Food forests on peat soil

An exploration and assessment of the potential of a food forest on peat soil in the Vrouwe Vennepolder in the Netherlands

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Preface

My father's dissertation started with the quote: "Take your time to be happy. Time is not a high way between cradle and grave, but space, to park in the sun" (Bosmans, 1987). Looking back at the past months I find it most applicable to do the same. It has been more challenging to park in the sun than I could ever expected it to be. In fact, the last months were among the most restless periods of time in which I had to force myself to park in the sun.

During the writing of this thesis many unexpected things came onto my journey path. Among them were some of the happiest moments, but unfortunately also some of the saddest moments. A dear friend tragically passed away, because he was not able to see the sun or a free place to park anymore. It was a great privilege that we strived together for our own food forest to show its potential to radically change our perception of agriculture. It formed the reason to write my thesis about the same topic. He was both a mentor and a friend, and it forms a great loss. For that reason I want to dedicate this thesis to him.

I also want to thank all people that supported me during this journey. Dorith with her good examples how not to combine a thesis with an internship; my friends from Plök who gave me the joy to work in an orchard instead of behind my computer; Sarah for all the ice cream and hot chocolate walks; my family who were always there to support me; and Cécile who parked together with me in the sun. Special thanks to my supervisors Maarten Schrama and Laura Scherer. The first field trip with Maarten proved to be an excellent metaphor for the process I underwent in which the crank of my OV-bike broke off and only with the help of Maarten I made it with some delay to the station. During this thesis there were many uncertainties and it did not always go as planned, but with Maarten's and Laura's support I am proud to present the exploratory work in this thesis.

Abstract

Food forests are gaining attention in the Netherlands as a concept that holds the promise of delivering a variety of ecosystem services our society depends upon. However, there are no insights available what a food forest could look like on peat soils nor what its environmental benefits could be. At the same time the Dutch peat area represents 12% of the total agricultural area and is subjected to soil subsidence releasing carbon dioxide, accounting for 2.5% of the national greenhouse gas (GHG) emissions. This thesis designed a food forest for the Dutch peat area and assessed it on three ecosystem services being: food provisioning, climate regulation and wildlife habitat provisioning. The results were put into perspective by comparing them to the currently predominant land-use for organic milk production. The plant species were selected based on selection criteria which took into account the environmental conditions and marketing potential. Yield estimates were made based on documented yields and proxies. GHG emissions and carbon sequestration potentials were determined by both available comparative literature and calculations. For the indications of wildlife habitat provisioning birds were taken as indicator species group and the attractiveness was determined by available literature. The proposed peatland food forest (PFF) consists of 21 different plant species that were estimated to produce a mean dry weight yield of 863 kg/ha/a over the first 20 years with a maximum of 1569 kg/ha/a. Furthermore, the PFF is expected to store between 0.37 and 0.52 Mg CO_2 eq./ha/a compared to the current emissions of 15.8 Mg CO_2 eq./ha/a. Finally, the PFF provides a habitat that is likely to attract more but different bird species than the current landscape, including a greater number of endangered species. The results are in range with existing literature on either food forests or swamp forests and highlight the potential of food forest on peat soil to contribute to sustainable food provisioning, reduction of GHG-emissions, and preservation of wildlife habitats. This study promotes to conduct a field experiment to validate the promising initial results.

Keywords: food forest, ecosystem services, agroforestry, peat soil

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Introduction

In context of the agricultural sustainability transition (LNV, 2019), food forests are gaining attention in the Netherlands as it holds the promise of delivering a variety of ecosystem services (ES) including carbon sequestration and biodiversity enhancement while also producing food (van Dooren, 2018; LNV, 2020; College van Rijksadviseurs, 2020). A food forest can be defined as “an edible, perennial, polyculture system that is designed and managed to mimic multi-storey forest structures and to function like a natural self-sustaining forest” (Jacke & Toensmeier, 2005; Gori et al, 2019). While in the last decades food forests have been shown to work on sandy and clay soils, no such initiative is present on peat soils. However, a substantial part of Dutch agriculture (12%) is conducted on peat soils, predominantly in the form of permanent grassland for milk production (82%) (de Vries, 2004; Van den Born et al, 2016). Soil subsidence is one of the consequences of these intensive agricultural practices, as active draining is essential. This forms a major concern as it increases flood risks and produces 2.5% of the total national GHG emissions (Van den Akker et al 2010). Raising water levels is an effective strategy to reduce this process (Jurasinski et al, 2016). However, it makes common agriculture impossible.

Besides subsidence and GHG emissions, agriculture in general can be seen as of one the main drivers of biodiversity loss which can be expressed in the loss of wild animals of 50% since 1990 onwards (CBS et al, 2021a). Grassland butterflies have decreased with over 40% in numbers since 1992 (CBS et al, 2021b), and farmland birds have been decreased with 70% since 1960 onwards (CBS et al, 2021c). In addition, the Netherlands belong to one of the most intensive meat and dairy producing countries worldwide (Jukema et al, 2020). In line with a sustainable diet, a shift from animal towards vegetable food production is needed to create a sustainable food sector (Willet et al, 2019).

Agroforestry, of which food forests are regarded to be a specific form (Augère-Granier, 2020), is also regarded as a promising practice in this transition (FAO, n.d; European Union, 2020). At the moment however, most effort in rewetting agricultural peatlands has been directed towards paludiculture, which allows for the production of food, fibre and energy in a single storey system (Biancalani & Avagyan, 2014; Geurts & Fritz, 2018). Although previous studies have worked on the concept of a food forest on peat soils (De Graaf, 2019; Permacultuurcentrum Den Haag, n.d), practical examples have not been realized yet. Besides it is poorly known what this multistorey system could look like, there is no insight of the additional ecosystem services the system could yield in comparison to the current agricultural system.

The field of Industrial Ecology researches the interaction between industrial systems and how they can be adapted in a way they are compatible with the functioning of ecosystems (Erkman, 1997). Agricultural systems are an excellent example in which industrial agricultural practices and ecosystems overlap and interdepend. In addition, societal perspectives regarding agriculture are changing. In which the farmer is not only kept responsible for producing sustainable food, but also for the preservation of biodiversity and landscape management (PBL, 2019). The holistic perspective that is required to answer these unknowns fits well to the field of industrial ecology.

The aim of this thesis is to explore and assess the potential of a food forest in the Dutch low peat areas with a focus on the case study of the Vrouwe Vennepolder in the Netherlands, which will be used as a testing area for sustainable agricultural practices (Land van Ons, 2020). The main research question for this thesis therefore is:

What would be the potential of a food forest in the Dutch low peat areas when taking into account food provision, climate regulation and habitat provision for wildlife compared to organic milk production?

The main research question is answered by separating it into the following two sub-questions:

- What would a food forest look like in the peat areas of the Netherlands?
- What would the performance of such a food forest be in comparison to organic milk production when assessing it on food provisioning, climate regulation and wildlife habitat provisioning?

Methods

The appearance of a peatland food forest

For studying the potential of a food forest in the low peat areas of the Netherlands, the Vrouwe Vennepolder (52.191634” N; 4.552483” E) was chosen as study site. The polder with a surface area of 33.2 hectares (ha) mainly consists of peat soil and is owned by the cooperation Land van Ons. Together with Leiden University the site will be used as research area to study several crop cultivations to minimize soil subsidence, sequester carbon and improve biodiversity for the coming ten years (Land van Ons, n.d).

In order to answer the question what peat soil landscape could facilitate a food forest while minimizing its decomposition, literature research was conducted on i) peat decomposition in the Netherlands and ii) potential solutions to minimize this process. In addition, a semi-structured interview discussed the potential landscapes for food forests (B. Rooduijn & P. de Graaf, personal communication, April 19th 2021). Based on these insights, a landscape design was proposed.

