Agroforestry comparative peat soil experiment in Land van Ons

MSc Biology
Julia Gómez-Lama Gutiérrez

S2925958

Institute of Environmental Sciences (CML), Einsteinweg 2, 2300 RA Leiden
Daily and responsible supervisor: Maarten Schrama
Start: 4-03-2021 End: 01-10-2022 EC: 42

INDEX

1. Abstract

Nowadays, the peat ecosystem has been severely modified for human use, such as intensive crop and livestock production. The modification of this ecosystem has led to severe problems, such as soil degradation and loss of biodiversity.

The peatland naturally functions as a carbon sequestrator, but its drainage for human purposes leads to its oxidation, reversing this effect and thus leading to the release of greenhouse gasses. In addition, this drainage causes the land surface subsidence, increasing the risk of flooding. On the other hand, the landscape modification generated by the widespread use of intensive crops generates serious problems such as the loss of biodiversity and subsequently, the reduction of pollinator biodiversity, as well as accentuating the effect of the fragmentation of natural habitats of wild species.

The implementation of more sustainable alternatives is vital to reverse these effects. This project will test whether it is possible to grow both annual and perennial crops on peat soil and whether it would be feasible to implement a food forest system on the Land van Ons site.

2. Introduction

The peatland ecosystem is estimated as 2.84% of the world's land area (Xu, J., Morris et al, 2018) with a concentration in north-western, Nordic and eastern European countries, covering an area of 350.000 km2, but they store approximately 30% of the world's terrestrial carbon stock (Joosten, H. et al, 2016)(Page, S. E. et al, 2021), of which more than 50% is degraded by the effects of drainage and used for agriculture, forestry and peat extraction ("Removing barriers to peatland climate protection", 2021). Agriculture, forestry, peat extraction for fuel and other commercial uses are the main uses of peatland. According to a 2015 report by the United Nations Environment Programme (UNEP), an estimated 12% of global peatlands have been drained for agriculture and forestry, while peat extraction for fuel and horticulture has impacted an additional 2-3% of the world's peatlands.

For peatlands in coastal areas to be used for this purpose, continuous drainage is necessary, and the result is almost exclusively grassland, often a monoculture of Ryegrass (*Lolium perenne*). Since the 15th century, large-scale digging of peat and intensified drainage of agricultural peatlands have occurred (van der Linden, 1982). There are about 160.000 ha of peatland in the western part of the Netherlands and over 90% of them are drained and used for agricultural purposes (van den Bos, 2003).

This research aims to fill the existing knowledge gaps about implementing low-intensity farming systems, such as food forests, in peat soil environments. Peat soils are rich in biodiversity, but little research has been done to explore their suitability for agroforestry purposes. This study focuses on identifying species that can flourish in peat soil despite potential challenges like unfavorable soil conditions, herbivory, and abiotic factors.

The findings of this study could promote agricultural practices that promote carbon sequestration and alleviate soil subsidence. This could contribute to conservation efforts, sustainable development, and climate change mitigation.

The research, carried out at Vrouwe Vennepolder, a recently acquired polder by Land van Ons, aims to examine the feasibility of developing such a system in peat soil. Despite the wide range of species in natural peatlands, there has been limited exploration about which crops can be cultivated in these conditions.

While food forests have been established in various soil types, there's a lack of research on their potential development in intact peat soils. To this point, no studies have examined the feasibility and implications of introducing food forests or agroforestry practices in undrained peat soils.

2.1. Soil degradation and biodiversity loss

In drained peatlands, there are two main soil layers: an upper unsaturated zone exposed to oxygen (O2) and a saturated zone at the water table level. Under normal conditions, fluctuations in water table levels are common with seasonal changes, and the saturated zone naturally increases or decreases (Strack, M., 2008). The water table in peatlands can fluctuate with seasonal changes, and this can affect methane emissions (Turetsky, M. R. et al, 2014).

In conditions of high-water tables, organic matter decomposition rates and carbon dioxide emissions are reduced because of the limited oxygen availability (van Diggelen et al., 2020). This means that they function as important carbon (C) sequestrators (Laiho, 2006). The Northern peatlands occupy only about 2.5% of the global terrestrial surface but contain approximately 32% of the total organic C of the world's soils (Gorham, 1991).

However, with the constant draining of peatlands, the unsaturated zone increases, thus increasing its oxidation and aerobic decomposition. Consequently, once important carbon sinks are drained, cultivated peatlands become carbon sources, releasing carbon dioxide into the atmosphere (Tiemeyer et al., 2016).

Furthermore, the drainage of peatlands results in the compaction of these soils; consequently, the land surface subsides (Van den Akker et al., 2008). This, along with the sea level rise in Northwestern Europe, resulted in a third of the country's land being below sea level (Kooi et al., 1998). Soil surfaces in many agricultural areas with a peat depth of 1–3 meters have dropped by more than 30 cm within the last 20 years (van den Akker et al., 2008). Sea level rise due to global warming together with land subsidence will also lead to an increased risk of flooding (Herbert et al., 2015) and increased upward seepage of brackish and nutrient rich groundwater (Remkes et al., 2007).

On top of that, intensive agriculture requires the application of a wide range of pesticides, which together with land-use intensity has a strong correlation with biodiversity loss (Tilman et al., 2001). Furthermore, it is widely acknowledged that landscape modification has severe effects on the ecology and survival of organisms living within the affected area (Fischer & Lindenmayer, 2007).

In addition to the significant decline in the transformative changes in community composition observed in natural peatlands, it is important to highlight that the shift to agricultural land has led to a drastic alteration in biodiversity composition. Furthermore, the current state of this already modified biodiversity, which can be exceptionally rich, is facing severe degradation and experiencing significant losses in biodiversity.

Several studies have demonstrated that pollinator insect decline (Biesmeijer et al., 2006) (Memmott et al., 2007) is connected with intensive agricultural practices (Goulson et al., 2008). In addition, these highly modified landscapes are one of the main causes of habitat loss and prevent the connectivity of suitable habitats for wild animals (Fahrig, 2003).

In addition to the significant loss of biodiversity resulting from transformations in community composition compared to natural peatlands, it is important to highlight that the shift to agricultural lands has led to a remarkable and substantial change in biodiversity composition. Presently, this modified biodiversity, which can already exhibit a considerable degree of alteration, faces the imminent risk of severe degradation and ongoing biodiversity loss.

2.3. Knowledge gaps and aims

Increasing the use of low-intensity farming systems is critical to nature conservation and protection of the rural environment (Bignal & McCracken, 1996). Therefore, exploring alternative production systems is greatly needed. Fortunately, in recent years, more sustainable alternatives have been developed. This is, for example, the case of the food forest system (Crawford, 2012), which is a form of agroforestry.

A food forest is a diverse planting of edible, mostly perennial plants, that tries to mimic the ecosystems and patterns found in nature, increasing vegetal biodiversity. This increase also leads to a rise in pollinators' biodiversity. It has been shown that pollinator density increases when the type of pollen sources increases, as this allows them to access different types of essential macronutrients in their diet (Patt et al., 2003) (Sigsgaard et al., 2001). Such a system, which is likely more like that found in a natural ecosystem may also improve landscape quality and ecosystem connectivity.

Furthermore, the use of agroforestry systems and their relationship to reducing the effects of climate change is clear. The Paris Agreement establishes that activities related to the change of use and management of forest and agricultural land (Article 5.2) can be used to mitigate and reduce greenhouse gas emissions and increase carbon sequestration. Moreover, Agroforestry systems are suggested for Europe through the European Rural Development Council regulation 1698/2005.

Despite the establishment of food forests on various soil types, there is a notable research gap regarding the exploration of their potential and agroforestry development specifically on intact or carbon-accumulating peat soils. To date, no studies have thoroughly investigated the feasibility and implications of implementing food forests or agroforestry practices in undrained peat soils.

2.4. Research question

The aims of this study are twofold:

First, I aim to demonstrate which species from a selection of (families of) annual and perennial crop species exhibit grown on this peat soil type. When testing whether species can grow under peat conditions, there are potentially 3 bottlenecks that may prohibit species from growing in these places. 1: Unsuitable soil conditions, 2: Herbivory, 3: Climatic conditions not adequate for plant survival.

Second, a proof-of-principle of the various crops that can be grown in this area without major drainage and resulting oxidation, the outcome of this study would be to increase the levels of peat in the cultivation areas. This, in turn, might lead to increased carbon sequestration and reduce the rate of soil subsidence or even increase soil levels:

1. Can the type of crops we want to plant grow in the peat and clay soils present at Land van Ons?

2. Would there be a difference in the growth of the crops with the same peat and clay soil in controlled conditions (Hortus) vs Land van Ons conditions over time?

H_{o2}: The growth of the species under study in the field may be limited with respect to controlled conditions (Hortus conditions). This could be caused by herbivory pressure + other physical variables (abiotic factors).

2.4. Species selection

The plant species chosen for this study were selected based on their ability to work together in an agroforestry system. The primary objectives behind this selection were to encourage crop diversification, and promote sustainable land use. The study includes the following species, which are planted on clay soil:

- Garden Rhubarb
- Cornelian Cherry
- Hazel

These perennial species are paired with annual plants to enhance the overall effectiveness of the agroforestry system. The annual plants planted alongside them are:

- Carrot
- Garden Bean
- Potato
- Radish
- Zucchini

Additionally, Blackcurrant, Raspberry, Strawberry, and Cranberry were planted in peat soil.

