 2018).

The site analyses and assessment of Food Forest Roggebotstaete showed that most plant essential nutrients are in low supply in the soil with most of the available nitrogen in nitrate form. The CEC of the sandy soil is low and susceptible to leaching cations (Kruse, 2018; Ketterings, Reid & Rao, 2007). Furthermore, the fungal/bacteria ratio is not beneficial, with only a small amount of beneficial fungi present (Kruse, 2018).

The analyses of international literature found that ecosystems could be actively directed towards a later successional stage (Young *et al*., 2005; Jacke & Toensmeier, 2005). By changing the organic matter input it is possible to create conditions beneficial for fungal growth (Seitra *et al*., 2009). Nutrient enrichment can lead to an increase in the net primary production, microbial biomass and productivity of the soil food web (Cross *et al*., 2006; Yuana *et al*., 2018; Maes *et al*., 2019). Soil nutrient availability is the key limiting factor for the growth of small trees (Yuana *et al.,* 2018). Assisting the introduced vegetation during the establishment phase by increasing nutrient supply could greatly improve success and reduce the need to replant, thus speeding up the ROI (Holl, Loik, Lin & Samuels, 2000).

An optional management strategy for Food Forest Roggebotstaete could include soil enrichment with fungal dominated compost (Lowenfels & Lewis, 2010). Compost can improve the physical and chemical properties of the soil (Hernández, Garcia & Garcia, 2015). The addition of compost also increases the bacterial and fungal biomass in the soil, together with the functional diversity of the soil food web by inoculation[13]. As a result, carbon, nitrogen and phosphorous cycling can increase and the growth of mycorrhizal fungi is stimulated (Hernández *et al*., 2015; Lowenfels & Lewis, 2010). Actively shifting the fungal/bacteria ratio can create the preferred growing conditions of the desired perennial vegetation (Lowenfels & Lewis, 2010). Increasing mycorrhizal symbioses can improve growing conditions, plant health and system stability and resilience (Courty *et al.,* 2010).

4.1.2 A case for active fertility management in Food Forest Roggebotstaete

Theoretically, progression in successional age will allow an ecosystem to bind nutrients in organic matter. Over time the nutrient balance will convert to a self-sustaining system. Poor-quality soil, such as that found at Food Forest Roggebotstaete has significantly less ability to develop self renewing fertility (Jacke & Toensmeier, 2005). In addition, the process of harvesting removes nutrients from the system and further interrupts nutrient cycling. The recovery of nutrient cycles after harvesting depends on the ability of the soil to supply nutrients to the plant roots (Foster & Bhatti, 2006; Crawford, 2010). Restitution of harvested nutrients by soil mineral weathering (Section *3.1.5*), is too unpredictable to be used as a reliable management practice (Klaminder *et al.,* 2011).

Before Food Forest Roggebotstaete was developed, the original forest planted in 2004 was largely removed. It was noted that the original vegetation already displayed signs of unhealthy development before being removed, with special mention made of unhealthy oak trees (Nijpels-Cieremans, 2015). The cutting down and removal of most of the original forest vegetation during the establishment of Food Forest Roggebotstaete has further decreased soil organic matter and has led to an increase in nutrient leaching. This may have had a significant effect on the soil fertility, nutrient status and, in turn, tree growth (Achat *et al.*, 2018).

Sufficient nutrient and energy flows are crucial components to the function and stability of an ecosystem (Young *et al.,* 2005). The optional enrichment of the soil with compost mentioned in 4.1.1 could be a short-term solution to alleviate the soil infertility of Food Forest Roggebotstaete. Another option worth considering is the addition of biochar[14] to compost. Provided the biochar is free of contaminants, it has added benefits for low fertility soils by forming stable, humus like substances and reducing nutrient loss by improving the CEC and water retention within the soil (Godlewska, Schmidt, Ok & Oleszczuk, 2017; Biederman & Harpole, 2012)

A healthy soil food web plays a crucial role in generating the long term self-renewing fertility in the food forest by creating functional interconnectedness among species. These social structures evolve over time as the food forest matures. While community social structure is fluid and invisible, a food forest farmer can use guild structures to anchor and stabilise them (Jacke & Toensmeier, 2005). Food forest plant guilds can be described as an assembly of various facilitating species that don't naturally occur together (Crawford, 2010). By making use of the intrinsic plant behaviours and minimising the overlap of ecological niches, they can have a positive influence on growth and spatial associations of desired food forest vegetation (Callaway & Walker, 1997; Tewksbury & Lloyd, 2001; Jacke & Toensmeier, 2005). International literature supports the following options to facilitate the attainment of self-sustaining fertility within Food Forest Roggebotstaete.

Introduction of nitrogen fixing species:
Lack of available nitrogen often limits the primary production in forest ecosystems (see Section *3.1.4*) (Lebauer & Treseder, 2008). Nitrogen fixing plants have symbiotic relationships with nitrogen fixing bacteria and can fix atmospheric nitrogen through nodules in their roots. They can be split into two groups; the legumes (rhizobial plants) and actinorhizal plants (Crawford, 2010).

In temperate forests, fast growing nitrogen fixing perennials are generally most abundant in early phases of succession (Rastetter *et al.,* 2001). They enrich the soil by increasing soil nitrogen levels and soil organic matter (Titus, 2009). The fixed nitrogen becomes available to other vegetation by litterfall, root turnover, leaching and distribution by mycorrhizal fungi (Crawford, 2010; Song *et al.*, 2010). The presence of nitrogen fixing vegetation can therefore enhance succession (Bruno *et al.,* 2003). Mimicking the development of a natural forest, food forest establishment and succession can be facilitated by introducing nitrogen fixing vegetation to serve as support species (Figure 10) (Lawton, 2011; Crawford, 2010). By introducing nitrogen fixing perennials, for instance false indigo (*Amorpha fruticosa*) long term nutrient accumulation in Food Forest Roggebotstaete can be facilitated (Crawford, 2010).

Utilising the herbaceous layer to speed up decomposition:
Nitrogen fixing perennials take time to grow and establish themselves before being beneficial to the system. Furthermore, their organic litter is woody and hard to decay. To keep the biochemical cycles of plant nutrients uninterrupted and continuous, fast growing nitrogen fixers (e.g. Clovers, *Trifolium spp.)* and nutrient accumulating herbs can be introduced into the herbaceous and groundcover layers (Figure 20). These plants grow, die and decompose quickly, thereby helping to speed up the breakdown of more decay resistant litter. This maintains a constant supply of nutrients to the soil food web preventing bottlenecks in the cycling of nutrients (Jacke & Toensmeier, 2005).

The above mentioned nutrient herbaceous layers are called "dynamic accumulators" in the permaculture fraternity. They can mine the soil for nutrients and accrue them at higher than soil levels. Many dynamic accumulators are deep rooted plants, allowing them to survive in nutrient poor environments. They can be used to "accumulate" minerals that have leached out of the the top soil but are less scarce in the soil parent material[15]. These plants also capture and recycle nutrients before they leach out of the system (Jacke & Toensmeier, 2005; Crawford, 2010). A widely used plant species, valued for its nutrient accumulating abilities are the comfreys (*Symphytum spp*). Figure 20 is an example of a plant guild supporting a fruit tree.