To answer the question what a food forest on peat soils would look like, the preconditions of the definition proposed by the Green Deal food forests were used (Wiebes et al, 2016). These include to have a minimal area of 0.5 ha, the presence of at least three vegetation layers, and the presence of high-rising trees. The peatland food forest (PFF) was created using the following approach. First, the suitability of plant species were sourced from the most comprehensive publicly available plant database “*plants for a future”* (pfaf, n.d) and were verified during a semi-structured interview (W. van Eck, personal communication, April 24th 2021). The selection criteria used were soil acidity, moisture tolerance, temperature tolerance in the form of hardiness zone and edibility. The physiological traits in which plant species can thrive are plant specific. Each of the environmental selection criteria relate to a limiting factor the selected plant species has to thrive on. Soil acidity generally limits the uptake of nutrients, moisture limits the availability of oxygen available for root systems, and temperature extremes limit the growing season (Brooker et al, 2014). Edibility was chosen since the food forest has to provide tasty food. The used threshold of these indicators can be found in appendix A. For soil acidity and moisture tolerance the database only allowed for qualitative thresholds. In addition, known potentially invasive species were removed (Hoppenreijs et al, 2019). The list was narrowed down further by meeting at least one of the following functional criteria: promising marketing potential according to MVO NL (2021), ability to bind nitrogen or to form peat. The final list was checked on the completeness of the blossom arch, and nutrient balance. A complete blossom arch will ensure a year-round habitat for pollinators. For the blossom arch, the flowering period was used from plants of a future (n.d) (Appendix D). The provisioning of nutrients are a limiting factor for plant growth in which nitrogen and potassium are often lacking (Brooker et al, 2015). By including nutrient fixating plant species such as Black alder *(Alnus glutinosa)* the nutrient demand of other species can be supplied. The balance of nutrients was calculated for nitrogen and potassium with the estimates presented by Crawford (2010) in which the productivity and surface area of the plant were used to calculate the nutrient demand and deliverance (appendix B). The plant species were arranged spatially on the plot taking into account their light preference and shadow tolerance (Crawford, 2010), the predominant wind direction to prevent wind stress (Gardiner et al 2016; KNMI, n.d), and moisture tolerance (W. van Eck, personal communication, April 24th 2021; Agroforestry Vlaanderen, 2021).

The assessment of a peatland food forest

The sustainability performance of the designed peatland food forest (PFF) was assessed based on three ecosystem services according to the common international standard for ecosystem services (Haines-Young and Potschin, 2018), being food provisioning potential (crops by amount, code 1.1.1.1) and its related market value, climate regulation potential (reduction of GHGs from the atmosphere, code 2.2.6.1), and the habitat provisioning potential for wild animals (by amount and source, code 2.2.2.3). These indicators were chosen because these are commonly regarded as the most functionally important services for agroforestry systems (Mosquera-Losada, 2012). The ecosystem services were compared with the current predominant land-use of the low peat areas in an area based comparison, being permanent grassland for cow milk production. The organic fat and protein corrected milk (FPCM) yield per ha of land was used since it uses no artificial fertilizer, and fewer concentrates than conventional farms which are in contrast to conventional farms organically sourced as well. To include the total area, both the on-farm and off-farm land-use were taken into account. This comparison puts the environmental performance of the PFF in the perspective of the current agricultural situation.

Food provisioning potential

For the assessment of the PFF yield potential and its market value, a myriad of sources were used. These included national harvest and market price data for commonly grown species (Heijerman-Peppelman & Roelofs, 2010; Schreuder & Hendriks-Goossens, 2010), food forest reports for species common for Dutch food forests (Boulestreau & Van Eck, 2016; van Eeden, 2020; Doomen et al, 2019). Data from tall-stemmed fruit trees (apple, pear and plum) was sourced from a report when this type of tree was still widely used in commercial cultivation (Anonymous, 1946). For species of which domestic commercial cultivation is not common, data was often lacking. In these cases, proxies were chosen based on the size and similarity of the plant size for yield and similarity of fruit for market prices. For the yield of bladdernut *(Staphylea colchica)* and Bog myrtle *(Myrica gale)* no direct proxies were available and personal estimations based on the size of the plant and fruit were necessary which were aimed to be conservative. Yield was calculated per species over a period of 20 years in which the PFF will reach maximum productivity. Afterwards the yield was adjusted for the expected losses common for organic production (-20%) (WUR, 2012). Market prices were taken from organic production data where possible or were derived from standard prices with an additional factor of 1.94 which was derived from organic versus regular apples (Heijerman-Peppelman & Roelofs, 2010). Subsidies were taken out of the revenue. In Appendix G the references and assumptions are indicated per species. The comparison with milk production was made for dry matter, revenue, energy, and three nutritional elements including fat, protein, carbohydrates. Fats were further analysed on fatty acids composition. For the nutritional elements, raw milk was used. In addition, the PFF yield was separated into nuts and fruits. Nutritional data was sourced from nutrition tables (RIVM, n.d; Voedingswaardetabel, n.d; tabele-kalorii, n.d) or nutritional values of processed products purely made of one fruit (gourmet-versand, n.d). For bladdernut *(Staphylea colchica)* and Bog myrtle *(Myrica gale)* no nutritional contents were available and were taken out of the comparison. The complete nutritional overview can be found in Appendix I. To compare the potential PFF yield with organic milk production, a Dutch life cycle analysis was used from which the production per hectare (Thomassen et al, 2008) and its corresponding market value (Agrimatie, 2020b, 2021) could be derived. The used variables can be found in Appendix J.

Climate regulation potential

For estimating the climate regulation potential of the PFF, three distinct elements of the system were taken into account. The GHG emissions associated with soil processes, the storage of carbon in biomass and soil by trees and shrubs, and carbon storage by peat formation. For calculating the soil emissions in CO_2 eq. the method of Stichting Nationale Koolstofmarkt (2021) was used. This method uses the measured correlation between CO_2 emissions of peat soils and the mean water level (Fritz et al, 2017).

$$Emissions = 0.45 \cdot MWL \cdot PF + 0.088 + associated\ CH_4/NO_{2\ emissions}$$

Here, the e*missions* are in Mg CO_2 eq./ha/a, the *MWL* refers to the mean water level, *PF* is the fraction of peat above the water level, and the $associated\ CH_4/NO_{2\ emissions}$ are related to the water level and were determined by a look-up table (Jurasinski et al, 2016). This formula was used to calculate the emissions for a number of scenarios in which the presence of a clay cover, mean water level, and presence of ridges were taken as variables. In addition to the calculated emissions, data from literature was used to compare and validate the calculations.

During the process of carbon sequestration, atmospheric carbon in the form of carbon dioxide is stored in biomass and soil organic carbon (Nair, 2012). The calculation of the carbon storage potential by the sequestration of carbon by trees and shrubs in both biomass and soil organic carbon was performed by using the formula:

$$Sequestered\ carbon\ biomass = height\ species \cdot CS_{coeff}$$

For this approach the *sequestered carbon biomass* is converted to $MgCO_2$ eq./ha/a by using the ratio of 44/12 between the molecular weight of carbon dioxide and the atomic weight of carbon (Boosten & Snoep, 2021). It is assumed that the amount of carbon a tree or shrub can sequester is depending on the plant's final height *(height species)* and the carbon sequestration coefficient (CS_{coeff}). Commonly (Schafer et al, 2019; Stichting Nationale Koolstofmarkt, 2021) tree diameter at breast level is used to determine carbon sequestration. Tree diameter at breast level correlates stronger with carbon sequestration than tree height (Afzal & Akhtar, 2013). Although diameter is a better indicator for carbon sequestration than height, it is out of data availability considerations that height was used. The carbon sequestration coefficient was derived from carbon sequestration data from apple trees and was validated for walnut trees of which similar data was available (Norèn et al, 2019). The understory species (< 3 meter high and/or < 1 m^2 surface covered per plant) were taken out of the equation, because they consist of either non-woody biomass such as garden rhubarb *(Rheum x hybridum)* or many small branches the formula does not apply to such as raspberry *(Rubus idaeus)*. In this way, overestimations are tried to be avoided. In addition, literature research was conducted for collecting carbon sequestration data to compare with the calculations. These included both corresponding systems and similar environments as a proxy to the overall PFF system.

For the carbon sequestering potential in the form of peat formation by water soldier (*Stratiotes aloides)*, no successful reintroduction studies were found in similar Dutch environments where the carbon sequestering was measured (Harpenslager et al, 2018). To get an impression of the potential of Water soldier two approaches were used. First a calculation was performed based on Holocene peat accumulation rates using the following formula:

$$\text{Sequestered carbon peat} = d_{acc} \cdot A \cdot \rho_{peat} \cdot Cf$$

Here, the *sequestered carbon peat* is converted to $MgCO_2$ eq./ha/a, d_{acc} is the accumulation rate of the peat layer, A the surface area covered with water soldier, ρ_{peat} the bulk density of peat, and Cf the carbon fraction of peat. The density was validated with measurements from a different study (Borren et al 2004). The second approach used the carbon sequestration rates of Water soldier under controlled environments which were available (Harpenslager, 2015). Finally, the emissions related to the production of milk were sourced from the same lify cycle analysis previously used for the yield comparison (Thomassen et al, 2008).