For clay soil, Cornelian cherry trees and hazel trees are selected due to their deep root systems which can penetrate and improve clay soil structure (Seho, M. et al., 2019). Their roots promote water infiltration and nutrient availability, which can be especially beneficial for associated annual crops. Additionally, hazel trees can form symbiotic relationships with nitrogen-fixing bacteria (Nicoletti, R. et al, 2022), benefiting not only themselves but also Cornelian cherries and the associated annual crops. Cornelian cherry (Kazimierski et al, 2019) and Hazel (Germain, 1994) flowering periods occur at the same time, increasing chances for cross-pollination (Jacimovic, et al, 2012) and yield improvement. The diversified yield from both species can also provide economic benefits by extending harvest periods and reducing crop-specific risks, as Cornelian cherry trees typically bear fruit in late summer to early autumn (Weaver, 1976), while hazel trees produce nuts in late summer or early fall (Germain, 1994).

In addition to improving soil structure, these trees can control erosion, a common issue in clay soils (Øygarden, et al., 1997). The understory crops, such as rhubarb, can contribute to the soil stability, as they have an extended root system (Holzmueller, E., et al, 2007), as well as providing protection to annual crops and providing yield variety, enhancing the system's overall productivity and stability.

Regarding peat soils, the selection includes raspberries, black currants, strawberries, and cranberries. These species are well-adapted to peat soil conditions, as they thrive in acidic soil (Joosten & Clarke, 2002). Their presence adds to crop diversity within the agroforestry system, which in turn reduces risks associated with monoculture, provides a wider range of products, and helps to maintain more moderate microclimatic conditions.

Similar to the clay soil system, these crops aid in erosion control, preventing the loss of valuable organic material in peat soils (Evans & Warburton, 2007). Furthermore, they extend the availability of fresh fruit throughout the growing season, maximizing income opportunities and meeting high market demand for berries due to their nutritional and culinary value (Nile & Park, 2014).

This study's selected species provide a comprehensive approach to land management, seeking to harness the benefits of a diverse agroforestry system while tackling specific challenges associated with different soil types.

3. Methods

This study consists of a comparative experimental methodology to explore the growth patterns of 12 selected plant species (comprising 7 perennials and 5 annuals) across two distinct locations with varying environmental conditions. The goal is to assess the feasibility of establishing an agroforestry system on the peat soil present in Land van Ons.

The two primary experimental areas are LVO, which is divided into LVOU and LVOF, and the *Hortus botanicus.* The LVO location is arranged in a gradient setup, with a higher, more clayey zone and a lower, peat-rich zone. These zones also have varying pH levels, with the higher zone exhibiting a higher pH than the lower one (figure 2). This gradient arrangement was manually done.

The central hypothesis of this study is that soil conditions significantly influence the growth of our selected plant species. As such, we want to know whether soil type is the only determinant factor of plant growth or if other factors, such as atmospheric conditions and herbivory, also play significant roles.

To achieve this, we created a controlled environment at Hortus, where we anticipate minimal challenging biotic and abiotic conditions. Meanwhile, LVOF serves as an intermediary stage with harsher atmospheric conditions but controlled herbivory, and LVOU is completely exposed to both factors. In each zone (Hortus, LVOU, and LVOF), we planted acidophilic plants in the clay soil and basophilic/neutrophilic plants in the peat soil.

At LVO, the gradient setup was divided into two parts, with LVOF being protected from herbivory by an electric fence. LVOU, on the other hand, was partially fenced to ward off grazing cows, but it remained susceptible to smaller herbivores.

3.1. Study areas

As it gets mentioned above, For the development of our experiments, we have two study areas, Hortus Botanicus (control area) and Land van Ons, which is an area where we find mostly peat soil. In Land van Ons (LVO), study area is divided into two sites: one is unfenced (LVOU), while the second zone is partially protected against the effect of herbivory with fences (LVOF),

We expect in LVO biotic and abiotic factors to be more aggressive (strong wind, heavier temperature fluctuation and presence of herbivores) than in Hortus, as the system is located outdoors, with no tree cover to protect it from atmospheric phenomena, in comparison with the conditions in a botanical garden.. Figure 1 shows the area where the experiments took place in LVO.

Figure 1: Land van Ons satellite image (source: Google Earth). The area marked in a white rectangle is the study area. Here we find both LVOU (the zone delimited by the upen rectangle) and LVOF (delimited by the bottom rectangle).

The part of the research carried out in LVO has two zones arranged in a height gradient: a higher zone (on an artificially created mound), where the soil was more clayey and the pH was higher and a lower zone (at the water level of the ditch), with peat soil and a more acidic pH (figure 2). This gradient disposition was arranged manually. This arrangement is interesting because in this way, we can integrate in the same system plants that favor different types of soils. In the case of this zone it is easy, since we have peat very close to the surface, as the water table is almost at the same level as the ground level.

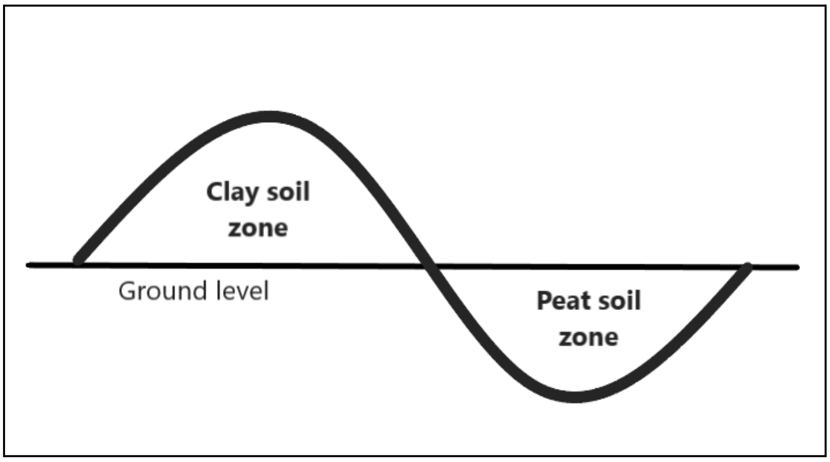

Figure 2: Graphic explanation of the disposition of the soil zones. Clay zone on the mound above ground level and peat zone in the digged area below ground level.

This mounded area with a gradient of soil types was divided into two parts (figure 3). LVOF was surrounded by an electric fence (B60 fence energizer (12V), Gallagher Europe) (Poultry netting, double spike, 112cm, Gallagher Europe) to avoid herbivory impact on the experiment. LVOU was only fenced on the side bordering a cow grazing area but still subjected to small herbivore impact.

Figure 3: Freshly planted system (3 of May 2021) in the background we can see the fenced area or LVOF. While in the nearest part of the photo we have Land van Ons unfenced or LVOU.

In Hortus, as its previously mentioned, It was expected that the biotic and abiotic factors were milder, as it is a garden with walls that protect from aggressive atmospheric phenomena (no strong wind, controlled temperature, and no presence of herbivores). Here, the plants were not planted in the ground, but in plastic pods. The clay and peat used for planting the crops were manually transported from LVO (figure 4). The idea of having the plants in pots was to get them to have the same type of soil as the plants in LVO, so the soil was transported to Hortus and manually potted.

Figure 4: System planted in Hortus botanicus (9 of June 2021). In this case, the individuals were planted in pots.

Peat soil, known for its high organic matter content, provides excellent moisture retention and nutrient availability for plant growth. It offers a favorable environment for plants that thrive in moist conditions. However, peat soil can be prone to compaction and drainage issues if not managed properly.

On the other hand, clay soil has smaller particles and tends to hold more water, making it less prone to drying out. While it can be heavy and dense, making it harder for roots to penetrate, clay soil offers good nutrient retention capabilities. It also has a higher cation exchange capacity, allowing for better nutrient availability to plants. This soil is used for planting both annual and perennial crops, which makes it ideal for a wide range of plants.

By incorporating both peat and clay soils, we can create a more diverse agroforestry system. Plants that prefer peat soil, such as Raspberries and Cranberries can thrive in the areas with peat soil. Similarly, plants that prefer clay soil, which may include Hazel or Cornelian cherry, can be cultivated in the areas with clay soil.

This diversity in soil types allows for a wider range of plants to be grown, resulting in a more resilient and productive agroforestry system. It increases the variety of crops, provides habitat for a broader range of beneficial organisms, and enhances overall ecosystem health. Additionally, the combined use of peat and clay soils can help improve soil structure and fertility over time.

In summary, incorporating both peat and clay soils, along with the plants that prefer them, in your agroforestry system can promote diversity, enhance soil health, and improve overall productivity.

3.2. Species selection

As it was previously mentioned, in this system we used both clay and peat soil. The plants shown in table 1 were used: Blackcurrants, Rhubarbs, Raspberries, Cranberries and Strawberries were obtained in the field from Maarten Schrama and then transported to the experimental area. Plants of the following genus have been used as they can grow in acidic soils: Ribes (Zhang et al., 2008), Ericaceae (Crowford, 2010), Rubus (Patamsytė et al., 2010) and Fragaria (Shahzad et al., 2018).

The rest of the perennials, Cornelian cherry, Hazel, Rhubarbs and the seeds of the annual plants (carrot, garden beans, potatoes, radish and zucchini) were obtained from the nursery garden "123 Zaden" (Table 1). The annual plants were first sowed in small wells and when they sprouted, they were planted in both experimental areas.

In clay soil, we chose Cornelian cherry trees (Cornus mas) and hazel trees (Corylus avellana) for their deep root systems that enhance soil structure and their ability to form symbiotic relationships with nitrogen-fixing bacteria (Seho, M. et al., 2019; Nicoletti, R. et al, 2022). Rhubarb was included as an understory crop for its ability to stabilize the soil and provide additional yield (Holzmueller, E., et al, 2007). In peat soil, we selected raspberries, black currants, strawberries, and cranberries for their adaptability to acidic conditions (Joosten & Clarke, 2002).