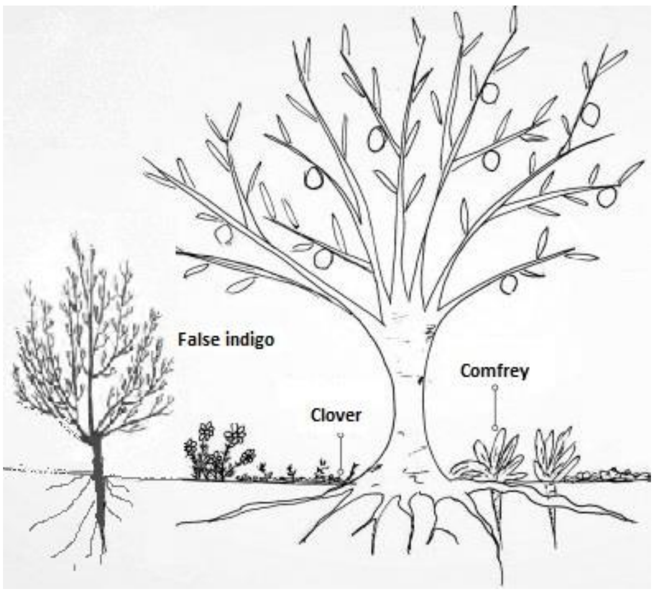

Figure 20. A plant guild consisting of False indigo, clover and comfrey around a fruit tree. Adapted from (Charbonneau, 2018).

Comfrey species can accumulate high amounts of nitrogen, potassium and calcium. They produce abundant biomass and their leaves decompose quickly (Crawford, 2010; Hills, 1976).

It is important to note the dearth of scientific literature on the topic and function of dynamic accumulators (Carter, 2017). However, the presence of these accumulators can minimise species competition by occupying various ecological niches. Thus, they can direct succession by occupying available space and help to move the system towards a later successional stage (Jacke & Toensmeier, 2005).

Influencing the short- and long-term plant nutrient availability will address the current soil fertility issues at Food Forest Roggebotstaete and the successional stage can be shifted towards a more matured self-fertilising system. Low intensity maintenance activities can ensure continuous productivity of heavily fruiting vegetation (Jacke & Toensmeier, 2005; Crawford, 2010). Cropping of come food forest species (e.g. currants) and especially heavily fruiting trees that make up most of the northern side of Food Forest Roggebotstaete (e.g. walnuts and apples) will require extra amounts of nitrogen and potassium to maintain productivity (Crawford, 2010). International literature shows the practice of applying biological fertilisers, such as human urine and bioactive compost tea[16] to be effective options to achieve this (Germer, Addai & Sauerborn, 2011; Pane *et al.,* 2016).

4.1.3 A case for minimising competition in Food Forest Roggebotstaete

A classic point of discussion between practitioners of various forms of sustainable agriculture and ecologists is the impact vegetation growing in between the introduced vegetation (the intermediate vegetation) has on the introduced vegetation (Davis, Wrage & Reich, 2001; Oostwoud, 2019). For example, permaculturist Taco Blom sees grasses as serving as valuable support for introduced plants in a food forest system (Oostwoud, 2019). In contrast, orchardists and ecologists view grasses as a problematic vegetation due to competition with tree seedlings, negatively affecting their growth and survival rates in their early stages of establishment (Rebele & Lehmann, 2016; Holl *et al.,* 2000).

Two plant species, living close to each other and occupying the same ecological niche, will share the same resources, including available light, water and nutrients. When the supply of those recourses becomes scarce, they will start to compete (Craine & Dybzinski, 2013). The higher the ecological niche overlap and the closer plants stand together, the greater the likelihood of competition (Jacke & Toensmeier, 2005; Fehmi *et al.,* 2004). Competition is a negative interaction for plants. By creating stress, it decreases the ecosystem productivity. Competition can be reduced by increasing the resource supply (e.g. by nutrient enrichment) or by reducing resource demand (e.g. mowing or pruning undesired vegetation). Both are traditional agricultural practices (Jacke & Toensmeier, 2005).

A small experimental field trial with alternative mowing regimes was conducted by Suzanne Miezgiel in Food Forest Roggebotstaete. Six rows of Japanese quince (*Chaenomeles japonica)* in the Southern corner of the food forest were used as an example. The intermediate vegetation between the rows was dominated by nettles (*Urtica dioica)* and goldenrods *(Solidago sp.).* In the first row the vegetation was allowed to grow (Figure 21.). In the second row the vegetation was mowed once at the start of summer (Figure 22.). Vegetation was mowed once at the start of summer and once mid-summer in the third row (Figure 23.). Photos were taken at the end of the growing season in early October. Albeit small and experimental in its setup, it gave an early indication of the possible benefits of decreasing competition on the planted vegetation by mowing the intermediate vegetation.

Figure 21. No mowing between the rows

Figure 22. Mowing once at the start of summer

Figure 23. Mowing once at the start and once mid-summer

As shown in figure 21 to 23 mowing the intermediate vegetation can reduce resource demand and therefore minimise competition (Jacke & Toensmeier, 2005). Nutrient cycling and succession could be improved and hastened in Food Forest Roggebotstaete by mowing, pruning and coppicing[16]. By using the obtained organic litter as mulch on the spot, a method also known as 'chop and drop', beneficial fungi are encouraged to develop (Lawton, 2011; Seitra *et al*., 2009). International literature readily identifies the application of organic mulch as a valuable option to reduce the competition between pioneer species and the planted vegetation, by reducing available sunlight (Crawford, 2010; Lowenfels & Lewis, 2010).

Mulching also slows down soil evaporation in the summer months and soil erosion in times of high precipitation. By maintaining a constant soil environment, it creates beneficial conditions for both tree roots and soil microbes (Crawford, 2010). Furthermore, organic mulch is a source of energy for the soil food web. Increasing the quantity and quality of the organic litter layer increases the productivity of the soil food web (Cross *et al.,* 2006). Mulch fills the empty spaces between vegetation, preventing pioneer species from invading this area by eliminating niche availability (Choudhary & SureshKumar, 2019).

Figure 24. Fungi growing on rolls of hay on Roggebotstaete

Succession can be directed by mulching with predominantly brown materials, such as leaves, hay and woody litter. This improves the soil fungal diversity (Figure 24.) (Huang, Zihan, Mou, Zhang & Jia, 2019; Lowenfels & Lewis, 2010). Mulch could therefore provide a good option for Food Forest Roggebotstaete

The management options outlined in Section *4.1.1* to *4.1.3* can be interconnected in their respective effects on the ecosystem dynamics of Food Forest Roggebotstaete. These effects have been summarised below and integrated in Figure 25.

- Shifting the fungal/bacteria ratio by directing succession could create the preferred growing conditions of the desired perennial vegetation.
- Active fertility management can increase the ability of the system to accumulate and conserve nutrients, facilitating the potential for self-renewing fertility.
- The increase of soil organic matter could improve the water holding capacity within the system.
- Increasing resource abundance and reducing resource demand minimises competition between species.
- Reducing competition can improve plant health and direct succession, by allowing the desired vegetation to develop into the dominant community.

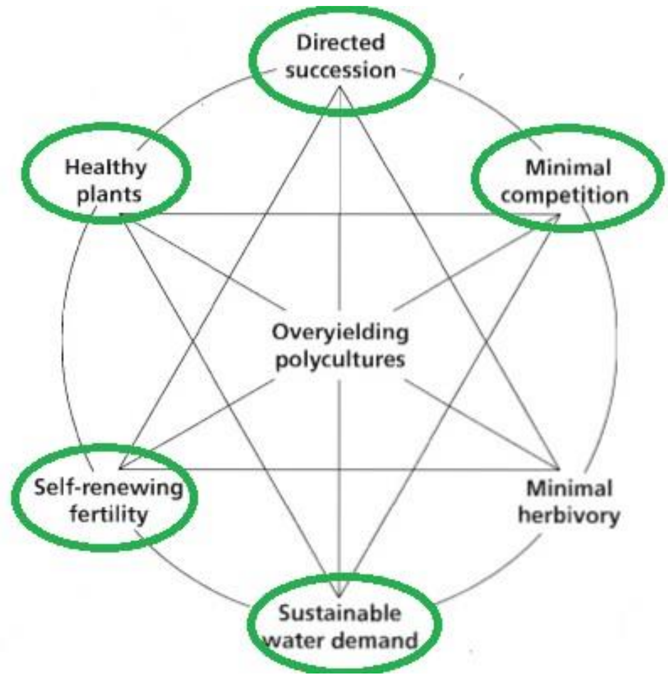

Figure 25. The effects of the optional management strategies on the ecosystem dynamics of Food Forest Roggebotstaete. Adapted from (Jacke & Toensmeier, 2005).