Habitat provisioning potential

For assessing the potential effects of the PFF on the habitat provisioning for wild animals, indicator species were used as a proxy for the habitat attractiveness of the PFF. The approach intends to gain insights of multiple species by studying only a selection (Cushman, et al, 2010). The indicator species approach is widely used and many different indicator species have been proposed (Lindenmayer

& Likens, 2011). Although criticism on the validity of the approach exist (Cushman et al, 2010), it is out of practical considerations to pick a relatively well-documented (group of) species as an indicator for the overall attractiveness of the system. This thesis took birds as indicator for habitat attractiveness. Birds were used since they are well-studied and documented, and are an indicator of the habitat quality (Gregory et al, 2008). This is expressed by the fact that many bird species are insectivorous during the breeding season and depend therefore on the presence of insects (Cramp & Perrins, 1994). In addition, meadow birds have gained more attention since populations have been steadily decreasing (van Turnhout et al, 2019). Predation pressure has been noticed as one of the factors contributing to this decrease (Teunissen et al, 2005) and is used in policy documents as an argument to minimize high rising woody vegetation as it forms a habitat for prey birds (Winsemius et al, 2020). The assessment focussed on two aspects. The attractiveness of the PFF for specific bird species was studied first. Proxies for both species composition and landscape similar to the PFF were used, being an existing food forest and peat swamp forests respectively. The combination of these two habitats compensates for the difference of the peatland environment compared to the existing food forest system, and the mix of domestic and alien species which is different from natural peat swamp forests. In addition, the potential effect of the PFF habitat on the predation of meadow birds was researched. Both aspects were studied based on available literature, to a great extend initiated by Sovon (Teunissen et al, 2005; van der Wal & Teunissen, 2018, van Kleunen et al, 2017; van Turnhout et al, 2019).

Results

The design of a peatland food forest

Landscape design

The current and potential soil structure in which soil subsidence by peat decomposition is minimized while creating a range of gradients on which a variety of food producing species can potentially thrive are visualized (Figure 1). The current soil structure of the Vrouwe Vennepolder (Figure 1a) consists of a thick clay cover with a mean thickness of 47 cm on top of a peat layer (bodemdata, n.d; Van Duin, 2021). Fourty percent of the Dutch peat soils has a clay cover (Lof et al, 2017; Van den Akker et al, 2010). Additionally, the mean water level in this polder is -60 cm with fluctuations between -40 cm and -80 cm (van de Riet et al, 2018; Hoogheemraadschap van Rijnland, 2020). In the proposed design (Figure 1 b,c) the water level is raised to a mean water level of -20 cm. To improve water infiltration into the peat layer, smaller ditches are created every 25 meters (F. Visbeen, personal communication, March 23rd 2021; Pijlman et al, 2020). Since most edible fruit trees prefer between 30 cm and 70 cm of aerated soil (W. van Eck, personal communication, April 24th 2021; Agroforestry Vlaanderen, 2021), the leftover clay from the ditches is used to construct ridges in between (Figure 1 b,c). This landscape design thus aims to minimize the decomposition of peat while preserving the possibility of food production.

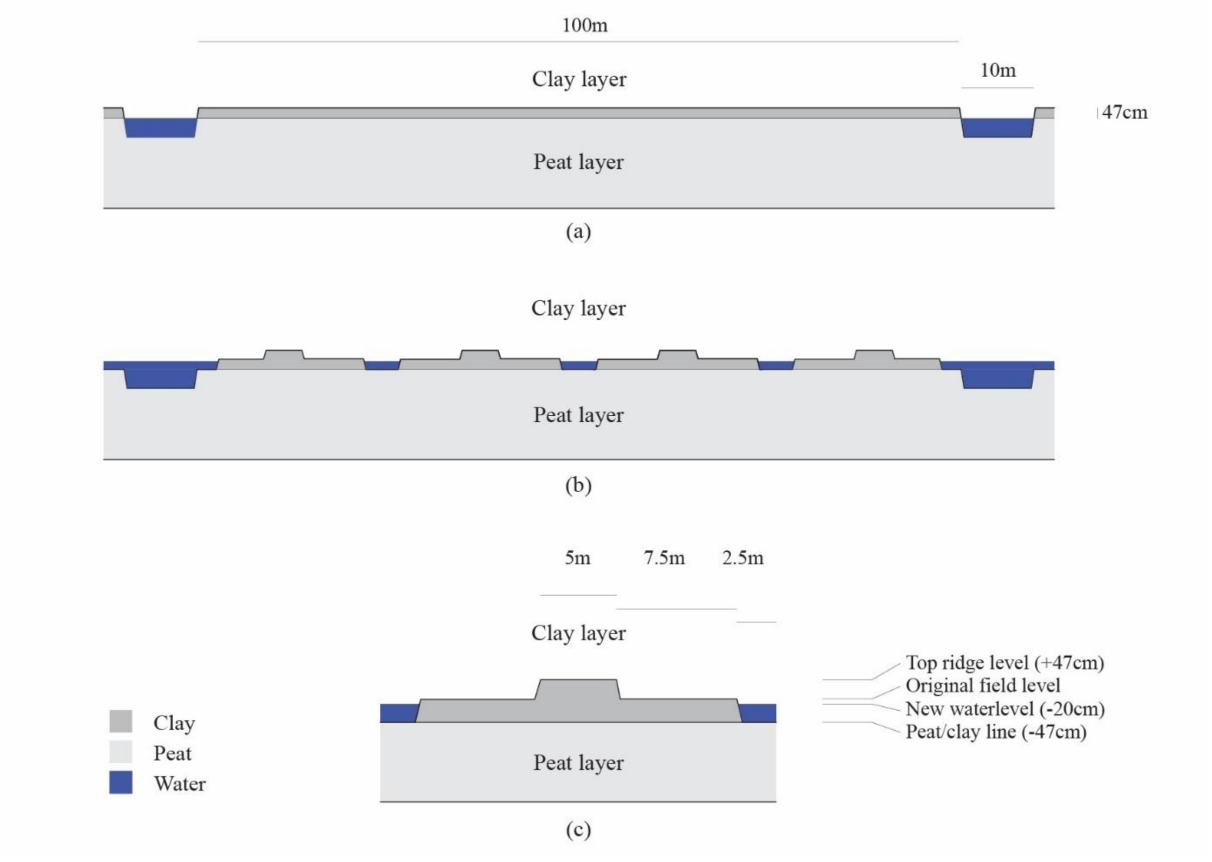


Figure 1: Soil section view of the old (a) and proposed situation (b,c) in which the height is magnified for visibility

Peatland food forest design

The top view (Figure 2a) and cross-section view (Figure 2b) of the proposed peatland food forest (PFF) on one ridge as seen on Figure 1 are displayed (Figure 2). For the calculations, four of these ridges have been used to create a rational hectare as proposed by Boulestreau & van Eck (2016) (Appendix F). The PFF consists of 21 different plant species with a total of 1080 specimens (Water soldier excluded). 17 species are primarily selected for their edible parts. The remaining four species have systemic functions e.g. nutrient fixation (*Alnus glutinosa*, *Elaeagnus x ebbingei*, *Symphytum officinale)*, attracting biodiversity (*Symphytum officinale*, *Stratiotes aloides)*, or peat formation (*Stratiotes aloides)*. All species and their characteristics can be found in Appendix C. The presented PFF has a near complete blossom arch in which January is the only exception (see Appendix D for more details) Regarding the fact that most pollinators hibernate during that month (The pollinators, 2017), this will not have a negative effect. The system will be auto sufficient for nitrogen but not for potassium (see Appendix E for details).