***Table 1: Species used for this experiment*[1]**

Common name	Scientific name	Crop type	Soil type used	Number of replicates per experimental area
Garden Rhubarb	*Rheum rhabarbarum*	Perennial	Clay	10
Cornelian cherry	*Cornus mas*	Perennial	Clay	10
Hazel	*Corylus avellana*	Perennial	Clay	10
Blackcurrant	*Ribes nigrum*	Perennial	Peat	5
Raspberry	*Rubus idaeus*	Perennial	Peat	10
Strawberry	*Fragaria ananassa*	Perennial	Peat	5
Cranberry	*Vaccinium macrocarpon*	Perennial	Peat	5

[1] *three of the crop types only had five replicates for each location because there were not enough individuals to include ten in each experimental area.*

Carrot	*Daucus spp.*	Annual	Clay	10
Garden bean	*Phaseolus vulgaris*	Annual	Clay	10
Potatoe	*Solanum tuberosum*	Annual	Clay	10
Radish	*Raphanus sativus*	Annual	Clay	10
Zucchini	*Cucurbita pepo*	Annual	Clay	10

All of the plants mentioned above are listed in the Plants for a Future database. The Plants for a Future (PFAF) database (Plants for a Future. n.d.) is valuable for its ecological and sustainability impact. It promotes biodiversity, offers alternative plant options for various uses and supports sustainable practices, fostering a balanced and regenerative approach to agriculture and land use. By documenting and promoting the cultivation and utilization of a wide range of plants, including lesser-known and underutilized species, the database encourages biodiversity and sustainability, it empowers individuals and communities to make informed choices for a more resilient relationship with the ecosystem.

3.3. Variables and measurements

The combination of perennial and annual plants in agroforestry systems on different soil types such as clay and peat offers numerous advantages. These include soil improvement, nitrogen fixation, pollination support, yield stability, erosion control, crop diversity, microclimate moderation, and enhanced nutrient cycling. Embracing such practices can foster more sustainable and resilient agricultural ecosystems, aligning with the goals outlined in the Plants for a Future database. Planting diverse crops that are well-adapted to specific soil conditions can ensure high productivity, soil health, and efficient land use while offering a range of marketable products to meet various consumer demands. Such strategies also contribute to overall biodiversity, promoting a balanced and sustainable approach to agriculture.

3.3.1. Biotic variables

The following measurements were collected for each individual of different species, taken every two weeks from April 26 to July 10, 2021, in the study areas of Hortus and LVO (LVOU and LVOF). Table 2 provides an example of the recorded measurements in the field notebook. After measuring each individual, we calculated the average values for each species.

Leaf area was determined by measuring the length and width of the leaves with a precise ruler, and multiplying the two values to obtain the area in square centimeters (cm^2). To calculate the average leaf area for each plant, we randomly selected and measured 10 leaves, then calculated the mean value.

We also recorded the **number of leaves per branch** and the **number of branches per tree**. These variables were chosen to assess the early-stage growth of our agroforestry system, as they can show relatively quick changes over time. We selected these traits due to the limited time available for the experiment. These two measurements were taken by counting manually.

Table 2: Example of a field notebook measurements taken to measure the plants growth in the field.

Hortus		**LVOU**		**LVOF**		
Clay soil	Peat soil	Clay soil	Peat soil	Clay soil	Peat soil	
						Nº leafs per branch
						Nº Branches
						Leaf surface (cm2)

In this study, we did not use more precise measurement equipment due to limitations in the available resources. We acknowledge that there are advanced techniques and tools that could potentially provide more accurate measurements for the variables investigated. However, given our circumstances, such equipment was not accessible.

It is important to note that despite the potential limitations in precision, our aim was to gather meaningful data within the constraints of our experimental setup. We believe that the chosen measurement approach still provides valuable insights into the growth patterns during the early stages of growth of these plants.

3.3.2. Abiotic variables

Furthermore, supplementary environmental data was collected for the study. Environmental parameters were recorded at Land van Ons and Hortus using weather stations and i-buttons. Weather stations recorded parameters such as air temperature, speed, humidity and atmospheric pressure.

Weather stations were installed at both locations for one month. This period was determined by the availability of these stations for this study.

The weather station at Land van Ons was installed on May 26th at 11:30 am, while the station at Hortus was installed on May 27th at 11:30 am. Data collection for the environmental parameters commenced from the installation date and continued until June 27th. The stations measured air temperature in ºC, air pressure in hPa and percent relative humidity during this time period. Weather stations collect data at hourly intervals.

The study involved the installation of four i-buttons, with two placed at each location. These i-buttons, produced by Maxim Integrated, are compact temperature loggers specifically designed for temperature monitoring. They are roughly the size of a coin and were inserted approximately 10 cm below the ground surface.

At each location, two i-button were installed. The i-buttons continuously measured the soil temperature at three hour intervals throughout the duration of their installation. The i-buttons were installed at both Hortus and LVO on April 28, 2021, and remained in place until July 7, 2021. This duration allowed for an extended monitoring period to capture temperature changes within the soil.

3.6. Statistical design

In this study, while some experimental results demonstrated statistical significance, we should be careful with their interpretation due to the limited sample size at each location (10 samples for certain species, and 5 for others). Small sample sizes like these may not provide sufficient statistical power, making it challenging to get reliable results. Statistical power (the probability that a test will correctly reject a null hypothesis when an alternative one is true) is crucial for an accurate outcome. When statistical power is low, there's an increased likelihood of a Type II error, where a significant difference is missed.

Additionally, small sample sizes present two problems: higher sensitivity to outliers and less capacity to find statistically significant results. With fewer data points, outliers can bias the results. Therefore, while it's possible to conduct statistical tests on smaller samples, the results must be interpreted carefully. For the biotic variables, statistical test Wilcoxon[2] was conducted where there were 10 replicas per study site. For species with only five samples, visual representations were created to have a basic understanding of the growth pattern on each location.

On the other hand, we did perform statistical tests on the environmental data produced by the i-buttons, as this data offered the most amount of data points. We used the daily mean temperatures for the two locations.

4. Results

The following section presents the findings from our study, which aimed to investigate the growth patterns of the species planted in our agroforestry system under different conditions, and to understand the impacts of various environmental factors on these growth patterns.

Our research questions were based on the following hypotheses: First, we wanted to know if the presence of peat soil in combination with clay soil significantly influenced the growth of our selected plant species, in other words: Can our plants thrive in such a system? Second, we hypothesized that abiotic factors including atmospheric conditions and herbivory, might also have a considerable impact on plant growth. Can this proposed system thrive in Land van Ons?

[2] Test used for comparing two paired samples, especially when the normality assumption of the data is violated or when sample sizes are small.

For the biotic variables, we assessed the leaf area, number of leaves per branch, and number of branches per tree for each individual of different species in our study areas (Hortus and LVO, subdivided into LVOU and LVOF). In addition, we gathered data on abiotic factors such as air temperature, air pressure, relative humidity, and soil temperature, by installing weather stations and i-buttons at each location.

It's important to note that for the biotic factors, we began taking measurements only from the fifth week of our experiment. Initially, we had a different approach, which involved using the length of the branches as a measure of the plants' growth rate. However, we found that this method wasn't particularly effective in the early stages of the experiment. Given the time constraints typical to a Master's project length, we needed a method that was more efficient. So, we decided to switch to different variables, ones that allowed us to measure growth rates faster.

We will first share the results of the plant measurements, followed by an exploration of the environmental data.

4.1. Results from Plant Measurements (biotic data)

Our analysis focuses on three key growth parameters across the three different locations: (1) leaf area, (2) number of branches per individual, and (3) number of leaves per branch.

The results will allow us to directly address our first research question, evaluating the ability of our chosen crops to grow in the distinctive soil types present at Land van Ons.

Following this, we will provide a comparative analysis of the growth between conditions at Hortus and Land van Ons over time. This is connected to our second research question, examining the potential differences in crop growth in controlled conditions (Hortus) versus real field conditions (LVO). We will illustrate the growth over time for each species in each experimental zone. This will further explore our hypothesis that the growth of the species in the field may be limited due to variables such as herbivory pressure and other abiotic factors.

Annual crops

Due to the immediate predation by herbivores in both Land van Ons locations, the planted annual crops were entirely consumed before their growth could be assessed. Consequently, we were unable to gather any information on their growth across the three experimental areas. This unfortunate circumstance indicates the need for alternative strategies in future investigations involving the cultivation of such crops.

The findings highlight the critical impact of herbivory on the successful establishment and growth of annual crops, which needs appropriate measures to manage these impacts in future studies.

Perennial crops

For the perennials, an intercropping methodology was used, In the clay zone, Hazel, Cornelian Cherry, and Rhubarb were planted, whereas Black Currant, Cranberries, Strawberries, and Raspberries were cultivated in the peat zone. The planting strategy involved an alternating pattern of all species. To explore the impact of climatic conditions on plant performance, I conducted comparative analyses of growth data from both the Hortus Botanicus and the Land van Ons site for each of the species detailed below (table 3).

Table 3: Species growth in the three sites: Hortus (Hortus botanicus), LVOF (Land van Ons fenced) and LVOU (Land van Ons unfenced). For each species we calculated the mean leaf area during the course of the experiment, the Standard deviation (SD) and the increase of the size of the leafs. We also calculated the number of leaves/branches and the SD of the total amount of samples.