4.1.4 Reflection on methods used

Although rapidly gaining in popularity, food forests still form a niche industry in the Netherlands. The Green Deal Food Forests was set up in 2017 to facilitate an increase in acreage and to help take the concept of food forests out of the hobby sphere (Green Deal, 2017; Green Deal workshop, personal conversations, 2018) Article 1 of the Green Deal outlines the various goals and identifies the lack of existing research, highlighting the need for a solid scientific foundation to serve as a basis for responsible development of Dutch food forests. Article 2 provides a definition of a food forest, but neither the role of a food forest farmer, nor the role of management are mentioned (Green Deal, 2017).

Temperate climate food forests are a relatively new concept, with most of the practical knowledge coming from the United States (US) and the United Kingdom (UK). This made temperate climate food forests a difficult topic to study. This research on the importance of management in a temperate climate food forest has been pioneer work in many ways and has presented some serious challenges. The information gathering stage was initiated by reading leading temperate climate food forest literature from the UK and US, watching instructional videos and talking to practitioners and farmers. This provided a clearer understanding of the theory and identified avenues in which to review scientific literature relevant to the topic.

The time it took to grasp the theory and to determine clear research questions took longer than originally planned. Additionally, taking an open-minded approach to valuable constructive criticism resulted in reconsideration of the presentation of the research and thus redrafting of the thesis to make it applicable to Food Forest Roggebotstaete. In hindsight making a comprehensive time schedule could have avoided some of the time constraints experienced in the conclusion of this research.

This investment of time and effort has resulted in the careful screening and selection of a wide array of information and literature on food forests and soil management. The analyses of all this provides insight into the possibilities of management practices in temperate climate food forests. The importance of active management, especially in the establishment phase, underpins most of the available international literature. The potential benefits for Food Forest Roggebotstaete summed up in this thesis are significant, which begs the question why active management of temperate climate food forests has not yet been applied on a much larger scale and furthermore, not mentioned in the articles of the Green Deal?

More constructive dialogue between stakeholders, including practitioners, scientific researchers, policymakers and educational institutes on the topic of food forest management under the Green Deal will be beneficial moving forward. Local and provincial governments can play a significant role in strengthening local organizations and networks. Furthermore, agricultural educational institutions, such as Aeres University of Applied Sciences, could play a pivotal role by developing education resources and providing research opportunities for students to study these systems, both in the Netherlands and abroad.

Chapter 5: Conclusion and recommendations

The objective of this project was to identify and combine suitable management strategies to solve the identified problems in Food Forest Roggebotstaete, by answering the following questions.

<u>What is the theoretical framework of a food forest?</u>

This research found that temperate climate food forests develop and grow due to the process of ecological succession. It was shown that temperate climate food forests are most productive at mid-successional stage. Furthermore, a healthy soil food web, especially mycorrhizal fungi play a crucial role in plant nutrient availability and for a temperate climate food forest to achieve self-sustaining fertility.

<u>What is the role of a food forest farmer?</u>

Food forest farming relies on the ability of the farmer to read the landscape and understand ecosystem functioning. The goal of a food forest farmer is to produce high and diverse yields from a self-fertilising system that maintains a healthy ecosystem. By respecting and embracing the local ecological conditions and facilitating self-regulation within the system the farmer can indirectly manage to achieve this outcome.

What are the ecosystem dynamics of Food Forest Roggebotstaete?

Three years after being created Food Forest Roggebotstaete is still in the early stages of succession. The planted vegetation has struggled to become established, with some species displaying limited growth and some failing altogether. Competition between introduced and pioneer vegetation has been too high in some areas. Food Forest Roggebotstaete could struggle with sustainable water supply in times of drought.

Food Forest Roggebotstaete could overcome the identified problems and develop into a productive and self-fertilising ecosystem by adopting management strategies that will direct the system to a later stage of succession, ensuring continuous short and long-term soil fertility and minimising competition between the planted and pioneer vegetation.

My recommendations for Food Forest Roggebotstaete are to commence production of large volumes of fungal dominant compost on site. This compost can be composed of base materials readily available on the estate and would benefit from being inoculated with biochar. Once matured, the compost should be divided over the various rows of the planted vegetation. Pioneer vegetation competing with the planted vegetation, such as brambles, bushgrass and nettles, should be chopped and dropped and comfrey along with other herbaceous and perennial nitrogen fixing vegetation planted in their place. A thick layer of organic mulch should be applied in between the vegetation. Once these strategies are applied biological fertiliser, such as bioactive compost tea should be used at regular intervals to keep the productivity of the larger fruit and nut trees high.

Appendix I: Glossary

1. **Polycultures:** a form of agriculture in which more than one species is grown at the same time and place in imitation of the diversity of natural ecosystems. Polyculture is the opposite of monoculture, in which only members of one plant or animal species are cultivated together. Polyculture has traditionally been the most prevalent form of agriculture in most parts of the world and is growing in popularity today due to its environmental and health benefits.
2. **Net primary productivity:** the formation of organic material from inorganic compounds by photosynthesis, minus the amount released by plant respiration.
3. **Biogeochemical cycles:** natural pathways by which elements crucial to life are circulated from nonliving (abiotic) components to living (biotic) components and back.
4. **Ecological guilds:** a system or group of plant species that cooperate with each other, in order to use all the recourses to the fullest potential.
5. **Saprobic fungi:** fungal species living on decaying organisms (e.g. dead wood).
6. **Atmospheric deposition:** the process by which gases and particles are deposited from the atmosphere in the form of dust or precipitation.
7. **Cation Exchange Capacity:** a measure of retention and exchange of positively charged atoms or molecules (cations) on negatively charged soil particle surfaces.
8. **Soil aggregates:** a group or collection of soil particles that adhere more strongly to one another than to surrounding soil particles.
9. **Rhizosphere:** the narrow zone of soil in direct proximity to the plant root, influenced by root secretions and associated microorganisms
10. **Root Exudates:** acids, sugars and polysaccharides exuded by plant roots to influence the micro-organisms of the rhizosphere.
11. **Hyphae:** long, branching structures of fungal vegetative growth. Collectively called mycelium.
12. **Capillary action:** the intermolecular forces between a liquid and the surrounding soil particles, enabling water to flow up without the assistance of external forces, such as gravity.
13. **Inoculation:** the introduction of certain desirable substances or organisms in a medium.
14. **Biochar:** a charcoal made from biomass via pyrolysis used as soil amendment.
15. **Soil parent material:** the underlying geological material from which the soil is composed of.
16. **Coppicing:** a pruning technique where a woody perennial is cut close to ground level in order to regenerate from the base.
17. **Bioactive Compost Tea:** brewing good quality mature compost in a volume of water by oxidising it with an airpump. It produces large amounts of the beneficial microbes found in the compost and is used as a type of fertiliser.

Appendix II: Literature list

Abdulai, I., Vaast, P., Hoffmann, M.P., Asare, R., Jassogne, L., Van Asten, P., (…) Graefe, S. (2018). Cocoa agroforestry is less resilient to sub-optimal and extreme climate than cocoa in full sun. In S. Long (editor) *Global Change Biology 24*(1), 273-286. Retrieved 02/04/2019, doi: 10.1111/gcb.13885

Achat, D.L., Martel, S., Picart, D., Moisy, C., Augusto, L., Bakker, M.R. & Loustau, D. (2018). Modelling the nutrient cost of biomass harvesting under different silvicultural and climate scenarios in production forests. In D. Binkley (Editor) *Forest Ecology and Management 429*, 642 -653. Retrieved 01/05/2019, https://doi.org/10.1016/j.foreco.2018.06.047

Amaranthus, M.P. (2000, July 26). *Mycorrhizal Management: A Look Beneath the Surface at Plant Establishment and Growth.* Retrieved 05/05/2019, https://fungi.com/blogs/articles/mycorrhizal-management

Babikova, Z., Gilbert, L., Bruce, T.J.A., Birkett, M, Caulfield, J.C., Woodcock, C., (…) Johnson, D. (2013). Underground signals carried through common mycelial networks warn neighbouring plants of aphid attack. In T. Coulson (Editor) *Ecology Letter 16*(7), 835 – 843. Retrieved 13/05/201, https://doi.org/10.1111/ele.12115

Bell, G. (2004). The Permaculture Garden, UK; Permanent Publications.