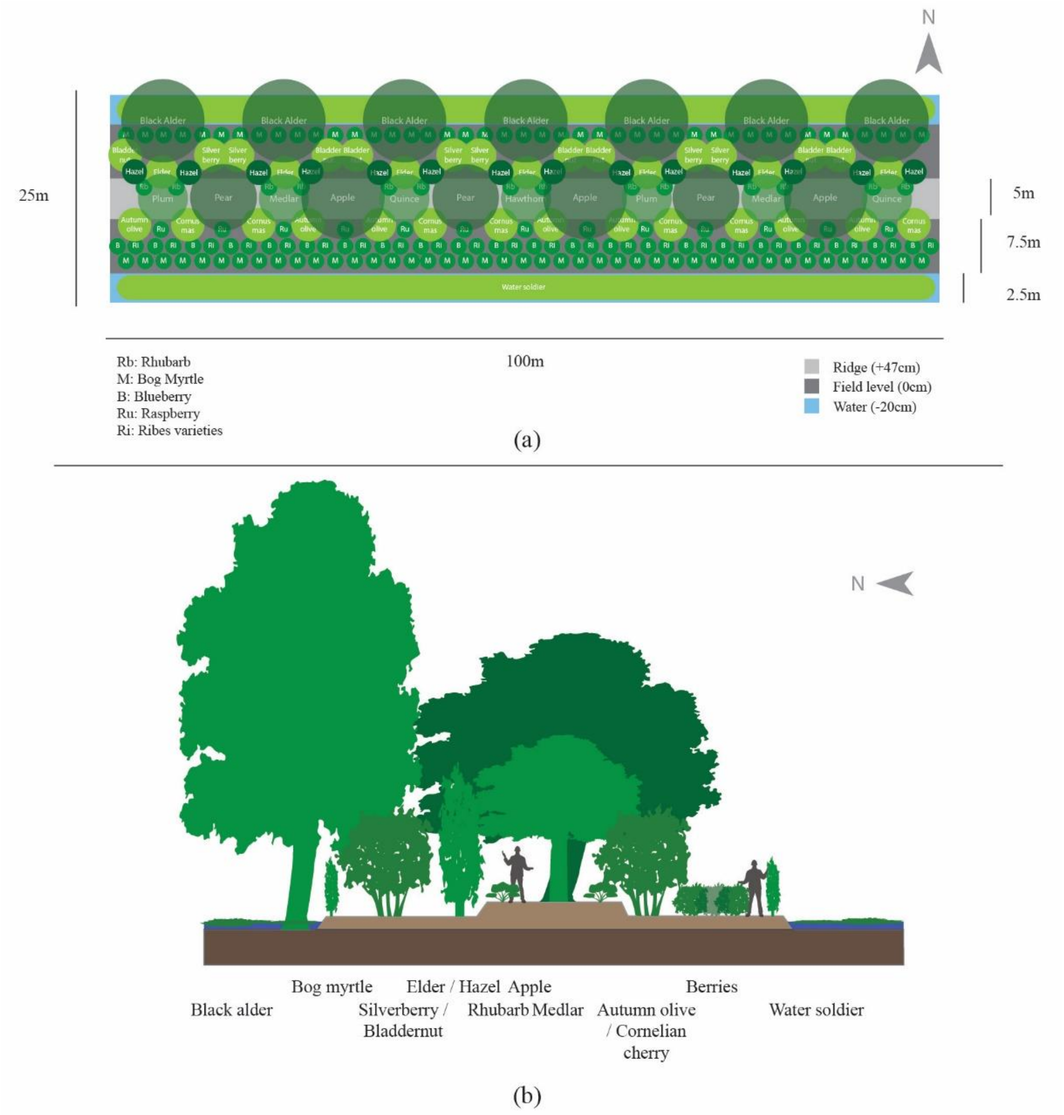


Figure 2: top view (a) and cross-section view (b) of the peatland food forest on scale

The environmental assessment of a peatland food forest

Food provisioning potential

The development of the potential yield of the previously described PFF in edible dry weight for the first 20 years of its development is projected (Figure 3). The annual yield increases to 1569 kg/ha/a in year 15 and stays relatively constant afterwards. The mean annual dry weight yield of the complete time period is 863 kg/ha/a. Overall, fruits contribute to 83% of the total yield. The organic milk production per ha is 789 kg/ha/a dry weight. The PFF yield in dry weight overtakes milk production in year ten.

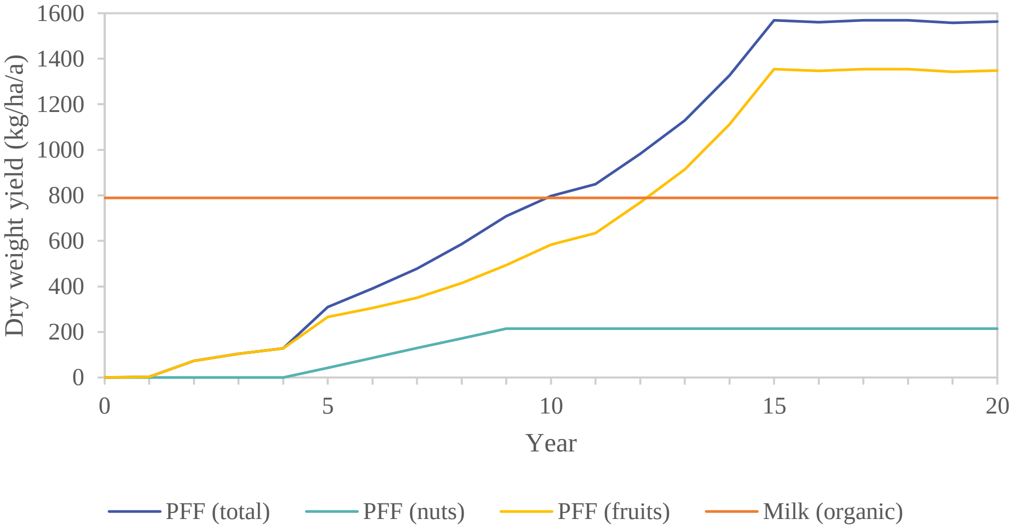


Figure 3: Yield potential peatland food forest (PFF) in dry weight compared to organic milk production for the first 20 years.

The yearly nutritional and energy content of the PFF compared to organic milk per ha is derived from the yield estimations (Figure 4). The PFF provides 34% less fat (Figure 4a), 55% less protein (Figure 4b), 240% more carbohydrates (Figure 4c) and 47% more energy (Figure 4d) in year 20.

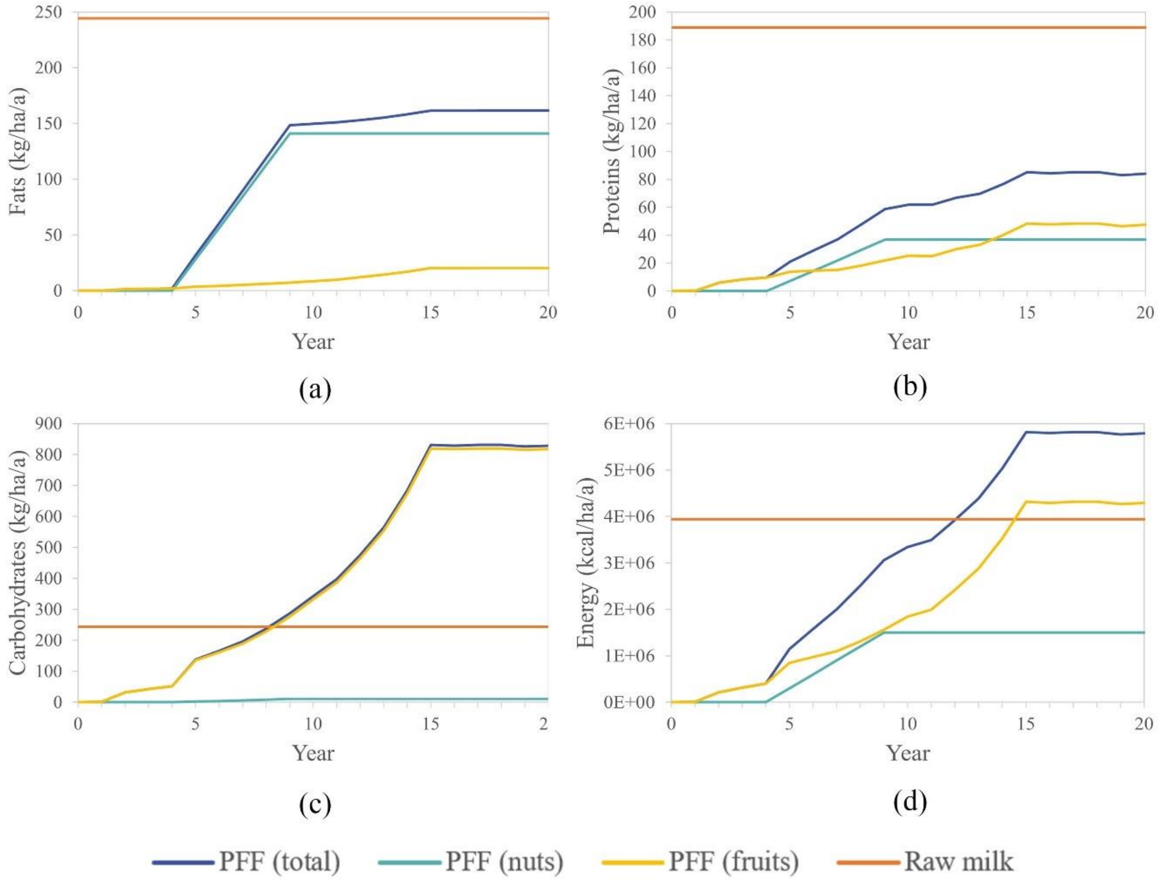


Figure 4: Nutritional and energy content of the PFF compared to raw milk from organic production for the following categories: fats (a), proteins (b), carbohydrates (c), and energy (d).

In addition to the quantities of fats the PFF provides, the composition of fatty acids is analysed for hazelnuts (representing 87% of the PFF fats) in comparison with raw milk (Figure 5). The PFF provides 90% and 230% more monounsaturated and polyunsaturated fatty acids respectively and 93% less saturated fatty acids compared to raw milk.