Cornus mas								
Leaf area (cm2)	*week 5*	*week 7*	*week 9*	*week 11*	*week 13*	*total SD*	*Δ(Leaf Area) (%)*	*Δ(Leaf Area) (%) SD*
Hortus		10,00	9,03	13,58	10,70	2,39	2,09	2,53
LVOF		7,37	8,59	12,94	9,36	2,39	2,30	2,21
LVOU		3,77	8,59	13,58	7,60	4,90	4,90	0,11
Number of leafs pre branch	*week 5*	*week 7*	*week 9*	*week 11*	*week 13*	*total SD*		
Hortus	28,71	34,33	12,54	18,11	21,75	9,89		
LVOF	19,46	34,31	34,34	37,81	30,52	8,18		
LVOU	22,45	29,56	33,45	34,33	29,55	5,41		
Corylus avellana								
Leaf area (cm2)	*week 5*	*week 7*	*week 9*	*week 11*	*week 13*	*total SD*	*Δ(Leaf Area) (%)*	*Δ(Leaf Area) (%) SD*
Hortus	x	26,15	39,89	46,79	36,55	10,51	7,45	0,10
LVOF	x	24,15	36,62	46,09	34,41	11,01	10,87	2,12
LVOU	x	26,15	39,89	46,79	36,55	10,51	9,74	4,83
Number of leafs pre branch	*week 5*	*week 7*	*week 9*	*week 11*	*week 13*	*total SD*		
Hortus	14,47	16,05	6,01	9,02	10,59	4,68		
LVOF	21,33	19,89	6,62	8,22	12,33	7,66		
LVOU	13,27	17,33	7,77	8,76	11,19	4,41		
Rheum rhabarbarum								
Leaf area (cm2)	*week 5*	*week 7*	*week 9*	*week 11*	*week 13*	*total SD*	*Δ(Leaf Area) (%)*	*Δ(Leaf Area) (%) SD*
Hortus	x	77,46	69,41	89,02	78,22	9,86	12,56	8,17
LVOF	x	126,34	201,13	212,92	175,55	46,95	29,70	44,54
LVOU	x	58,01	348,76	263,50	174,69	149,46	157,44	145,31

Number of leafs pre branch	*week 5*	*week 7*	*week 9*	*week 11*	*week 13*	*total SD*		
Hortus	2,79	2,14	3,93	5,79	3,41	1,60		
LVOF	1,64	3,56	4,77	4,43	3,33	1,40		
LVOU	2,17	2,53	4,93	5,13	3,43	1,56		
Ribes nigrum								
Leaf area (cm2)	*week 5*	*week 7*	*week 9*	*week 11*	*week 13*	*total SD*	*Δ(Leaf Area) (%)*	*Δ(Leaf Area) (%) SD*
Hortus	x	26,42	38,26	49,81	36,92	11,69	6,90	3,25
LVOF	x	26,42	38,26	49,81	36,92	11,69	11,69	0,20
LVOU	x	26,42	38,26	49,81	36,92	11,69	3,31	1,95
Number of leafs pre branch	*week 5*	*week 7*	*week 9*	*week 11*	*week 13*	*total SD*		
Hortus	5,06	5,95	6,64	9,32	6,57	1,84		
LVOF	7,49	5,95	15,52	17,03	10,42	5,59		
LVOU	9,45	1,82	2,52	3,63	3,54	3,48		
Rubus idaeus								
Leaf area (cm2)	*week 5*	*week 7*	*week 9*	*week 11*	*week 13*	*total SD*	*Δ(Leaf Area) (%)*	*Δ(Leaf Area) (%) SD*
Hortus	x	40,94	36,33	44,91	40,58	4,30	6,29	2,81
LVOF	x	46,88	46,40	59,04	50,45	7,16	2,47	8,60
LVOU	x	33,51	36,33	44,91	37,96	5,94	4,92	4,08
Number of leafs pre branch	*week 5*	*week 7*	*week 9*	*week 11*	*week 13*	*total SD*		
Hortus	4,53	13,32	9,80	10,58	8,89	3,68		
LVOF	9,24	7,80	9,48	10,97	9,30	1,3		
LVOU	10,41	10,21	9,63	10,76	10,24	0,47		
Fragaria ananassa								
Leaf area (cm2)	*week 5*	*week 7*	*week 9*	*week 11*	*week 13*	*total SD*	*Δ(Leaf Area) (%)*	*Δ(Leaf Area) (%) SD*
LVOF	x	22,39	31,12	35,33	29,09	6,60	6,06	3,19
LVOU	x	20,89	24,39	31,16	25,13	5,22	4,87	2,31
Number of leafs pre branch	*week 5*	*week 7*	*week 9*	*week 11*	*week 13*	*total SD*		
LVOF	12,91	15,05	19,62	23,62	17,32	4,78		
LVOU	9,51	10,19	11,95	17,04	11,85	3,4		
Vaccinium macrocarpon								
Branch length	*week 5*	*week 7*	*week 9*	*week 11*	*week 13*	*total SD*		
Hortus	x	x	37,92	46,28	41,89	5,91		
LVOF	x	x	23,84	30,01	26,75	4,36		
LVOU	x	x	33,31	42,4	37,58	6,42		

CLAY SPECIES

Cornus mas (Cornelian cherry)

The data suggests that plants at all three sites are showing an overall increase in leaf area. The growth rate, however, varies, with plants at the LVOU site growing fastest (4.90%), followed by LVOF (2.30%), and Hortus (2.09%). There's also greater variation in leaf sizes at LVOU, as suggested by the highest standard deviation (4.90) compared to Hortus and LVOF (both 2.39).

Additionally, growth rate consistency is highest at LVOU (with an SD of 0.11 for growth rate), indicating a more uniform growth rate compared to the other sites.

For the number of leaves per branch, the data seems to indicate that there are different growth patterns across the three sites. In Hortus, they show steady growth up to week 11 followed by a decline. In LVOF our plants experience an initial decline, an increase, and a final dip. In LVOU they show a drop from week 5 to week 7, and then a little rise, indicating possible environmental or plant health factors affecting the initial stages of growth.

The very different growth patterns at each site might be due to differences in the abiotic factors between the two locations..

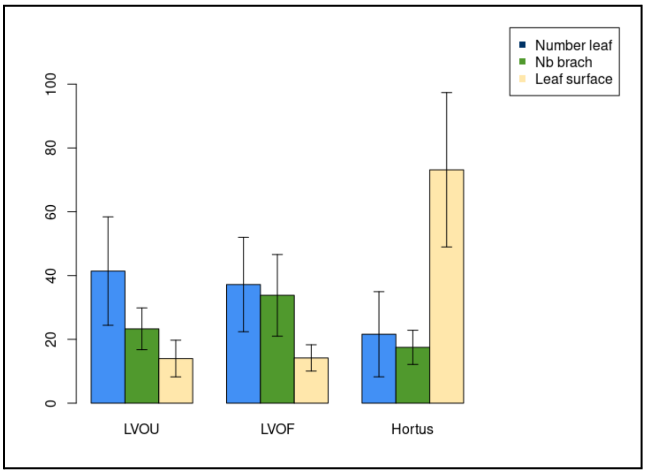

Figure 5: For Cornelian cherry, differences in final mean and SD at the three locations (Hortus, LVOF and LVOU) for the 3 main biotic variables under study: (1) Number of leaves, (2) Number of leaves per branch and (3) Leaves area in cm2.

As we can see in the picture above, the final growth for the variable number of leaves per plant, LVOU, presented the highest results. For the number of leaves per branch, the results were slightly better for LVOF. For leaf surface, we can observe that the results are visibly better for Hortus than for Land van Ons (figure 5).

After performing the Wilcoxon test on our data, the data supports that there are significant differences between number of leaves:

- Between LVO and LVOU → p-value: 4,199e-08
- Between LVOU and Hortus → p-value: 4,193e-08

- Between LVO and Hortus → p-value: 4,199e-08

For all the variables measured, the results of the tests are significant across the three locations.

Corylus avellana (Hazel)

The leaf area expanded in all locations over time, with different growth rates. The leaf area in LVOF had a substantial standard deviation (11.01) and a growth rate (Δ Leaf Area) of 10.87%, considerably rapid. The LVOU site showed a growth rate (9.74%) close to that of LVOF. In contrast, the Hortus site exhibited steady growth with a lower standard deviation (10.5) and a slower growth rate (7.45%).

Concerning the number of leaves per branch, all sites seemed to show a fluctuating trend. The LVOF site showed the highest variability (SD: 7.66) and had an initial rise in leaf count followed by a big decline and subsequent recovery. Interestingly, despite having the same location as LVOF, the LVOU site had a lower variability (SD: 4.41) and showed a rise in leaf count until week 7, followed by a decline and recovery. The Hortus site presented the most steady trend with fewer leaves initially, a sudden dip at week 9, and a steady recovery afterwards (SD: 4.68). The impact of the protective fence at LVOF is visible in both leaf area and leaf count, indicating its role in promoting growth compared to LVOU.

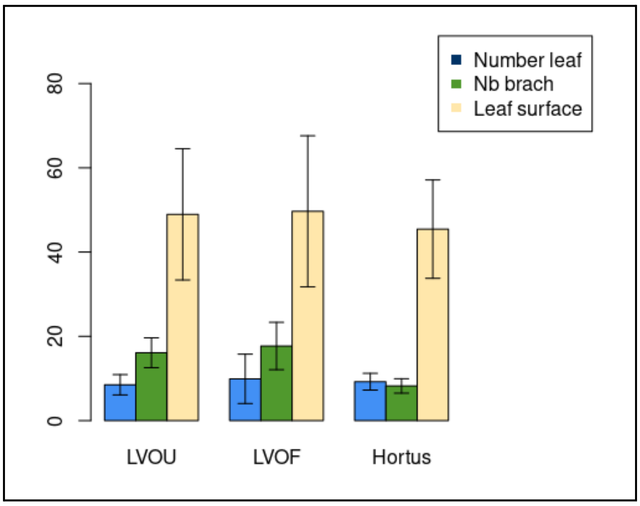

Figure 6: For Corilus avellana, differences in final mean and SD at the three locations (Hortus, LVOF and LVOU) for the 3 main biotic variables under study: (1) Number of leaves, (2) Number of leaves per branch and (3) Leaves area in cm2.