Bellingham, P.L., Walker, L.R., Wardle, D.A. (2001). Differential facilitation by a nitrogen-fixing shrub during primary succession influences relative performance of canopy tree species. In D. Gibson, R. (Editor) *Journal of Ecology 89*, 861–875. Retrieved 08/05/2019, https://besjournals.onlinelibrary.wiley.com/doi/pdf/10.1046/j.0022-0477.2001.00604.x

Biederman, L.A. & Harpole, W.S. (2012). Biochar and its effects on plant productivity and nutrient cycling: a meta-analysis. In S. Long (Editor) *Global change biology – Bioenergy 5*(2), 202-214. Retrieved 02/06/2019, https://doi.org/10.1111/gcbb.12037

Bot, A. & Benites, J. (2005). Organic matter decomposition and the soil food web. In FAO Soils Bulletin, The importance of soil organic matter. Key to drought-resistant soil and sustained food production (5 – 8). Retrieved 04/05/2019, http://www.fao.org/3/a0100e/a0100e05.htm

Bouma, J. (2019, Maart 7). Nederlands oppervlaktewater scoort een dikke onvoldoende. *Trouw*. https://www.trouw.nl/groen/nederlands-water-scoort-een-dikke-onvoldoende~a5c63d67/

Bouma, J. (2019, Maart 6). Drentse burgers meten landbouwgif in bodem en vinden 57 middelen. *Trouw.* https://www.trouw.nl/groen/drentse-burgers-meten-landbouwgif-in-bodem-en-vinden-57-middelen~a3c65540/

Bouma, J (2019 Maart 2). Nederland verliest in hoog tempo zijn weidevogels. *Trouw.* https://www.trouw.nl/groen/nederland-verliest-in-hoog-tempo-zijn-weidevogels-~a874abd2/

Breidenbach, J., Dijkgraaf, E., Rooduijn, B., Nijpels-Cieremans, & R., Strijkstra, A. (2014). Voedselbossen van belang voor biodiversiteit. *De levende natuur 118*(3), 90 – 94.

Bruno, J.F., Stachowicz, J.J., Bertness, M,D. (2003). Inclusion of facilitation into ecological theory. In A.E.A. Stephen (Editor) *Trends in ecology and evolution 18*(3), 119 – 125. Retrieved 09/05/2019, https://doi.org/10.1016/S0169-5347(02)00045-9

Buiter, M. (2017, January 18). *Wat doet een voedselbosbouwer en wat is een voedselbos?* Retrieved 30/04/2019, https://docs.wixstatic.com/ugd/34bf21_9d71b69af9694a4888d9750a022bdbdf.pdf

Buiter, M., De Waard, F. (2017, January 18). *Ontwerp, aanleg en beheer van voedselbossen.* Retrieved 30/04/2019, https://docs.wixstatic.com/ugd/34bf21_6ca41618dcb343339fc4be4d58068a5e.pdf

Burtner, N. [School of Permaculture] (2014). *Permaculture Tip of the Day – The 7 Layers of a Forest.* Retrieved 31/01/2019, https://schoolofpermaculture.com/permaculture-tip-day-7-layers-forest/

Campbell, N, A., Reece, J, B. (2017). *Biology, A Global Approach, Global Edition (11e druk).* Ney York: Pearson Education Limited

Callaway, R.M. & Walker, L.R. (1997). Competition and facilitation: a synthetic approach to interactions in plant communities. In D.R. Strong (Editor) *Ecology 78*(7). Retrieved 09/05/2019. https://doi-org.aeres.idm.oclc.org/10.1890/0012-9658(1997)078[1958:CAFASA]2.0.CO;2

Carter, A. (2017, June 8th). *Are 'dynamic accumulators' a thing?* Retrieved 18/05/2019, https://scottishforestgarden.wordpress.com/2017/06/08/are-dynamic-accumulators-a-thing/

Castillo, B.T., Lucas, E.N., Le Moine, J.M., James T.Y. & Nadelhoffer, K.J. (2018). Impacts of experimentally accelerated forest succession on belowground plant and fungal communities. In K. Ritz (Editor) *Soil Biology and Biochemistry 125*, 44-53. Retrieved 20/04/2019, https://doi.org/10.1016/j.soilbio.2018.06.022

Charbonneau, J. (2018, January 17). *Planning a Fruit Tree Guild.* Retrieved 18/05/2019, https://www.southernexposure.com/blog/2018/01/planning-a-fruit-tree-guild/

Choudhary, V.K. & SureshKumar, S. (2019). Weed suppression, nutrient leaching, water use and yield of turmeric (*Curcuma longa* L.) under different land configurations and mulches. In J.J. Klemeš, C.M.V.B. de Almeida, Y. Wang (Editors) *Journal of Cleaner Production 210*, 795-803. Retrieved 11/05/2019, https://doi.org/10.1016/j.jclepro.2018.11.071

Clements, F.E. (1916). *Plant succession: an analysis of the development of vegetation*. Washington: Carnegie Institution of Washington

Cole, C.V., Duxbury, J., Freney, J., Heinemeyer, O., Minami, K., Mosier, A., (…) Zhao, Q. (1997). Global estimates of potential mitigation of greenhouse gas emissions by agriculture. In J. Lehmann (Editor) *Nutrient Cycling in Agroecosystems 49*(1-3), 221–228. Retrieved 24/04/2019, https://doi-org.aeres.idm.oclc.org/10.1023/A:1009731711346

Connell, J, H. & Slatyer, R, O. (1977). Mechanisms of succession in natural communities and their role in community stability and organization. *The American Naturalist 111*(982), 1119-1144.

Courty, P., Buée, M., Diedhiou A.G., Frey-Klett, P., Le Tacon, F., Rineau, F., (…) Garbaye, J. (2010). The role of ectomycorrhizal communities in forest ecosystem processes: New perspectives and emerging concepts. In K. Ritz (Editor) *Soil Biology and Biochemistry 42*(5), 679-698. Retrieved 02/05/2019, https://doi.org/10.1016/j.soilbio.2009.12.006

Craine, J, M. Dybzinski, R. (2013). Mechanisms of plant competition for nutrients, water and light. In C. Fox, K. Thompson, A. Knapp, L. Ferry and E. Rezende (Editors) *Functional Ecology 27*(4), 833 – 840. Retrieved 01/03/2019, https://doi.org/10.1111/1365-2435.12081.

Craves, J. (2006, February 6). *What is shade grown coffee?* Retrieved 08/05/2019, https://www.coffeehabitat.com/2006/02/what_is_shade_g/

Crawford, M. (2010). Creating a Forest Garden. Working with Nature to Grow Edible Crops. Cambridge: Green Books.

Cross, W.F., Wallace, J.B., Rosemond, A.D., Eggert, S.L. (2006). Whole- system nutrient enrichment increases secondary production in a detritus-based system. In O. Sarnelle (Editor) *Ecology 87*(6), 1556-1565. Retrieved 02/05/2019, https://doi-org.aeres.idm.oclc.org/10.1890/0012-9658(2006)87[1556:WNEISP]2.0.CO;2

Davis, M.A., Wrage, K.J. & Reich, P.B. (2001). Competition between tree seedlings and herbaceous vegetation: support for a theory of resource supply and demand. In D. Gibson, R. Bardgett, M. Rees & A. Austin (Editors) *Journal of Ecology 86*(4), 652 – 661. Retrieved 14/05/2019, https://doi.org/10.1046/j.1365-2745.1998.00087.x

De Waard, F. & Van der Kamp, J. (Regiseurs). (2015). *Bodemboeren : een grondige kijk op de landbouw* [DVD]. Future Farmers Film Productions 2015.