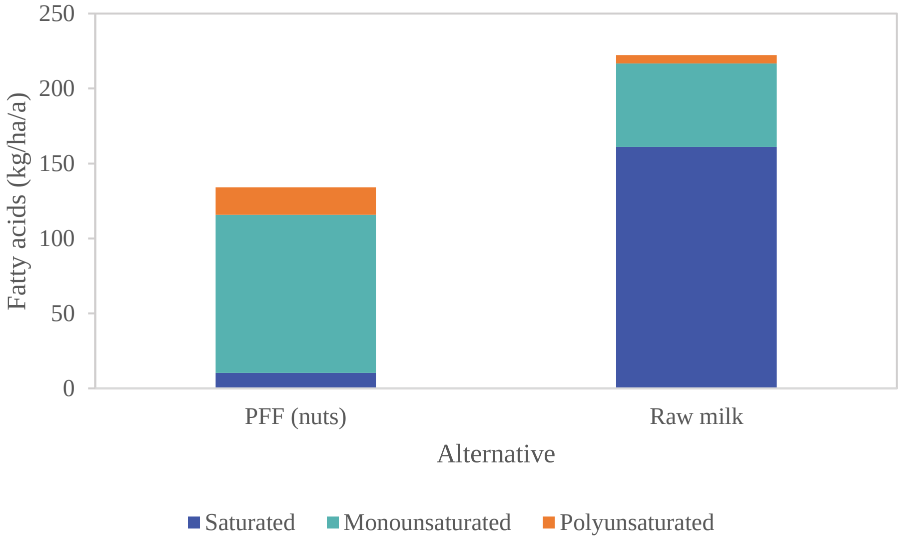


Figure 5: Fatty acids composition of nuts from the PFF and raw milk

The revenue potential from the PFF in comparison with organic milk production has been calculated based on marked prices (Figure 6). It rises up to 25.608 euros/ha/a in year 15 and stays relatively constant afterwards. The mean revenue of the PFF is 16.074 euros/ha/a for the complete time period. What can be noticed is that the mean revenue of the PFF is five times higher than the revenue from milk production and surpasses it from the second year onwards.

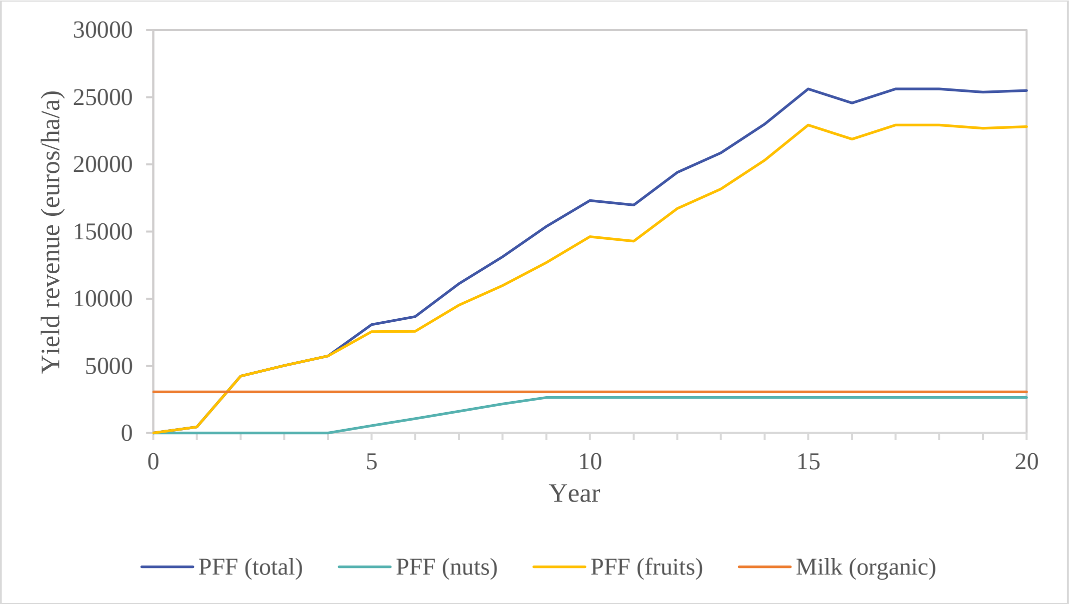


Figure 6: Yield revenue potential PFF compared to organic milk production for the first 20 years

Climate regulation potential

GHG emissions associated with soil processes

The annual GHG emissions from several sources and for different scenarios are determined (Figure 7). The national average of 19 Mg CO_2 eq./ha/a is based on the average Dutch soil subsidence (Van den Akker, 2008). The emissions of the modern peat (23 Mg CO_2 eq./ha/a) and historic peat (2.6 Mg CO_2 eq./ha/a) are based on the national inventory reports (Van den Born et al, 2002; Klein Goldewijk et al, 2005). The business as usual (BAU) Vrouwe Vennepolder (VVP), raised VVP, PFF VVP, BAU not clay, Raised no clay and PFF no clay scenario are calculated scenarios with GHG emissions of 7.5, 2.0, 4.1, 28.9, 11.0 and 15.8 Mg CO_2 eq./ha/a respectively. The BAU no clay and raised no clay scenarios are used as reference calculations in which the national average and modern peat can be compared with the BAU no clay scenario, and the historic peat with the raised no clay scenario. From the calculated scenarios, the PFF VVP emits 3.5 Mg CO_2 eq./ha/a (46%) less GHG emissions than the current situation, taking into account the different heights of ridges in relation to the raised water level. The PFF VVP scenario emits 2.1 Mg CO_2 eq./ha/a (105%) more than the scenario in which only the water level is raised and no ridges are constructed. The calculations can be found in appendix H.

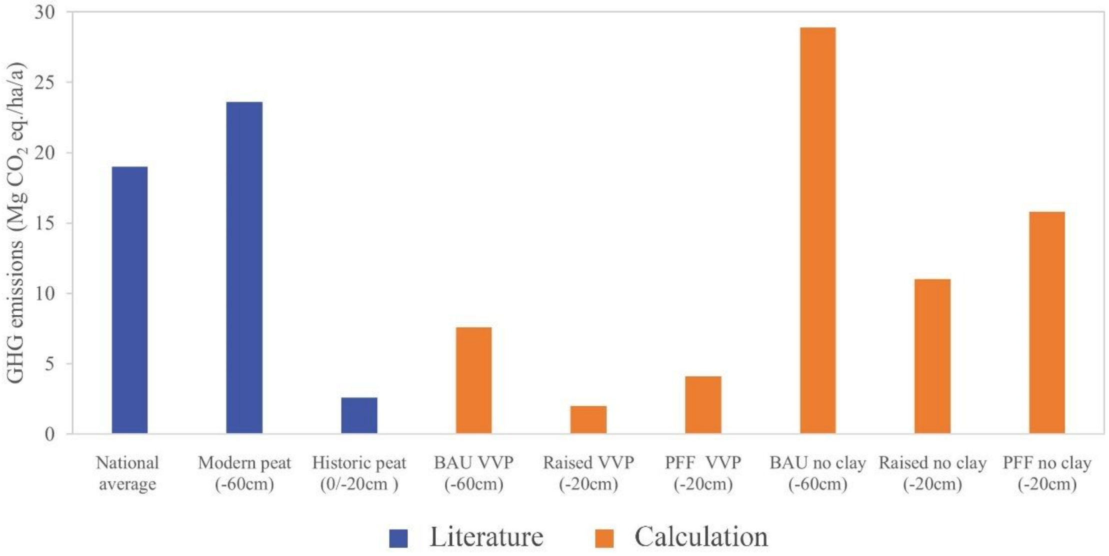


Figure 7: GHG emissions (Mg CO_2 eq./ha/a) associated by soil processes of peat soils from different sources. The blue scenarios only take CO_2 emissions from peat degradation into account. The orange calculated scenarios include both CO_2, and NO_2 and CH_4 emissions.

Carbon storage potential of the trees and shrubs of the PFF

The atmospheric carbon dioxide uptake potential by carbon storage in biomass from several forest types and agroforestry systems is presented (Figure 8). The forest average and deciduous forest (CBS) with the potential of storing 4.6 and 6.6 Mg CO_2 eq./ha/a are based on the natural capital accounting (Statistics Netherlands & WUR, 2021; De Jongh et al, 2021). One of oldest temperate food forests in the UK sequestered 6.9 Mg CO_2 eq./ha/a (Lehmann et al, 2019). The swamp forest potential of 7.3 CO_2 eq./ha/a (Van den Born et al, 2002) presents a scenario similar to the PFF in terms of water and soil conditions. The agroforestry scenarios from France and Canada are measured case studies of alley cropping systems in which 3.3 and 8.3 Mg CO_2 eq./ha/a was sequestered respectively (Cardinael et al, 2007; Alam et al, 2016). Norèn et al (2019) regards the mean carbon sequestration potential of Dutch agroforestry systems to be 4.7 Mg CO_2 eq./ha/a. The calculated sequestered carbon of the PFF is equal to 4.3 Mg CO_2 eq./ha/a. In contrast, organic milk production releases 8.3 Mg CO_2 eq./ha/a which are mostly related to enteric fermentation (Thomassen et al, 2008).