As we can see in the picture above, the final growth for the variable number of leaves per plant, LVOF, presented slightly higher results, as well as for the number of leaves per branch and leaf surface (figure 6). For all the variables measured, the results of the tests are significant across the three locations.

Rheum rhabarbarum (Rhubarb)

Given the morphology of this plant species, a greater growth in leaf size rather than the quantity is expected. The leaf area at LVOF, exhibited a substantial increase over the weeks, showing a growth rate of 29.70%. However, the high total SD (46.95) indicated a considerable variability in leaf growth. LVOU, showed an impressive Δ(Leaf Area) of 157.44%. Hortus, by contrast, demonstrated more stable growth and less variation, with a Δ(Leaf Area) of 12.56% and a lower total SD (9.8).

In respect to the number of leaves per branch, all sites demonstrated less variation (SDs: 1.40-1.60), consistent with Rheum rhabarbarum's growth tendency of growing larger leaves rather than more leaves. LVOF saw an increase in leaf count up to week 9, with a slight decline by week 13. Similarly, LVOU and Hortus, as both showed an increase, peaking at week 11, with a slight decline by week 13. These trends suggest that despite the leaf area's drastic changes, the number of leaves per branch stays relatively stable.

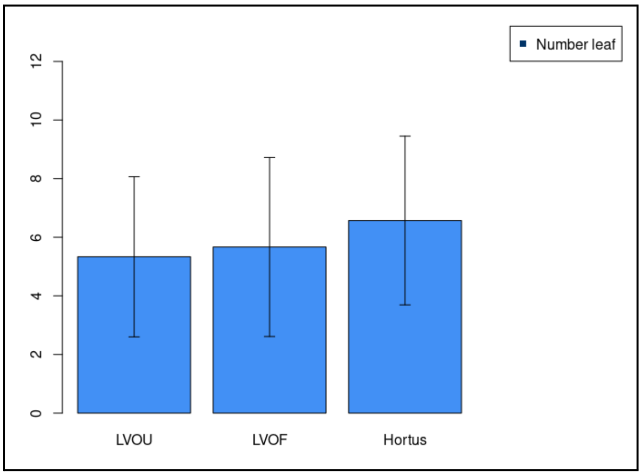

Figure 7: For Rheum rhabarbarum differences in final mean and SD at the three locations (Hortus, LVOF and LVOU) for the number of leaves.

For this species, when we combine the leaf data from LVOF and LVOU, the total leaf count at LVO is different from what we found at Hortus. By the end of our experiment, Hortus had more leaves, as shown in Figure 7.

PEAT SPECIES

Rubus idaeus (Raspberry)

For this peat-growing crop, leaf area growth indicated variable trends across the sites with the highest variability seen in LVOF, which showed a significant leaf area increase and SD (total SD: 7.16, Δ Leaf Area (%): 2.47, Δ Leaf Area (%) SD: 8.60). This was followed by LVOU (total SD: 5.94, Δ Leaf Area (%): 4.92, Δ Leaf Area (%) SD: 4.08) and the least variability was observed at Hortus (total SD: 4.30, Δ Leaf Area (%): 6.29, Δ Leaf Area (%) SD: 2.81).

In terms of leaves per branch, LVOF showed a gradual increase over the weeks with a small SD (total SD: 1.3), suggesting a consistent growth. LVOU displayed a consistent trend in leaf number per branch with the lowest SD (total SD: 0.47), signifying less variation in leaf number over time. Hortus showed more variability in leaves per branch with the highest SD (total SD: 3.68), indicating a less consistent leaf growth compared to the other sites (figure 8).

For this species, as we have a sample size of less than 10, we do not have statistical results, so our results are merely indicative.

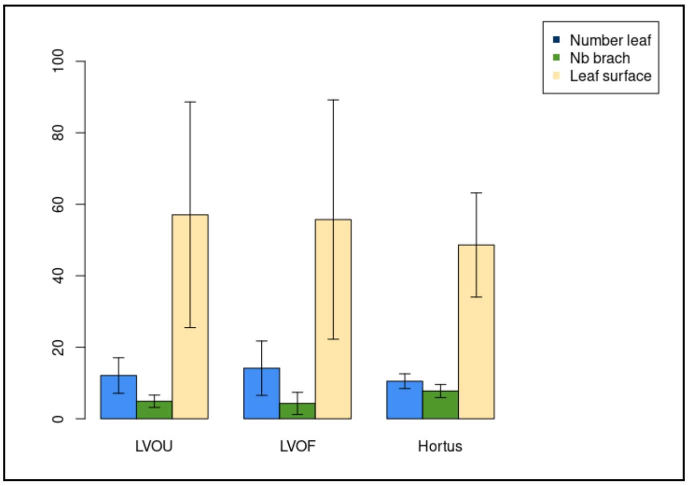

Figure 8: For Rubus idaeus, differences in final mean and SD at the three locations (Hortus, LVOF and LVOU) for the 3 main biotic variables under study: (1) Number of leaves, (2) Number of leaves per branch and (3) Leaves area in cm2.

Ribes nigrum (Black currant):

In the case of this acidic soil liking crop, we could observe tha at Hortus, leaf number per branch increased from week 5 to week 11, before slightly dropping at week 13, with relatively low variability (total SD: 1.84). LVOF showed the most variable trend, with a notable increase in leaf numbers at weeks 9 and 11, but with the highest variability (total SD: 5.59). LVOU had a very different pattern, with a peak in leaf numbers at week 5, followed by a steep drop at week 7, and then slight increases through week 13, while maintaining a moderate level of variability (total SD: 3.48).

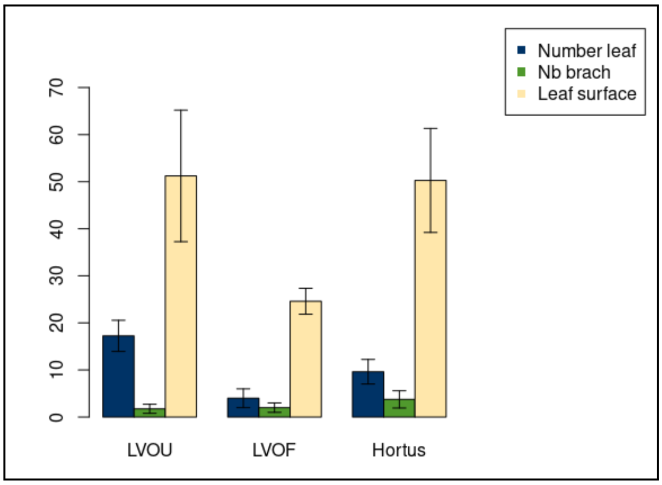

Figure 9: For Ribes nigrum, differences in final mean and SD at the three locations (Hortus, LVOF and LVOU) for the 3 main biotic variables under study: (1) Number of leaves, (2) Number of leaves per branch and (3) Leaves area in cm2.

For the species under study, given our sample size of fewer than 10, our findings are indicative rather than statistically significant. Nevertheless, we can affirm that growth was observed across all three locations. The amount of leaves appears to be slightly higher at the LVOU location (Figure 9). The leaf surface area seems to be smaller at LVOF compared to the other sites. However, considering the sample size, these observations may not accurately represent the overall growth pattern of this species in this soil type.

Vaccinium macrocarpon (Cranberry)

In the case of this species, only the length of the branches was used to measure the growing rate. As this is a species with relatively fast-growing branches but similar leaf size. At Hortus, branches showed steady growth from week 9 to 11, before receding slightly by week 13, with moderate variability (total SD: 5.91). The LVOF site showed lower branch lengths across the weeks. LVOU demonstrated similar growth patterns as Hortus, with the highest variability (total SD: 6.42). This plant species was introduced later into the sites, so fewer measurements were recorded. Again in the case of this species, with a sample size under 10, our results are only indicative

Fragaria ananassa (Strawberry)

The LVOF location, protected from herbivory by a fence, showed a consistent increase in leaf area (in cm2) from week 7 to 11, followed by a slight decrease at week 13, with a moderate total SD of 6.60. The increase in leaf area showed a relatively low variability, with a percentage change SD of 3.19. In terms of the number of leaves per branch, LVOF exhibited an increasing trend across all the weeks with a total SD of 4.78, reflecting a relatively stable growth pattern. In contrast, LVOU, not protected from herbivory, demonstrated a slightly less consistent increase in leaf area across the weeks, with a slight decrease in week 13.

For the number of leaves per branch, LVOU also showed an increase across the weeks, but the growth was less consistent, especially at week 13, with a lower total SD of 3.4 compared to LVOF. These results may suggest that the fence at LVOF facilitated more consistent growth in Fragaria ananassa. It's important to note that no data was collected from Hortus for this species.

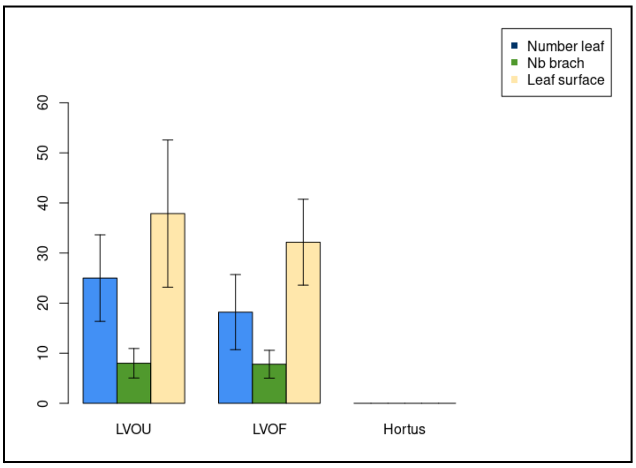

Figure 10: For Fragaria ananassa, differences in final mean and SD at LVOF and LVOU for the 3 main biotic variables under study: (1) Number of leaves, (2) Number of leaves per branch and (3) Leaves area in cm2.