Deelder, M. (2016, June 3rd) *Maak kennis met de spannendste voedselinnovatie van de afgelopen jaren: het voedselbos*. Retrieved 23/04/2019, https://decorrespondent.nl/4663/maak-kennis-met-de-spannendste-voedselinnovatie-van-de-afgelopen-jaren-het-voedselbos/280974334190-e73357b4

Den Helden, C. (Sr. Adviseur biologische landbouw Delphy NW). (2019). *Biologische landbouw* [Powerpoint presentatie]. Delphy NW.

Duijvestijn, L. (2016). *Natuurbeheerplan en bedrijfsplan Landgoed Roggebotstaete* (Beheerplan). Dronten: Stichting Roggebotstaete.

Egberts, J. (2017). *Flora inventarisatie mei 2017*. Examenproject Helicon opleidingen

Eldredge, B. (2017). *Restoration Agriculture interview with Mark Shepard*. [Video] Retrieved 17/01/19, https://www.youtube.com/watch?v=5xKb8rPb2ps

Eliades, A. (2009). Accelerating Succession and Evolution. Retrieved 20/12/2018, https://deepgreenpermaculture.com/permaculture/permaculture-design-principles/8-accelerating-succession-and-evolution/

Emery, S. (2010). Succession: A Closer Look. In U.N. Nielsen (Editor) *Nature Education Knowledge* 3(10):45. Retrieved 24/04/2019, https://www.nature.com/scitable/knowledge/library/succession-a-closer-look-13256638

Erisman, J. W., Galloway, J., Seitzinger, S., Bleeker, A. & Butterbach-Bahl, K. (2011). Reactive Nitrogen in the Environment and Its Effect on Climate Change. In Dr. C. Kroeze & Dr. L. Bouwman (Editors) *Current Opinion in Environmental Sustainability 3*(5), 281–290. Retrieved 28/04/2019, https://doi.org/10.1016/j.cosust.2011.08.012

European Commission (2016). Sicco Mansholt: farmer, resistance fighter and a true European June. Retrieved 16/2/2019. https://europa.eu/european-union/sites/europaeu/files/docs/body/sicco_mansholt_en.pdf

Falconer, J., Arnold, J.E.M. (1991). *Household food security and forestry. an analysis of socio-economic issues.* Retrieved 17/12/18, http://www.fao.org/docrep/006/T6125E/T6125E00.HTM#TopOfPage

FAO. (2018). *The future of food and agriculture – Alternative pathways to 2050*. Retrieved 26/11/2018. http://www.fao.org/3/CA1553EN/ca1553en.pdf

FAO. (2015). Agroforestry, definition. Retrieved 26/11/2018, http://www.fao.org/forestry/agroforestry/80338/en/

Fehmi, J.S., Rice, K.J. & Laca, E.A. (2004). Radial Dispersion of Neighbors and the Small-Scale Competitive Impact of Two Annual Grasses on a Native Perennial Grass. In S. Murphy (Editor) *Restoration Ecology 12*(1), 63 – 69. Retrieved 14/05/2019, https://doi-org.aeres.idm.oclc.org/10.1111/j.1061-2971.2004.00266.x

Foley, J. (2014). A five stap plan to feed the world. National Geographic, October 2014. Retrieved 24/01/2019. https://www.nationalgeographic.com/foodfeatures/feeding-9-billion/

Foster, N.W. & Bhatti, J.S. (2006). *Forest Ecosystems: Nutrient Cycling. Encyclopaedia of Soil Science*. Retrieved 01/05/2019, http://www.nofc.cfs.nrcan.gc.ca/bookstore_pdfs/26204.pdf

Garnier, J., Le Noë, J., Marescaux, A., Cobena, A.S., Lassaletta, L., Silvestre, M., (…) Billen, G. (2019). Long-term changes in greenhouse gas emissions from French agriculture and livestock (1852–2014): From traditional agriculture to conventional intensive systems. In D. Barceló, J. Gan (Editors) *Science of The Total Environment* 660, 1486-1501. Retrieved 02/04/2019, https://doi.org/10.1016/j.scitotenv.2019.01.048

Germer, J., Addai, S. & Sauerborn, J. (2011). Response of grain sorghum to fertilisation with human urine. In R. Savin, H. Dong (Editors) *Field Crops Research 122*(3), 234-241. Retrieved 15/05/2019, https://doi.org/10.1016/j.fcr.2011.03.017

Gleason, H.A. (1926). The Individualistic Concept of the Plant Association. In *Bulletin of the Torrey Botanical Club 53* (1): 7–26, Retrieved 09/05/2019, doi:10.2307/2479933

Glenn-Lewin, D.C., Peet, R.K., Veblen, T.T. (1992). Plant succession, theory and prediction. Cambridge; Chapmann & Hall.

Godlewska, P., Schmidt, H.P. Ok, Y.S., Oleszczuk, P. (2017). Biochar for composting improvement and contaminant reduction. A review. In A. Pandey (Editor) *Bioresource Technogy 246*, 193 – 202. Retrieved 16/05/2019. https://doi.org/10.1016/j.biortech.2017.07.095

Graham (2016, 26th March). *Permaculture and the Edible Forest Garden: a Critical Analysis.* Retrieved 23/03/2019, https://theculturalwilderness.wordpress.com/2016/03/26/permaculture-and-the-edible-forest-garden-a-critical-analysis/

Green Deal 219. (2017). *Samenvatting Voedselbossen*. Retrieved 26/11/18, https://nmfflevoland.nl/friksbeheer/wp-content/uploads/2017/11/Green-Deal-C-219-VBv2.pdf

Hartnett , D.C. & Wilson, G.W.T. (2002). The role of mycorrhizas in plant community structure and dynamics: lessons from grasslands. In H. Lambers (Editor) *Plant and Soil 244*: 319–331. Retrieved 12/05/2019, https://link.springer.com/article/10.1023/A:1020287726382

Hernández, T., Garcia, E., Garcia, C. (2015). A strategy for marginal semiarid degraded soil restoration: A sole addition of compost at a high rate. A five-year field experiment. In *Soil Biology and Biochemistry 89*, 61-71. Retrieved 16/05/2019, https://doi.org/10.1016/j.soilbio.2015.06.023

Haeussler, S., Bertemucci, P., Bedford, L. (2004). Succession and resilience in boreal mixedwood plant communities 15–16 years after silvicultural site preparation. In In D. Binkley (Editor) *Forest Ecology and Management 199*(2-3), 349 – 370. Retrieved 25/06/2019, https://doi.org/10.1016/j.foreco.2004.05.052

Hills, L.D. (1976). *Comfrey. Past, Present and Future*. London: Faber and Faber

Holl, K.D., Loik, M.E., Lin, E.H.V. & Samuels, I.A. (2000). Tropical montane forest restoration in Costa Rica: overcoming barriers to dispersal and establishment. In Stephen Murphy (Editor) *Restoration Ecology 8,* 339 – 349. Retrieved 09/05/2019, https://doi-org.aeres.idm.oclc.org/10.1046/j.1526-100x.2000.80049.x

Huston, M. & Smith, T. (1987). Plant succession: Life history and competition. In *The American Naturalist 130*(2),168-198. Retrieved 27/04/2019, https://doi.org/10.1086/284704

Huang, F., Zihan, L., Mou, H., Zhang, P. & Jia, Z. (2019). Effects of different long-term farmland mulching practices on the loessial soil fungal community in a semiarid region of China. In J. Ascher-Jenull, S. Deng, R.P. Dick, H. Insam, A.S. Zaytsev (Editors) *Applied Soil Ecology 137*, 111-119. Retrieved 16/05/2019, https://doi.org/10.1016/j.apsoil.2019.01.014

Ingham, E.R., Moldenke, A.R. & Edwards, C.A. (2000). The soil food web. In A.J. Tugel, A.M. Lewandowski & D. Happe – Von Arb (Editors) Soil biology primer (pages not displayed). Retrieved 04/05/2019, https://www.envirothonpa.org/wp-content/uploads/2014/04/7-Soil-Biology-Primer.pdf

Jacke , D & Toensmeier, E. (2005). Edible forest gardens. Volume 1. Ecological vision and theory for temperate climate permaculture. Volume 2. Ecological design and practice for temperate climate permaculture. White River Junction, Vermont: Chelsea Green Publishing.