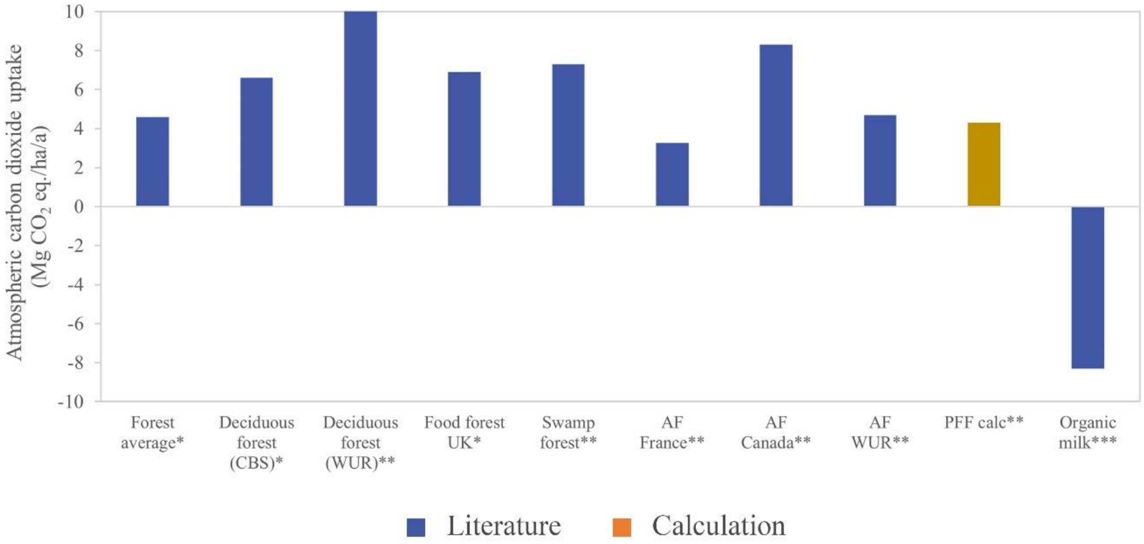


*Figure 8: Carbon sequestering potential (Mg CO_2 eq./ha/a) for several scenarios. * only living biomass (above and below) was taken into account. ** Both biomass and soil organic carbon. *** Life cycle emissions associated with organic milk production.*

Carbon storage potential of Water soldier

In addition to carbon storage in the woody biomass of trees and shrubs, the PFF stores carbon by the formation of peat by Water soldier *(Stratiotes aloides)*. The amount of carbon that can potentially be stored by the formation of peat depends highly on its accumulation rate. A wide range of accumulation rates during the Holocene have been determined by ^{14}C dating, ranging between 0.01 and 3.1 mm/a (Harpenslager, 2015). When translating this range to the PFF the carbon storage potential by peat formation would vary between 0.064 and 2.0 Mg CO_2 eq./ha/a. During controlled experiments, the carbon storage for Water soldier varied between 84 and 161 g CO_2 eq./m^2/a. (Harpenslager, 2015). For the PFF this would result in a rate between 0.17 and 0.32 Mg CO_2 eq./ha/a. The smaller range based on Water soldier measurements fits within the wider range of peat accumulation rates from the Holocene. For that reason, the Water soldier range will be taken as plausible peat accumulation rate for the PFF.

Total climate regulation potential

Taking both the soil processes, carbon sequestration potential by the woody vegetation and Water soldier into account, the PFF will capture between 0.37 and 0.52 Mg CO_2 eq./ha/a, compared to the current emissions related to organic milk production of 15.8 Mg CO_2 eq./ha/a (Figure 9).

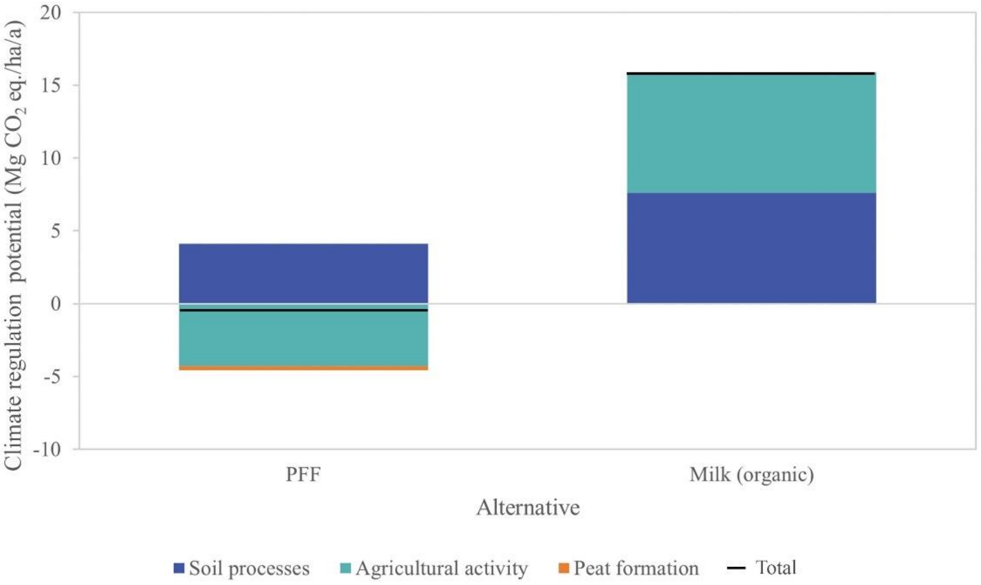


Figure 9 Total climate regulation potential (Mg CO_2 eq./ha/a) for the PFF and organic milk production.

Habitat provisioning potential

The provision of habitats for wildlife focusses on the presence of ecological conditions that are required for specific species, which is linked to biodiversity (Haines-Young & Potschin, 2018). In general biodiversity has proven to increase when implementing a form of agroforestry, ranging from invertebrates to birds and mammals (Burgess, 1999; Torralba et al, 2016; Varah et al, 2013). Based on observations linked to regional landscape conditions, Kwak et al (1988) were able to connect the relative presence of bird species to a particular landscape in the Netherlands. From their different landscape categories, the low peat swamp district can be regarded most similar to the PFF. It consists of a diverse landscape with high water levels including both low and high rising woody vegetation and open water. The current situation can be gathered under the peat polder district.

Although the low peat swamp district is much smaller (13% of the surface of the peat polder district), more than twice as many bird species (42 versus 19) occur relatively often. These include 15 of the 27 typical farmland birds compared of which 11 bird species are present in the peat polder district. Furthermore, 11 more threatened species from the red list (van Kleunen et al, 2017) are present in the low peat swamp district than the peat polder district. An overview of the occurring threatened species per district can be found in detail in Appendix L. Because of the diverse landscape, the low peat swamp district forms a habitat for both swamp and forest bird species (Clerkx et al, 1994). The composition of bird species is found to be related to the succession phase of the swamp forest. The succession progress induces a change from swamp to forest birds species (Woets, 1990).

Arguably, food forests differ from natural forests in terms of species and management. A direct comparison between natural swamp forests and the PFF is not valid. However, efforts have been made to compare the occurrence of bird species of food forests to adjacent natural forests (Breidenbach et al, 2017). They found a very similar number of different bird species (22 species in the food forest versus 23 in the natural forest), although similarity in composition of species was only 36.4%. In this comparison the food forest was in an early development stage whereas the forest had reached its climax stage. In line with the findings of succession of swamp forests the difference in succession can be one of the explanations of the difference in bird species composition.

Predation is a natural regulating process in which eggs and chickens of meadow birds are eaten by prey animals (van der Wal & Teunissen, 2018). However, during the recent decades, predation of meadow birds have increased to up to 70% for Black-tailed godwit *(Limosa limosa)* and Northern lapwing offspring *(Vanellus vanellus)* (Teunissen et al, 2005; Schekkerman et al, 2009). However, it seems that this is especially the case for landscapes that have been intensified (Kentie et al, 2015). Nest survival rates in extensively managed grasslands remained similar over the last 40 years. The densification of landscapes as a result of urbanization also played a role in predation as it resulted in the construction of roads frequently accompanied by rows of trees (Lesbarrères & Fahrig, 2012). It caused the habitat of predators to increase and decreased the preferred open landscapes of meadow birds as they tend to avoid the presence of high rising vegetation when nesting (Besnard et al, 2016). However, high rising vegetation not necessarily causes a higher predation pressure. The presence of predators is area specific (Oosterveld, 2011), and complex landscapes also provide room for shelter (Whittingham & Devereux, 2008).