For these species, due to a sample size of fewer than 10 per site, the results serve predominantly as indicative. When considering the three measured variables, the final growth outcomes don't appear to differ significantly between the two locations where this species was planted (Figure 10).

Overall growth in the three locations

From the data that we have, it is possible to draw some tentative conclusions regarding the growth patterns on peat versus clay soil. However, it should be again noted that the sample size we work with is not large enough to have statistical significance on the presented results. With this being taken into account, we can observe some patterns:

The clay soil species (Corylus avellana, Cornus mas and Rheum rhabarbarum) generally demonstrated higher variability in their growth patterns, particularly in terms of leaf area and leaves per branch, when compared to the peat soil species (Rubus idaeus, Ribes nigrum, Viburnum opulus, and Fragaria ananassa).

Rheum rhabarbarum, tended to show larger leaf area and substantial growth in leaf numbers over time. However, this was not consistent across species or locations, suggesting other factors, such species-specific characteristics, might play a role.

In comparison, the peat soil species showed a more consistent growth pattern. Rubus idaeus, for example, had little changes in leaf area and number of leaves per branch, with relatively low standard deviations. Vaccinium macrocarpon was measured by branch length and demonstrated fairly consistent growth across weeks and locations. Ribes nigrum showed a significant increase in the number of leaves per branch, particularly in LVOF, while Fragaria ananassa demonstrated a consistent increase in both leaf area and number of leaves per branch.

It is worth mentioning that all plants of various species planted on peat soil (raspberries, blackberries and strawberries) produced fruits, which were harvested in the last week of experimentation. The plants with fruit production were black currant, strawberries and raspberries. The production of edible fruit is a good indicator of the condition of the plants after only a few months in the experimental area after planting.

4.2. Environmental Data (abiotic data)

In this section we look at the results of the environmental data. As previously explained in the methodology section, environmental data were collected from two locations, Land van Ons and Hortus, using weather stations and i-buttons. These stations were installed for one month, from May 26th to June 27th, and recorded hourly measurements of air temperature, pressure, and humidity.

Alongside, four i-buttons were deployed, two at each site, for temperature monitoring. These loggers, placed approximately 10 cm below the ground surface, operated from April 28th to July 7th, 2021, and registered soil temperature at three-hour intervals.

These methodologies ensured the monitoring of both atmospheric and soil conditions, capturing potential temperature variations between different soil types and understanding their possible effects on the study.

4.2.1. Weather stations

The weather station data could not be utilized to examine growth outcomes as the stations were only installed for a month, so its comparisons with plant growth were not possible. Moreover, the weather station at Hortus ceased functioning for reasons beyond our control on June 8, 2022.

However, we present an example of the air temperatures at both locations to provide a rudimentary understanding of air temperature variation in both locations (Table 4). Please note that this information does not carry statistical significance and should be interpreted with caution.

Table 4: Air temperature in the experimental sites

Air temperature (ºC) Weather Stations												
Date	***27/5/21***	***29/5/21***	***31/5/21***	***2/6/21***	***4/6/21***	***6/6/21***	***8/6/21***	***10/6/21***	***12/6/21***	***14/6/21***	***16/6/21***	***18/6/21***
LVOU and LVOF	17,94	21,31	25,66	24,19	21,27	23,66	23,20	23,64	23,63	25,86	21,54	17,56
Hortus	18,65	21,14	19,03	22,16	19,50	25,41	20,47					

To obtain the data of table 4, we extracted the mean temperature per day.

4.2.2. Soil temperature

Pertaining to the i-button data, we made the mean temperature recorded by the two devices at each location (table 5). Given the amount of data points we have of this variable, this could be a reliable environmental measure that can be used for the duration of the study. Again, to obtain the data of table 5, we extracted the mean temperature of each day.

Table 5: Soil temperature in ºC, registered by i-buttons.

Soil Temperature (ºC) i-buttons									
Date	***28/4/21***	***8/5/21***	***18/5/21***	***28/5/21***	***7/6/21***	***17/6/21***	***27/6/21***	***7/7/21***	***9/7/21***
Mean LVO	20,27	8,75	13,38	11,88	18,00	23,13	16,63	17,88	15,50
Mean Hortus	10,63	9,38	13,00	13,00	17,63	22,38	15,88	18,25	15,75

From our first assessment, it seemed that the temperature data for both locations do not follow a normal distribution. We used the Shapiro-Wilk test to statistically confirm the non-normality of the data, with significant p-values (less than 0.05) supporting our initial observations. Then, we apply Pearson's correlation test, revealing a strong correlation (around 82%) between the temperatures at the two sites, which means they tend to rise and fall together.

To check if there is a significant difference in temperature between the two locations, we first use a t-test. The t-test shows no significant difference in temperatures between the two sites. Lastly, we use the Bartlett test to check if the variances between the two locations are equal (this is required to do an ANOVA test). Our results suggest that ANOVA might not be reliable, as the variances of the two locations seem to be different.

In essence, while the two sites' temperatures are strongly correlated and don't differ significantly, their variances differ. We can observe that, although the minimum temperatures seem to be similar, we can observe in the graph 5 that the maximum temperatures seem to be higher in Hortus. This could be due to the fact that this was a small close garden with brick walls, which could be a plausible explanation for maximum temperatures to be higher in this location and the variances to be different.

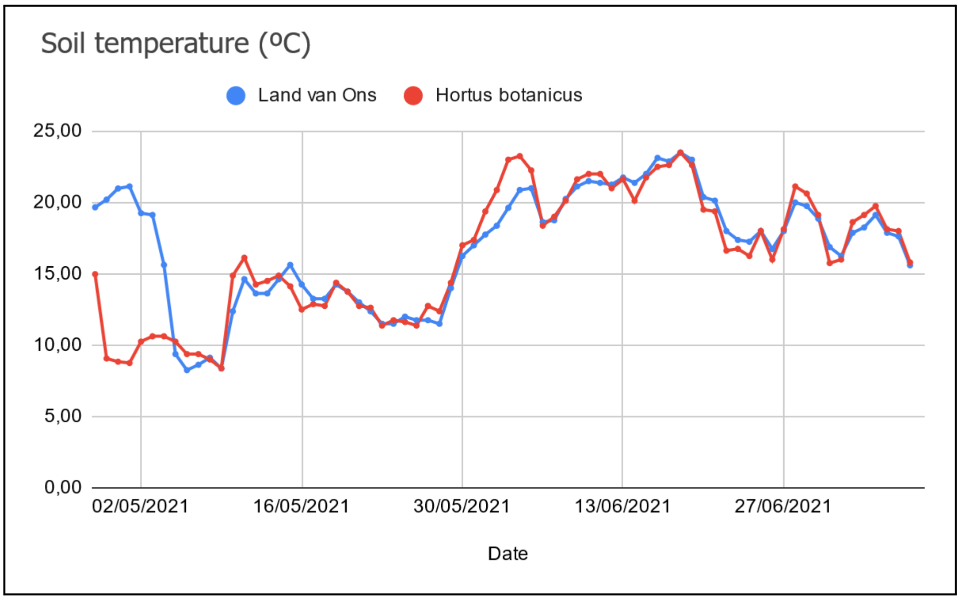

Figure 5: Soil temperature on ºC in Land van Ons and Hortus botanicus.

The data suggests that the mean temperatures recorded over the installation period were roughly the same at both locations. This indicates that if there are significant disparities in plant growth, they are likely attributable to factors other than the soil temperature.

5. Discussion

coments of cornus mas)

We recall that at the beginning of this report, we wanted to answer the question of whether the type of crops chosen is compatible with the creation of an agroforestry system in the biotic and abiotic conditions found in the Land van Ons. Specifically, we wanted to know if growing in soil as acidic as the peat present in these lands is possible. To create such a system we chose acid-resistant shrubs such as Black currant, Cranberries, Strawberries and Raspberries. As previously mentioned, these were planted intercalated with other plants such as Cornelian Cherry, Hazel and Rhubarbs, which were planted in an area with less acidic clay soil.

We wanted to find out concretely whether (1) the chosen annual and perennial crops can grow in the soil found in Land van Ons and (2) if this is possible, whether there would be a difference in the growth of these crops in the same soil type under more controlled abiotic conditions than those found in Land van Ons (as is the case for the Hortus conditions).

5.1. Can our crops grow in the soil in LVO?

Regarding the first RQ, whether the chosen plants are able to grow in the soil present in Land van Ons, the results show that all perennial crops can grow in this environment, while annual crops remain unknown.

Concerning the annual crops, we do not know what the effect of the peat soil is on them, but we can state that the pressure produced by herbivory is very strong both in Hortus and Land van Ons. In order to check whether these crops are adapted to this type of soil, it is suggested to first carry out experiments in a completely controlled environment, such as a greenhouse, and then transplant the crops to the experimental area once they are sufficiently overgrown so that the impact of herbivory is lessened.

Regarding the cultivation of perennials, there are several clear results: all of them show, to a greater or lesser extent, growth in the peat soil present in the Land van Ons area.

The differing growth patterns observed between species suggest that certain plants might be more suitable for this environment than others. For instance, species such as *Rheum rhabarbarum* (clay soil species) and *Ribes nigrum* (peat soil species) demonstrated substantial growth and could potentially be good candidates for successful cultivation in the LVO soil. Additionally, the consistent growth shown by *Fragaria ananassa* suggests this species might also be a good fit for the LVO sites.