Jacobi, J., Mathez-Stiefel, S., Gambon, H., Rist & S., Altieri. (2017). Whose Knowledge, Whose Development? Use and Role of Local and External Knowledge in Agroforestry Projects in Bolivia. In B.W. Brooks (Editor) *Environmental Management 59*(3), 464-476. Retrieved 03/03/2019, doi:10.1007/s00267-016-0805-0.

Jeffery, S., Gardi, C., Jones, A., Montanarella, J., Marmo, L., Miko, L., (…) Van der Putten, W.H. (2010). European Atlas of Soil Biodiversity. European Commission, Publications Office of the European Union, Luxembourg. Retrieved 26/11/18. doi 10.2788/94222.

Kay, S., Rega, C., Moreno, G., Den Helder, M., Palma, J.H.N., Borek, R., (…) Herzog, F. (2019). Agroforestry creates carbon sinks whilst enhancing the environment in agricultural landscapes in Europe. In J.A.Zevenbergen (Editor), *Land Use Policy 83,* 581-593. Retrieved 05/04/2019, https://doi.org/10.1016/j.landusepol.2019.02.025

Ketterings, Q., Reid, S. & Rao, R. (2007) *Cation Exchange Capacity (CEC).* Retrieved 06/06/2019, http://nmsp.cals.cornell.edu/publications/factsheets/factsheet22.pdf

Klaminder, J., Lucas, R.W., Futter, M.N., Bishop, K.H., Köhler, S.J., Egnell, G. & Laudon, H. (2011). Silicate mineral weathering rate estimates: Are they precise enough to be useful when predicting the recovery of nutrient pools after harvesting? In D. Binkley (Editor) Forest Ecology and Management 261(1), 1-9. Retrieved 11/05/2019, https://doi.org/10.1016/j.foreco.2010.09.040

Köhl, L., Van der Heijden, M.G.A. (2016). Arbuscular mycorrhizal fungal species differ in their effect on nutrient leaching. In K. Ritz (Editor) *Soil Biology and Biochemistry 94*, 191-199. Retrieved 11/05/2019. https://doi.org/10.1016/j.soilbio.2015.11.019

Kruse, J. (2018). Bedrijfsopdracht Roggebotstaete. Nulmeting van vegetatieve groeifactoren binnen voedselbos Roggebotstaete, als opzet voor meerjarig onderzoek. Almere

Lal, R (1995). *Sustainable management of soil resources in the humid tropics.* Retrieved 27/02/2019, *http://archive.unu.edu/unupress/unupbooks/uu27se/uu27se0l.gif*

Lawton, G. (15/09/2011). *Establishing a Food Forest the Permaculture Way* [Movie]. Retrieved 16/02/2019 https://archive.org/details/EstablishingAFoodForestThePermacultureWay

Lawton, G. (25th February 2019). *What is a Food Forest?* Retrieved 25/02/2019, https://www.facebook.com/geofflawtononline/photos/a.1006638159522715/1006731379513393/?type=3&theater
LeBauer, D.S. & Treseder, K.K. (2008). Nitrogen limitation of net primary production in terrestrial ecosystems is globally distributed. In J. B. Yavitt (Editor) *Ecology 89*(2), 371-379. Retrieved 09/05/2019, https://doi.org/10.1890/06-2057.1
Lewis, W. J., Lenteren, J.C., Phatak, S.C. & Tumlinson, J.H. (1997). A total system approach to sustainable pest management. In M. R. Berenbaum (Editor) *Proceedings of the National Academy of Sciences, 94*(23), 12243-12248. Retrieved 15/04/2019, doi:10.1073/pnas.94.23.12243.
Lowenfels, J. (2003). Teaming with nutrients. The Organic Gardener's Guide to Optimizing Plant Nutrition. Portland, London: Timber Press.
Lowenfels, J. & Lewis, W. (2010). Teaming with Microbes. The Organic Gardener's Guide to the Soil Food Web. Portland, London: Timber Press
Lowenfels, J. (2016). Teaming with Fungi. The Organic Grower's Guide to Mycorrhizae. Portland, London: Timber Press
Maes, S.L., Blondeel, H., Perring, M.P., Depauw, L., Brümelis, G., Brunet, J., (…) Verheyen, K. (2019). Litter quality, land-use history, and nitrogen deposition effects on topsoil conditions across European temperate deciduous forests. In D. Binkley (Editor) *Forest Ecology and Management 433,* 405-418. Retrieved 15/04/2019, https://doi.org/10.1016/j.foreco.2018.10.056
McConnell, D. J. (1973). *The economic structure of Kandyan forest garden farms.* https://books.google.nl/books?id=G3QPo7lThXsC&lpg=PP1&dq=The+forest-garden+farms+of+Kandy,+Sri+Lanka.&pg=PA1&redir_esc=y#v=onepage&q&f=false
McConnell, D, J. (1992). *The Forest-Garden Farms of Kandy, Sri Lanka*. https://books.google.nl/books?id=G3QPo7lThXsC&lpg=PP1&dq=The+forest-garden+farms+of+Kandy,+Sri+Lanka.&pg=PA1&redir_esc=y#v=onepage&q&f=false
Mohren, G.M.J. & Vodde, F. (2006). *Forests and Forestry in The Netherlands.* Retrieved 26/04/2019, https://www.researchgate.net/publication/40110393_Forests_and_Forestry_in_the_Netherlands
Mulder, M. (2014, 14 februari). De storm Sicco Mansholt en het Nederlandse boerenlandschap. Retrieved 16/02/2019, https://www.archined.nl/2014/02/de-storm-sicco-mansholt-en-het-nederlandse-boerenlandschap
Nijpels-Cieremans, R. (2015). *Voedselbos Roggebotstaete. Een eetbaar landgoed in Flevoland*. (Rapport). Amsterdam: Both ENDS (Rich Forests)
Oelsner, G.P., Sprague, L.A., Murphy, J.C., Zuellig, R.E., Johnson, H.M., Ryberg, K.R., (…) & Farmer, W.H. (2017). *Water-quality trends in the Nation's rivers and streams, 1972–2012 - Data preparation, statistical methods, and trend results.* Retrieved 05/04/2019, https://pubs.usgs.gov/sir/2017/5006/sir20175006_ver2.0.pdf
Oostwoud, M. (2019). *Voedselbos. Inspiratie voor ontwerp en beheer.* Zeist: KNNV
Pane, C., Palese, A.M., Spaccini, R., Piccolo, A., Caleno, G., Zaccardelli, M. (2016). Enhancing sustainability of a processing tomato cultivation system by using bioactive compost teas. In J.P. Bower, G. Colla, W.W. Guo, S. Kondo, P. Martinez-Gómez, B. Pennisi & D. Schwarz (Editors) *Scientia Horticulturae 202*, 117 – 124. Retrieved 18/05/2019, https://doi.org/10.1016/j.scienta.2016.02.034
Perring, M.P., Standish, R. J., Price, J. N. Craig, M. D. Erickson, T. E., Ruthrof, K. X. (…) Hobbs, R. J. (2015). Advances in restoration ecology: rising to the challenges of the coming decades. In D. Peters (Editor) *Ecosphere 6*(8): 131. Retrieved 01/05/2019, http://dx.doi.org/10.1890/ES15-00121.1
Perrenoud, S. (1990). *Potassium and plant health*. Retrieved 18/04/2019, https://www.ipipotash.org/uploads/pdf/review/4_1990_3.pdf
Peterson, C.H. & Lipcius, R.N. (2003). Conceptual progress towards predicting quantitative ecosystem benefits of ecological restorations. In *Marine Ecology Progress Series 264***,** 297 – 307. Retrieved 01/05/2019, doi:10.3354/meps264297