Discussion

The aim of this thesis was to explore and assess the potential of a food forest on peat soils in the Netherlands as an alternative to the currently predominant cow milk production. The key results are a landscape and food forest design which together have been assessed on food provisioning, climate regulation and habitat provisioning for wild life. This chapter is discussing the limitations of this project first. Next, the results are interpreted and put into perspective. Additionally, the societal implications of the PFF are discussed. Finally, recommendations for further research based on this thesis are provided.

Limitations of the current study

The shortcomings and their potential impacts on the results that are presented here cover the availability and quality of the used data, the limitations of the PFF design and the methods for its assessment including the carbon sequestration calculations and the comparison with organic milk production.

The data availability of this study was limited by its explorative character with no directly related example studies. The lack of direct representable data means that the results heavily depend on the use of both assumptions and proxies.

The design of the PFF only took into account the voluminous species, meaning that smaller herbs such as mint *(Mentha piperita)* could be added. This will probably not have a major impact on the dry weight yield, but can increase the revenue since fresh herbs have a high market price (Ah, n.d). Based on this, the revenue of the PFF is likely to be underestimated.

The methods to assess the PFF had to be feasible regarding the available data. For yield prognoses data was readily available for most species. For Black currant and Rhubarb yield estimates, data deviated up to a factor 10 from the available sources. In this case the main source for Dutch fruit production (KWIN) were an outlier and seemed to be erroneous. In these two cases a conservative value from a different source was used. For Bladdernut and Bog Myrtle no harvest data was available. For these species a conservative personal estimate was made, but were taken out the equation for nutritional content. Since they represent only a small fraction of the total yield by mass (1.7%), the results were not influenced. The revenue was substantially influenced by Bog Myrtle (19%) since it has the highest market value of all species as a herb, mainly for brewing beer (Behre, 1999). The impact of the landscape characteristics on the growth could not be included since no substantiated assumptions from literature were available. Because of the higher ground water levels, yield estimates presented here will probably be an overestimate. For grass a reduction of 11.6% could be derived for higher water levels (de Vos et al, 2004). In the financial translation of the yield, both the investment costs and running costs are not considered. The investment costs for planting and earthmoving of an average food forest are estimated to be 12.500 euros per hectare (Buiter & de Waard, 2020). For the running costs, representatives of the food forest sector itself claim that labour costs for maintaining a food forest are lower than conventional agricultural activities (Buiter & de Waard, 2017). On the other hand, agroforestry representatives point out that the current lack of mechanisation options makes harvesting and maintenance labour intensive and therefore more costly (Luske et al, 2020). Therefore, no overall conclusions on the profitability of the PFF can be drawn.

To estimate the climate reduction potential by biomass a simplified model was used since the model from Stichting Nationale Koolstofmarkt could not be used because the necessary data was lacking. However, the results are in line with field experiments from other studies, indicating that although the model is simplified, the results seem plausible. For the reference literature different elements were taken into account. Most of them took both biomass and soil organic matter into account, whereas three only did biomass. These represent a underestimation of the total potential.

The performance of the PFF was compared to Dutch organic milk production. I can be argued that the products of the PFF (fruits and nuts) are not a direct substitute for milk. However, this thesis takes the perspective of substituting the agricultural activity of producing milk by running a PFF. The comparison is looking at the impacts of that substitution. For the comparison the single Dutch LCA study of organic milk production that was available, included only organic farms on clay and sandy soils. Since the milk production on peat is generally lower (Agrimatie, 2020a), the amount of milk per ha used in the comparison is likely to be an overestimation. Furthermore the area-based assessment only took into account the production stage of the PFF while for milk the life cycle was used. Impacts related to other stages of the PFF such as the construction of the ridges itself were therefore not considered. Therefore the impacts of the PFF are underestimated.

Despite these limitations, this study provides insight what a PFF could look like in the context of the low peat areas with clay cover in the Netherlands and in order of magnitude what the PFF can provide based on three ecosystem services.

Discussion of the results

This part discusses the results in the same order as the results were presented. First, the formation of ridges is discussed. Next, the feasibility of the PFF is debated with a focus on the Water soldier and the field experiment conducted parallel to this thesis. Next, the results of the environmental assessment are interpreted.

From flat and open to curved and afforested

Paul de Graaf and Bastiaan Rooduijn (personal communication, April 19th 2021) were critical about the construction of ridges on peat soils (appendix M). It was argued that the ridges would decompose resulting in increased GHG emissions. The calculations presented in this thesis agree with this notion: indeed higher emissions are predicted for the scenarios in which ridges are constructed compared to only raising the water level. Almost 5 Mg CO_2 eq./ha/a when a clay cover is absent, and 2.1 Mg CO_2 eq./ha/a when a clay cover is present such as at the Vrouwe Vennepolder. Although the emissions increase slightly in the case of a clay cover, it also enables a food producing system such as a food forest that has the potential to capture up to 4.6 Mg CO_2 eq./ha/a. Therefore the ridges can be seen as a trade-off, in which the combination with a food forest captures more GHGs than it emits. In addition, clearing topsoil for the ridges might have a positive impact on the starting conditions for growing peat as it will reduce the mobilization of nutrients and limits GHG emissions in comparison to rewetting agricultural pastures completely (Harpenslager, 2015). The idea of using the leftover topsoil to raise a neighbouring pasture was already mentioned by the same author.

The PFF design is a first exploration of how a food forest under the specific circumstances of the Vrouwe Vennepolder could look like. It proposes a variety of species which produce both familiar and yet unfamiliar fruits. Yet it is a selection and many other species can potentially grow in under these circumstances. To my knowledge, integrating peat forming species in a food forest design has not been proposed before. Previous projects either focussed either on reintroducing peat forming species (Harpenslager et al, 2018; Geurts & Fritz, 2018) or on the design of a food forests (De Graaf, 2019; Permacultuurcentrum Den Haag, n.d). Previous efforts have showed that the eutrophic conditions present at (former) agricultural pastures such as the Vrouwe Vennepolder make the reintroduction of peat mosses *(Sphagnum spp.)* difficult (Berendse et al, 2001). Other proposed peat forming species in paludiculture such as Cattail *(Typha spp.)* and Common reed *(Phragmites australis)* form aerenchyma which facilitate the exchange of gasses including direct methane emissions to the atmosphere (Jurasinski et al, 2016). Water soldier *(Stratiotes aloides)* has proven to be able to thrive under high nitrogen loads typical for agricultural pastures, although dense population are required for its successful reintroduction (Harpenslager et al, 2016). Dense populations are therefore recommended to introduce in the PFF. Water soldier also has the capacity to actively alter its habitat to facilitate growth by detoxifying the water from ammonium, reducing water oxygen concentrations and increasing carbon dioxide concentrations resulting in a lower pH. These capabilities facilitate other high productive peat forming species such as peat mosses *(Sphagnum spp.)* in a later stage (Harpenslager et al, 2015). The water soldier in the PFF design thus can be regarded as a first step in the succession of peat formation.

During the writing of this thesis a field experiment was conducted simultaneously (Appendix K). The aim of experiment was to research the suitability of a selection of the species proposed in the design of the PFF at the Vrouwe Vennepolder. The species were selected in such a way that a variety of the plant families of the PFF were present. They included Common hazel *(Corylus avellana)*, Cornelian cherry *(Cornus mas)*, Raspberry *(Rubus idaeus)*, Black currant *(Ribes nigrum)*, and Rhubarb *(Rheum ×*

hybridum). In addition, small ridges were constructed in order to simulate the landscape conditions proposed by this thesis. The statistical analysis of the results was not finished at the end of this study (July 2021), so no conclusions were drawn yet. The results however, show that all species could survive and showed a positive grow curve. The raspberry even produced fruits. However, the test period was only 5 months and the number of specimens per species only ten. Data for a longer time span with more specimens is needed to get insight in the growth patterns at the Vrouwe Vennepolder.

From animal to vegetable food production

Compared to milk production, the PFF offers a promising alternative in terms of yield and revenue. Based on the yield estimations and the nutritional content of all individual products, the overall nutritional composition of the PFF is different from milk production. The PFF produces less fat and proteins, and more carbohydrates and energy. The nutritional composition of the PFF depends on the selected species and the number per species planted. The PFF of this thesis is a first exploration which is therefore not optimized to provide a specific nutritional composition. A nutritional optimization, while ensuring the preservation of other functions such as providing sufficient nutrients, is an interesting topic for further development.