The potential impact of herbivory, as suggested by some data trends between LVOF and LVOU, should also be taken into consideration when selecting species for cultivation and planning for site management. The protective fence at LVOF could have provided an advantage for plant growth in some cases, suggesting that herbivory may be a factor affecting the plants' development. However, this wasn't always the case, this could be because the effect of herbivory might be species-dependent.

On top of this, in the last sampling carried out during the experimental phase, several species showed fruit production. This was the case of the species *Rubus idaeus, Fraggaria assana* y *Ribes nigrum.* Fruit production has been used to measure the suitability of soil type by other authors, as is the case of the work done by other authors (M.Sulieman et al., 2015). In conclusion, it appears that an agroforestry system can indeed be successful at the LVO sites.

5.2. Difference in the growth across locations

Considering the second question of the study: Could there be a difference in the growth of the crops with the same type of soil in controlled conditions (Hortus) vs Land van Ons conditions over time? several notable findings emerged:

We have identified significant variations in growth across different locations for certain species, including rhubarbs, raspberries, hazel and cornus mas. However, it's crucial to approach these findings with caution. The sample size for all these cases is limited, potentially compromising the reliability of the results.

Although ground temperature at Land van Ons were not more extreme than at Hortus (as we expected), we believe that Hortus experienced less wind due to its enclosed garden setting, in contrast to the exposed field location of Land van Ons. Although this information can not be corroborated, as we do not have reliable information from the weather stations, we experienced it when working in the two locations.

For most species, initial growth was more favorable in Hortus, likely due to the controlled conditions. However, over time, superior growth was observed in Land van Ons. This shift can possibly be attributed to the unrestricted root development at Land van Ons, in contrast to the limitations of pot growth in Hortus, a phenomenon previously noted by Mcconnaughay et al., (1993). They highlighted that smaller pots not only limit the physical space for root development but also offer fewer nutrients, possibly tempering growth enhancement.

Lastly, the Hortus peat soil underwent oxidation and subsidence, probably due to soil transportation, as the intact peat was exposed to open air during the transportation process. This issue was further exacerbated by the particularly hot conditions during the third experimental week (figure 5). Despite continued watering, the peat soil in Hortus could not retain water as effectively as Land van Ons, leading to rapid water drainage. The water absorption by plants can drastically drop in peat soil that isn't constantly wet, posing a risk of subsidence and impacting the crop production.

In conclusion, our findings suggest that the Land van Ons sites can support plant growth effectively, despite the varied weather conditions. This might be due to the unrestricted development of plant roots in this location. However, the study also indicates certain challenges with peat soil when used in pot cultivation, particularly with respect to water retention, which could potentially affect plant growth.

It is interesting that we initially hypothesized that the Hortus would serve as an ideal control environment, expecting plants to thrive better there than in other locations due to its controlled environment and that it is less exposed to the influence of extreme climate conditions than LVO. However, due to the pot effect and soil subsidence previously mentioned, the anticipated "better" growth did not materialize as expected.

Interestingly, we observed that the growth rates of the species at Land van Ons were not significantly different when compared to Hortus. This positive outcome indicates that these plant species can, indeed, flourish at Land van Ons. Therefore, despite initial expectations, our study successfully demonstrates the viability of Land van Ons for supporting healthy plant growth under its unique environmental conditions.

Nonetheless, it is crucial to pay attention to the fact that certain species exhibit a higher susceptibility to herbivory than others (like *Fragaria ananassa)*. Therefore, for future studies, it would be prudent to make species selection with this consideration in mind. This will ensure a more solid experimental design and further enhance our understanding of plant resilience in varying environments at Land van Ons.

5.3. Study limitations

This study has obvious limitations that make the results obtained statistically insignificant. This is due to several factors: (1) Research design limitations, (2) statistical limitations and (3) Sampling issues.

Research design limitations: The study should have been conducted over a period of at least one full natural year in order to have sufficient data. To be able to justify the appropriate growth and establishment of these perennial crops in the experimental area, it would have been interesting to observe how these crops evolved after the winter. Due to the length of the thesis, the experimental time was limited and therefore the number of data points was also limited.

Statistical limitations: for the study to be statistically significant, it would have been convenient that a larger number of replicates of each species would have been used. This was not possible due to the time constrictions and people working on this project.

Sampling issue: Because this was a new study and we did not have many references from previous studies in this field, many of the sampling techniques were improvised. Some of them had to be changed during the course of the experiment because they proved to be ineffective in answering our RQs. For example, we initially tried to use branch growth as an indicator of perennial crop growth, but we realized that this was not an appropriate indicator, so those data points were lost and other more effective growth indicators such as leaf area or number of leaves per branch had to be used. In addition, it would have been desirable to have weather data from both locations in order to have a detailed overview of their abiotic conditions, but due to limitations in available equipment, this data could only be obtained for a period of one month, so this data cannot be used to obtain meaningful results.

Valuable information can still be extracted from these results even if they do not have statistical significance. We can state that, although the abiotic conditions of the land in Land van Ons can be harsh at certain times of the year, the crops chosen for this study are able to grow in the soil present on this land, peat and clay soil. These results are very positive, as they give rise to the possibility of using this land for the production of perennial crops adapted to acidic soils, thus making use of land that is difficult to work.

For future studies, it would be recommended to use annual crops that have been previously cultivated in greenhouses and then transplanted in the Land van Ons area, so that the feasibility of planting annuals on this land can be tested. Perhaps it would be advisable to take extra measures to prevent consumption by herbivores.

6. Future research and Conclusions

Even if we faced some limitations, our research has illuminated new, previously unexplored paths. The study brings to light the resilience of certain plants, which despite the harsher climate condition of Land van Ons, managed to thrive. This raises the question of if there might be a wider repertoire of plant species that could potentially show similar resilience and adaptability to the soil conditions in LVO?
Our understanding of herbivory's role in plant growth remains a work in progress. The species-specific impacts of herbivory should be explored in a bit more depth in future studies.

Observations from the controlled environment at Hortus revealed a significant "pot effect". Could a change in pot design or size alter plant growth dynamics for better control in future research? How can we compensate for this 'pot effect' for optimal growth in a controlled environment? The limitations of our study period brings also the question of long-term weather impact. How would the flow of seasons affect the growth and survival of these plants over a year or more?

The feasibility of annual crops in this context remains a mystery for future research. Which specific annual crops might perform nicely in these soils?

Certain adjustments in our methodology could enrich the outcomes:

- The study's time limitations affect our results indicates that a longer observation period would be useful in order to get significant results. A full natural year or multi year study would give us a better view of plant growth dynamics in this environment.
- Future studies could use more standardized sampling techniques for more accurate and representative data collection.
- An interesting proposition would be to start the growth of annual crops in a controlled greenhouse environment before moving them to Land van Ons. This could help us figure out if they are viable in these soil conditions.
- The collection of detailed weather data across all study sites and during the entire course of the experiments would offer a better understanding of the abiotic influences at play, a crucial aspect of plant growth.
- Lastly, larger pots may offer a solution to the 'pot effect' by encouraging unrestricted root growth and improving plant health and growth rates in Hortus.

As has already been mentioned at the beginning of this report, traditionally peat soil has been excavated and replaced by more fertile soils for cultivation, such as clay, which is suitable for a wide variety of crops (examples from the usual cultivation literature of this area in the Netherlands at the time). Having positive results on the growth of perennial crops on such soils is very positive, as it opens up the possibility of a form of consumption of local, sustainable products, which preserve the very valuable peat, reducing the possibility of its oxidation, subsidization and release of vast amounts of CO2 into the atmosphere. By not removing the crops from the soil as in the case of annual crops, we have the possibility of preserving the peat intact. In addition, by promoting soil cultivation using peat, we help to promote the use of a wider variety of plants that are suitable in this ecosystem naturally. This should help the conservation of local species and increase biodiversity, decreased in the first place by the generalized used of intensive agricultural practices.

8. Bibliography

Altieri, M. A. (1999). The ecological role of biodiversity in agroecosystems. Agriculture, Ecosystems & Environment, 74(1-3), 19-31. https://doi.org/10.1016/S0167-8809(99)00028-6

Biesmeijer, C., Roberts, S.P.M., Reemer, M., Ohlemüller, R., Edwards, M., Peeters, T., Schaffers, A.P., Potts, S.G. ,Kleukers, R., Thomas, C.D., Settele, J., Kunin., W.E. (2006) Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. Science, 313 , pp. 351-354.

Bignal, E.M., McCracken, D.I. (1996) Low-intensity farming systems in the conservation of the countryside. J Appl. Ecol., 33 , pp. 413-424.

Evans, M., & Warburton, J. (2007). Geomorphology of upland peat: erosion, form, and landscape change. Blackwell Publishing.

Fischer, J. ,Lindenmayer, D.B. (2007) Landscape modification and habitat fragmentation: a synthesis. Global Ecol. Biogeogr., 16 , pp. 265-280.

Germain, E. (1994). THE REPRODUCTION OF HAZELNUT (*CORYLUS AVELLANA* L.): A REVIEW. Acta Hortic. 351, 195-210 DOI: 10.17660/ActaHortic.1994.351.19. https://doi.org/10.17660/ActaHortic.1994.351.19
Gorham, E. (1991). Northern Peatlands Role in the Carbon Cycle and Probable Responses to Climatic Warming. Ecological Applications 1(2),: 182-195.

Goulson, D. , Lye, G.C. , Darvill, B. (2008) Decline and conservation of bumble bees

H. Kooi, P. Johnston, K. Lambeck, C. Smither, R. Molendijk. (1998) Geological causes of recent (100 yr) vertical land movement in the Netherlands Tectonophysics, 299, pp. 297-316.