Portela, E., Fernando, M., Fonseca, M. & Abreu, M.M. (2019). Effect of soil mineralogy on potassium fixation in soils developed on different parent material. In J. W. van Groenigen (Chair of Editors-in-Chief) *Geoderma 343*, 226-234. Retrieved 10/05/2019, https://doi.org/10.1016/j.geoderma.2019.02.040

Rahman, M.M., Tokumoto, Y. (2013). The Role of Quantitative Traits of Leaf Litter on Decomposition and Nutrient Cycling of the Forest Ecosystems. In J. Janovcová (Editor) *Journal of Forest Science 29*(1), 38 – 48. Retrieved 15/05/2019, 10.7747/JFS.2013.29.1.38

Rastetter, E. B., Vitousek, P. M., Field, C., Shaver, G. R., Herbert, D. & Gren, G. I. (2001). Resource Optimization and Symbiotic Nitrogen Fixation. In M.G. Turner; S.R. Carpenter (Editors) *Ecosystems 4*(4), 369–388. Retrieved 08/05/2019, https://doi-org.aeres.idm.oclc.org/10.1007/s10021-001-0018-z

Ratay, J. (2018, 6th of August). *What is a food forest?* Retrieved 31/01/19, https://foodforestsoftheworld.com/2018/08/06/whats-a-food-forest/

Rebele, F. & Lehmann, C. (2016). Twenty years of woodland establishment through natural succession on a sandy landfill site in Berlin, Germany. In C.C. Konijnendijk van den Bosch & W.Y. Chen (Editors) *Urban Forestry & Urban Greening 18*, 182-189. Retrieved 08/05/2019, https://doi.org/10.1016/j.ufug.2016.06.006

Rijksoverheid. (23/05/18). Doel 2030: alle Nederlandse landbouwgronden duurzaam bewerkt. Retrieved 30/11/18. https://www.rijksoverheid.nl/persinformatie-ministerie-van-lnv/nieuws/2018/05/23/doel-2030-alle-nederlandse-landbouwgronden-duurzaam-bewerkt

Rigueiro-Rodriguez, A., McAdam, J. & Mosquera-Losada, M.R. (2009). A*groforestry in Europe- Current Status and Future Prospects.* Retrieved 27/12/2018, http://library.uniteddiversity.coop/Permaculture/Agroforestry/Agroforestry_in_Europe-Current_Status_and_Future_Prospects.pdf

Sahu, P.K., Singh, D.P., Prabha, R., Meena, K.K. & Abhilash, P.C. (2018). Connecting microbial capabilities with the soil and plant health: Options for agricultural sustainability. In J.C. Marques (Editor) *Ecological Indicators*. Retrieved 02/04/2019, https://doi.org/10.1016/j.ecolind.2018.05.084

Seitera, S., Ingham, E.R., William, R.D. (1999). Dynamics of soil fungal and bacterial biomass in a temperate climate alley cropping system. In J. Ascher-Jenull and S. Deng (editors) *Applied Soil Ecology 12 (2),* 139-147. Retrieved 12/05/2019, https://doi.org/10.1016/S0929-1393(98)00163-2

Shao, P., Liang, C., Rubert-Nason, K., Li, X., Xie, H. & Bao, X. (2019). Secondary successional forests undergo tightly-coupled changes in soil microbial community structure and soil organic matter. In K. Ritz (Editor) *Soil Biology and Biochemistry 128*, 56-65. Retrieved 14/05/2019, https://doi.org/10.1016/j.soilbio.2018.10.004

Smit, P, H. (2018, September 20). Minister Schouten heeft grote plannen met circulaire landbouw. 'Duurzaamheid gekoppeld aan onze hoge opbrengst, daar zit de hele wereld op te wachten. Retrieved 23/02/2019, https://www.volkskrant.nl/nieuws-achtergrond/minister-schouten-heeft-grote-plannen-met-circulaire-landbouw-duurzaamheid-gekoppeld-aan-onze-hoge-opbrengst-daar-zit-de-hele-wereld-op-te-wachten-~b5c8e58a/

Song, X,Y., Zeng, R.S., Xu, J.F., Li, J., Shen, X. (2010). Interplant Communication of Tomato Plants through Underground Common Mycorrhizal Networks. In M. Van der Heijden (Editor) *PLoS ONE 5*(10): e13324. Retrieved 13/05/2019, https://doi.org/10.1371/journal.pone.0013324

Strouts, G. (2016). *Permaculture and the Edible Forest Garden: a Critical Analysis.* Retrieved 23/02/2019, https://theculturalwilderness.wordpress.com/2016/03/26/permaculture-and-the-edible-forest-garden-a-critical-analysis/

Sutton, M.A., Oenema, O., Erisman, J.W., Leip, A., van Grinsven, H. & Winiwarter, W. (2011). Too Much of a Good Thing. In *Nature 472* (7342): 159–161. Retrieved 16/05/2019, https://doi.org/10.1038/472159a

Ten Napel, J., Bianchi, F., Bestman, M. (2006). *Utilising intrinsic robustness in agricultural production systems: Inventions for a sustainable development of agriculture.* Retrieved 05/04/2018, http://orgprints.org/16807/1/Transforum_robustness_ENG.pdf

Tewksbury, J.J., Lloyd, J.D. (2000). Positive interactions under nurse-plants: spatial scale, stress gradients and benefactor size. In C.L. Ballaré, R. Brandl, K.L. Gross, R.K. Monson, J.C. Trexler, H. Ylönen (Editors) *Oecologica 127*(3), 425 – 434. Retrieved 09/05/2019, https://doi.org/10.1007/s004420000614

Titus, J.H. (2009). Nitrogen-fixers *Alnus* and *Lupinus* influence soil characteristics but not colonization by later successional species in primary succession on Mount St. Helens. In W.E. Rogers & N. Enright (Editors) *Plant Ecology 203*(2), 289–301. Retrieved 07/05/2019, https://link-springer-com.aeres.idm.oclc.org/article/10.1007/s11258-008-9549-0

UCSUSA (n.d). What Is Sustainable Agriculture? Retrieved 23/02/2019, https://www.ucsusa.org/food-agriculture/advance-sustainable-agriculture/what-is-sustainable-agriculture

Udeigwe, T. K., Teboh, J.M., Eze, P.N., Stietiya, M.H., Kumar, M.H., Hendrix, J., (…), Kandakji, T. (2015). Implications of leading crop production practices on environmental quality and human health. In R. Dewil, J.M. Evans, B. Tansel (Editors) *Journal of Environmental Management 151*, 267-279. Retrieved 05/04/2019, doi:10.1016/j.jenvman.2014.11.024.

Van Andel, J. & Aronso, J. (2005). Challenges for ecological theory. In M.A. Malden Restoration Ecology (223-233). Retrieved 09/05/2019, https://books.google.nl/books?hl=en&lr=&id=xpOXuBwIGxgC&oi=fnd&pg=PR5&ots=p5jgG7JP8N&sig=fSiBH-jjh2tcjK_STx8eXjSb3QI&redir_esc=y#v=onepage&q&f=false

Van Bruggen, A.H.C., Goss, E.M., Havelaar, A., Van Diepeningen, A.D., Finck, M.R. & Morris, G. (2019). One Health - Cycling of diverse microbial communities as a connecting force for soil, plant, animal, human and ecosystem health. In D. Barceló, J. Gan (Editors) *Science of The Total Environment 664*, 927-937. Retrieved 16/05/2019, https://doi.org/10.1016/j.scitotenv.2019.02.091

Van Buuren, A. (Teacher Organic arable farming & Agricultural entrepreneurship, Aeres) Biologische landbouw [Powerpoint Presentation]. Aeres University of Applied Sciences.