Herbert, E.R., Boon, P., Burgin, A.J., Neubauer, S.C., Franklin, R.B., Ardón, M., Hopfensperger, K.N., Lamers, L.P.M., Gell, P. (2015) A global perspective on wetland salinization: Ecological consequences of a growing threat to freshwater wetlands. Ecosphere, 6(10), 206, 43 pp.

Holzmueller, E., Jose, S., & Jenkins, M. A. (2007). Influence of common rhubarb (Rheum rhabarbarum) on the regeneration of yellow-poplar (Liriodendron tulipifera). Forest Ecology and Management, 242(2-3), 656–663. https://doi.org/10.1016/j.foreco.2007.02.009

Jacimovic, V., Radovic, M., Bogavac, M., & Bozovic, Đ. (2012). IMPACT OF HONEY BEES (Apis mellifera L.) ON POLLINATION AND YIELD OF CULTIVATED PLUM VARIETIES. Poljoprivreda i Sumarstvo, 58(2), 151.

Joosten, H., Tapio-Biström, M.-L., Tol, S., & Sjögersten, S. (2012). Peatlands - guidance for climate change mitigation through conservation, rehabilitation and sustainable use. FAO and Wetlands International. http:// https://www.fao.org/3/i3013e/i3013e.pdf

Joosten, H., & Clarke, D. (2002). Wise use of mires and peatlands: Background and principles including a framework for decision-making. International Mire Conservation Group and International Peat Society.

Kazimierski, M., Regula, J., Molska, M. (2019). Cornelian cherry (Cornus mas L.) – characteristics, nutritional and pro-health proper-
ties. Acta Sci. Pol. Technol. Aliment., 18(1), 5–12. http://dx.doi.org/10.17306/J.AFS.2019.0628

Kasimir-Klemedtsson, A. ,Klemedtsson, L. ,Berglund, K. ,Martikainen, P. ,Silvola, O. ,Oenema, J. (1997) Greenhouse gas emissions from farmed organic soils: a review.

Lal, R. (2002). Soil carbon dynamics in cropland and rangeland. Environmental Pollution, 116(3), 353–362. https://doi.org/10.1016/S0269-7491(01)00211-1

Laiho, R. (2006) Decomposition in peatlands: Reconciling seemingly contrasting results on the impacts of lowered water levels. Soil Biology & Biochemistry, 38, 2011–2024.

Mcconnaughay, K. D. M., Berntson, G. M., & Bazzaz, F. A. (1993). Limitations to CO2-induced growth enhancement in pot studies. In Oecologia (Vol. 94).

Memmott, J., Craze, P.G., Waser, N.M., Price, M.V. (2007) Global warming and the disruption of plant-pollinator interactions. Ecol. Lett., 10 , pp. 710-717.

Nicoletti, R.; Petriccione, M.; Curci, M.; Scortichini, M. Hazelnut-Associated Bacteria and

Their Implications in Crop Management. Horticulturae 2022, 8, 1195. https://doi.org/10.3390/horticulturae8121195.

Nieuwenhuis, H.S., Schokking, F. (1997) Land subsidence in drained peat areas of the Province of Friesland, The Netherlands Quarterly Journal of Engineering Geology, 30 , pp. 37-48.

Nile, S. H., & Park, S. W. (2014). Edible berries: Bioactive components and their effect on human health. Nutrition, 30(2), 134-144. https://doi.org/10.1016/j.nut.2013.04.007

Øygarden, L., Kværner, J., & Jenssen, P. D. (1997). Soil erosion via preferential flow to drainage systems in clay soils. Geoderma, 76(1-2), 65–86. doi:10.1016/s0016-7061(96)00099-7

Page, S. E., Rieley, J. O., & Banks, C. J. (2021). Global and regional importance of the tropical peatland carbon pool. Global Change Biology, 27(10), 1992–2003. https://doi.org/10.1111/gcb.15529

Patamsytė, Jolanta, Kleizaitė, Violeta, Čėsnienė, Tatjana, Rančelis, Vytautas and Žvingila, Donatas. "The genetic structure of red raspberry (Rubus idaeus L.) populations in Lithuania" Open Life Sciences, vol. 5, no. 4, 2010, pp. 496-506. https://doi.org/10.2478/s11535-010-0034-0

Patt, J.M., Wainwright, S.C., Hamilton, G.C.,Whittinghill, D., Bosley, K., Dietrick, J., Lashomb, J.H. (2003) Assimilation of carbon and nitrogen from pollen and nectar by a predaceous larva and its effects on growth and development. Ecol. Entomol., 28 , pp. 717-728.

Plants for a Future. (n.d.). Edible Uses of Plants. Plants for a Future. Retrieved from https://pfaf.org/user/cmspage.aspx?pageid=18

Remkes, J.W., D'Angremont, K., Donze , M., Feddes, R.A., Vellinga, P. ,Huisman., P. (2007). Water en Bodemdaling in Groot-Mijdrecht.

Removing barriers to peatland climate protection. (2021). Greifswald Mire Centre. https://greifswaldmoor.de/home.html

Sida, T. S., Olsson, M., & Ekelöf, J. (2021). The benefits of shade: A review of shading impact on coffee quality and yields. Journal of Cleaner Production, 291. https://doi.org/10.1016/j.jclepro.2021.125865

ŠEHO M, AYAN S, HUBER G,KAHVECI G 2019 A Review on Turkish Hazel (Corylus colurna L.): A Promising Tree Species for Future Assisted Migration Attempts. South-east Eur for 10 (1):53-63. DOI: https://doi.org/10.15177/seefor.19-04.

Shahzad, U., Ijaz, M., Noor, N., Shahjahan, M., Hassan, Z., Abbas Kahn, A., & Calica, P. (2018). Variations in Growing Media and Plant Spacing for the Improved Production of Strawberry (Fragaria ananassa cv. Chandler).

Strack, M. (2008). Wetland ecology: principles and conservation. Cambridge University Press.

Sulieman, M. M., Ibrahim, I. S., & Elfaki, J. (2015). Land Suitability Characterization for Crop and Fruit Production of Some River Nile Terraces, Khartoum North, Sudan. International Journal of Scientific and Research Publications, 5(10). www.ijsrp.org

Tiemeyer, B., Albiac Borraz, E., Augustin, J., Bechtold, M., Beetz, S., Beyer, C., Drösler, M., Ebli, M., Eickenscheidt, T., Fiedler, S., Förster, C., Freibauer, A., Giebels, M., Glatzel, S., Heinichen, J., Hoffmann, M., Höper, H., Jurasinski, G., Leiber-Sauheitl, K., Peichl-Brak, M., Roßkopf, N., Sommer, M., Zeitz, J. (2016) High emissions of greenhouse gases from grasslands on peat and other organic soils. Global Change Biology, 22, 4134–4149.

Tilman, D., Fargione, J. , Wolff, B. ,D'Antonio, C., Dobson, A. , Howarth, R., Schindler, D., Schlesinger, W.H., Simberloff, D., Swackhamer, D. (2001) Forecasting agriculturally driven global environmental change. Science, 292 , pp. 281-284.

Turetsky, M. R., Kotowska, A., Bubier, J., Dise, N. B., Crill, P., Hornibrook, E. R., ... & Waddington, J. M. (2014). A synthesis of methane emissions from 71 northern, temperate, and subtropical wetlands. Global Change Biology, 20(7), 2183-2197. https://doi.org/10.1111/gcb.12580

United Nations Environment Programme. (2015). Peatlands: Our hidden treasure. https://www.unep.org/resources/report/peatlands-our-hidden-treasure

van den Akker, J.J.H. , Kuikman, P.J., de Vries, F., Hoving, I., Pleijter, M., Hendriks, R.F.A., Wolleswinken, R.J., Simões, R.T.L., Kwakernaak, C. (2008) Emission of CO2 from agricultural peat soils in the Netherlands and ways to limit this emission.

Van den Akker, J.J.H., Kuikman P.J., De Vries, F., Hoving, I., Pleijter, M., Hendriks, R.F.A., Wolleswinkel, R.J, Simões, R.T.L., Kwakernaak, C. (2018) Emission of CO2 from agricultural peat soils in the Netherlands and ways to limit this emission.

Van den Bos, R. M. (2003). Human influence on carbon fluxes in coastal peatlands; process analysis, quantification and prediction.

Van der Linden, H. (1982). History of the reclamation of western fenlands and of the organizations to keep them drained. In: de Bakker, H. and Van den Berg, M. W. (eds.): Proceedings of the symposium on peat lands below sea level. International Institute for Land Reclamation and Improvement, ILRI (Wageningen): 42-73.

Rochefort, L., Quinty, F., Campeau, S., Johnson, K., & Malterer, T. (2003). North American approach to the restoration of Sphagnum dominated peatlands. Wetlands Ecology and Management, 11(1-2), 3-20. https://doi.org/10.1023/A:1022046407436

Van Diggelen, J.M.H., Lamers L.P.M., Loermans J.H.T., Rip W.J., Smolders, A.J.P. (2020). Towards more sustainable hydrological management and land use of drained coastal peatlands - A biogeochemical balancing act.

Weaver, R. E. (1976). The Cornelian Cherries. Arnoldia, 36(2), 50–56. http://www.jstor.org/stable/42954080

Xu, J., Morris, P. J., Liu, J., & Holden, J. (2018). PEATMAP: Refining estimates of global peatland distribution based on a meta-analysis. CATENA, 160, 134–140.

Zhang, Z.D., H.G. Liu, Y.D. Li, G.H. Gong, L. Wu and X.D. Tang (2008). Study on adaptation of blackcurrant to soil ph. Acta Hortic. 772, 361-364.