Van der Goes, D.J., Thijssen, L. (2009) *Landgoed Roggebotstaete, biotoop en flora inventarisatie 2009* (Report). Kwintsheul, Alkmaar: Stichting Pulsar Instituut

Van der Heijden, M.G.A., Martin, F.M., Selosse, M.A. & Sanders, I.R. (2015). Mycorrhizal ecology and evolution: the past, the present, and the future. In A.M. Hetherington (Editor) *New Phytologist 205*(4), 1406 – 1423. Retrieved 15/05/2019. https://doi.org/10.1111/nph.13288

Viviano, F. (2017). This tiny country feeds the world. Natural Geographic, September 2017. Retrieved 25/11/18. https://www.nationalgeographic.com/magazine/2017/09/holland-agriculture-sustainable-farming/

White, P.S. & Jentsch, A. (2004). Disturbance, succession and community assembly in terrestrial plant communities. In V.K. Temperton, R.J. Hobbs, T. Nuttle, S. Halle (editors) *Assembly Rules and Restoration Ecology: Bridging the Gap Between Theory and Practice* (342 – 366). Washington: Island press

WUR (n.d.) Kringlooplandbouw. Retrieved 16/03/2019, https://www.wur.nl/nl/Dossiers/dossier/Kringlooplandbouw.htm

Yuana, Z., Ali, A., Wang, S., Gazol, A., Freckleton, R., Wang, X., (…) Loreauf, M. (2018). Abiotic and biotic determinants of coarse woody productivity in temperate mixed forests. In D. Barceló & J. Gan (Editors) *Science of The Total Environment 630*, 422-431. Retrieved 07/05/2019, https://doi.org/10.1016/j.scitotenv.2018.02.125

Young, T.P., Petersen, D.A., Clary, J.J. (2005). The ecology of restoration: historical links, emerging issues and unexplored realms. In J. Grover (Editor) *Ecology Letters 8*(6), 662 – 673. Retrieved, 10/05/2019, https://doi.org/10.1111/j.1461-0248.2005.00764.x 26/04/2019

Zhao, F.Z., Ren, C.J., Han, X.H., Yang, G.H., Wang, J., Doughty, R., Wang, Z.T. (2019). Trends in soil microbial communities in afforestation ecosystem modulated by aggradation phase. In D. Binkley (Editor) *Forest Ecology and Management 441*, 167-175. Retrieved 06/05/2019, https://doi.org/10.1016/j.foreco.2019.03.036

Appendix III: Checklist Report Writing

Naam: Klas:

---

*De beoordelingscriteria die met een * zijn aangegeven, zijn 'killing points'. Wanneer de beoordelaar daarvan meer dan vijf heeft aangekruist, dien je het rapport/verslag op alle onvoldoende onderdelen te verbeteren. In het afstudeerwerkstuk zijn geen 'killing points' toegestaan.*

---

1. Het taalgebruik
- ☐ Bevat niet meer dan drie grammaticale, spel- en typefouten per duizend woorden; het rapport/verslag is dan afgekeurd*
- ☐ Heeft een actieve schrijfstijl*
- ☐ Is zakelijk, formeel en objectief *
- ☐ Is coherent (verwijs- en verbindingswoorden)*
- ☐ Heeft een adequate interpunctie*
- ☐ Bevat niet de persoonlijke voornaamwoorden 'ik/ mij/me, jij/je/jou, jullie, u, wij/we/ons' *
- ☐ Is doelgroepgericht*
- ☐ Heeft een uniforme stijl*

2. De ordening
- ☐ Het verslag/rapport heeft een logisch opbouw
- ☐ Elk hoofdstuk heeft een logische alineastructuur
- ☐ Elk hoofdstuk kent een introductie (m.u.v. H.1)

3. Het rapport/verslag
- ☐ Is vrij van plagiaat*
- ☐ De pagina's zijn genummerd*
- ☐ Heeft een uniforme opmaak

4. De omslag
- ☐ Bevat de titel
- ☐ Vermeldt de auteur(s)

5. De titelpagina/het titelblad
- ☐ Heeft een specifieke titel*
- ☐ Vermeldt de auteur(s)*
- ☐ Vermeldt de plaats en de datum*
- ☐ Vermeldt de opdrachtgever(s)*

6. Het voorwoord:
- ☐ Bevat de persoonlijke aanleiding tot het schrijven van het rapport/verslag
- ☐ Bevat persoonlijke bedankjes (persoonlijke voornaamwoorden toegestaan)

7. De inhoudsopgave:
- ☐ Vermeldt alle genummerde onderdelen van het rapport/verslag*
- ☐ Vermeldt de samenvatting en de bijlage(n)
- ☐ Is overzichtelijk/gestructureerd
- ☐ Heeft een correcte paginaverwijzing

8. **De samenvatting:**
- ☐ Is een verkorte versie van het gehele rapport/verslag
- ☐ Bevat de conclusies
- ☐ Bevat suggesties voor verder onderzoek
- ☐ Bevat geen persoonlijke mening
- ☐ Staat direct na de inhoudsopgave

9. **De inleiding**
- ☐ Is hoofdstuk 1*
- ☐ Beschrijft het kader/de context en de aanleiding*
- ☐ Geeft inhoudelijke relevante achtergrondinformatie*
- ☐ Bevat de probleemstelling/de onderzoeksvraag*

☐ Vermeldt het doel*
☐ Bevat een leeswijzer voor het rapport/verslag*

10. **Materiaal en methode**

☐ Beschrijft de gevolgde onderzoeksmethode
☐ Motiveert de keuze voor de gevolgde onderzoeksmethode
☐ Past bij de probleemstelling/de onderzoeksvraag*
☐ Beschrijft de variabelen/eenheden
☐ Beschrijft de methode van data-analyse

11. **De (opmaak van de) kern**

☐ De hoofdstukken en de (sub)paragrafen met maximaal drie niveaus zijn genummerd*
☐ De hoofdstukken en (sub)paragrafen hebben een passende titel
☐ Een hoofdstuk beslaat ten minste één pagina
☐ Een nieuw hoofdstuk begint op een nieuwe pagina
☐ De zinnen lopen door (geen 'enter' binnen een alinea gebruiken)
☐ De figuren zijn (door)genummerd en hebben een passende titel (onder de figuur)*
☐ De tabellen zijn (door)genummerd en hebben een passende titel (boven de tabel)*
☐ Tabellen en figuren zijn zelfstandig te begrijpen
☐ In de tekst zijn er verwijzingen naar figuren en/of tabellen*
☐ De tekst bevat verwijzingen naar de desbetreffende bijlage(n)
☐ De tekst is ook zonder verwijzingen te begrijpen

12. De discussie

☐ Vermeldt de interpretatie(s) van de resultaten
☐ Bevat een vergelijking met relevante literatuur
☐ Geeft de valide argumentatie weer
☐ Evalueert de gevolgde onderzoeksmethode
☐ Bevat een kritische reflectie op de eigen bevindingen

13. De conclusies en aanbevelingen

☐ Bevatten antwoord(en) op de onderzoeksvraag
☐ Zijn gebaseerd op relevante feiten
☐ Bevatten geen nieuwe informatie*

14. **De bronvermelding**

☐ Verwijzingen in de tekst zijn conform de APA-normen*
☐ De bronnenlijst is conform de APA-normen*

15. De bijlagen

☐ Zijn genummerd
☐ Zijn voorzien van een passende titel
☐ Bevatten geen eigen analyse
☐ Zijn overzichtelijk weergegeven