The fats of the PFF, mainly delivered by hazelnuts (89%), consists mainly of mono- and polyunsaturated fatty acids which include the essential omega 3 and 6 fatty acids. These are also present in low quantities in fruits such as apples and pears (RIVM, n.d). Raw milk on the other hand mostly consists of saturated fatty acids. Evidence supports that a shift from saturated to (poly)unsaturated fats reduces cardiovascular diseases (Willet et al, 2019). Therefore, the shift from milk production towards vegetable food production in the form of fruits and nuts provided by the PFF is in line with a healthy diet (Willet et al, 2019).

To verify the yield estimations of the PFF they are compared to those of Skrøder & Henriksen (2019) and van Eeden (2020) and Boulestreau & van Eck (2020) (Figure 10). The PFF is relatively similar to Skrøder & Henriksen, but differs with van Eeden which presents the highest nutritional value except for carbohydrates. The differences can be partly explained by the absence of larger nut trees such as walnut and chestnuts in the PFF. Additionally, yield estimates of the PFF for high-stemmed fruit trees were made with data from high-stemmed trees instead of deriving them from low-stemmed trees as was the case in previous studies (van Eeden, 2020; Doomen et al, 2019). Taking into account that the food forests in this comparison are different in terms of species composition, landscape design and yield assumptions, their nutritional compositions are relatively similar in pattern and orders of magnitude. It indicates that the estimates of the PFF are likely to be plausible. However, major uncertainty on how the proposed species will behave remains to exist.

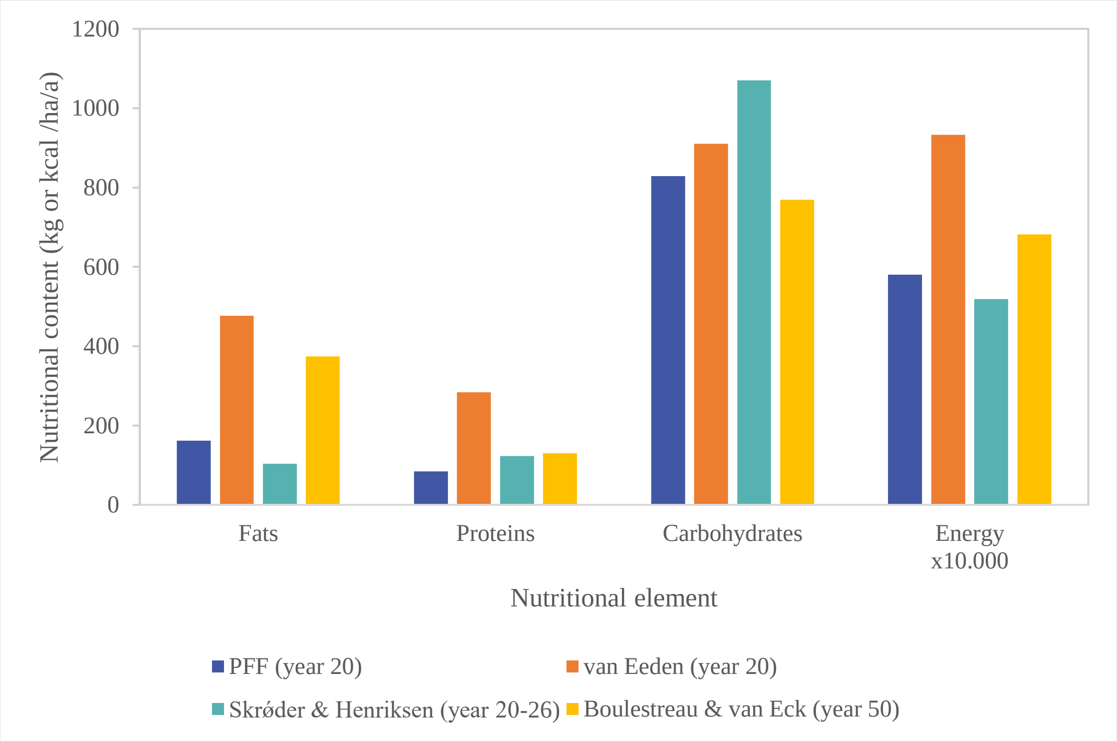


Figure 10: Comparison yield estimations for fat, protein carbohydrates and energy of different food forests.

From carbon emitter to net carbon sink

The differences in GHG emissions from decomposing peat soils are substantial and portrait the diversity of the area and the importance of understanding that diversity. The calculated emissions of the BAU no clay scenario are higher than both the National average and Modern peat scenario, which can be partly explained by the fact that the BAU no clay scenario also includes potent GHG emissions in the form of CH_4 and NO_2. In addition, the average scenario includes a mix of peat soils with and without clay cover reducing the average emissions. The reduction impact of a clay cover on the GHG emissions in literature is usually smaller than in the BAU VVP scenario (Van den Akker et al, 2010). However, the relative thick clay cover present at the VVP might explain the substantial reduction. Although the emissions from BAU VVP are not as high as without clay cover, raising the water level still results in a further decrease, indicating that even with clay cover, rising water levels is an effective method to reduce GHG emissions. As previously indicated, the construction of ridges is a trade-off. For this reason, constructing ridges on peat soils without clay cover is not recommendable.

Calculating the carbon sequestration potential of the PFF has been proven challenging without data on tree diameter at breast hight. The calculated carbon sequestration rate of 4.3 Mg CO_2 eq./ha/a fits within the range presented in literature (3.2 and 10 Mg CO_2 eq./ha/a). The study conducted by Wendel (2021) researched the carbon sequestration of a Dutch food forest on clay soils planted in a chronosequence which makes it possible to measure a number of time frames at once. The sequestration rates of Wendel’s study are high compared to the results of this thesis. During the fifth year sequestration rates varied between 6.6 and 15.8 Mg CO_2 eq./ha/a for above and belowground biomass. In this study the hedges around the plots contributed substantially to the overall result (25%). The explanation for this might be found in the tree density of the hedges. The majority of the trees studied (80%) were found in hedges. Stichting Voedselbosbouw Nederland even claims a higher potential of 25.6 Mg CO_2 eq./ha/a (Buiter & de Waard, 2017). The PFF design does not have a hedge all around and the herbaceous layer was not taken into account. Two explanations why the potential carbon sequestration rate of this thesis is lower than the measurements of Wende. The sequestration rates of this thesis are very similar to those of the same food forest without the hedges and herbaceous layer as measured by the national monitoring programme food forests (4.4 Mg CO_2 eq./ha/a) (Wendel, 2021). Although the actual sequestering rate is very context specific as is portrayed by the variance in measurement results, it also indicates that the estimates of this study are plausible. This means that the proposed PFF is likely to be a net carbon sink instead of a source of GHG emissions which it currently is.

From swamp birds to forest birds

It is likely to assume that the overall biodiversity will benefit from the creation of a PFF. Similar landscapes are attracting more bird species than the predominant peat polder landscape, and agroforestry systems in general increase the biodiversity compared to monoculture cropping (Burgess, 1999; Torralba et al, 2016; Varah et al, 2013). However it is not feasible to predict which exact bird species are attracted or repelled by the PFF. In that regard, the discussion whether a food forest should be avoided in the open landscape to protect the meadow bird species is difficult. As for some meadow bird species the majority of the European population is using this area to breed (Winsemius et al, 2020). However, the Dutch government has the formal obligation to ensure the conservation of all characteristic species and habitats including some of the prey birds found in similar landscapes to the PFF.

To regard predation as the main problem averts to ask critical questions about our agricultural practices. While predation is a natural process, monocropping and pesticide use is not. As Kentie et al (2015) stated, predation is especially a problem in areas where habitat quality is low. The implementation of a PFF will reduce the openness of the landscape. But when located near existing buildings or bushes, the additional impact will likely to be small, as these areas are already avoided by meadow birds. The prey birds that are attracted to the PFF include also red list species such as the Common kestrel (*Falco tinnunculus)* and the Eurasian hobby (*Falco Subbuteo)* (van Kleunen et al, 2017). A PFF is improving the habitat for a great number of bird species. The aim of biodiversity strategies thus should be focussed on creating the right habitat conditions for both groups of birds to thrive. Since, the projected area for food forests in the Netherlands for the coming decade is marginal compared to the total agricultural area, this is within reach.

Societal implications

The Dutch government has acknowledged the importance of an agricultural sector which minimizes the effects on its environment (LNV, 2019). The ambition for agroforestry formulated in *"de Bossenstrategie"* aims at the realization of 25.000 ha of agroforestry together with 1.000 ha of food forests by 2030 (LNV, 2020a). The complete strategy aims at a reduction of 0.4 to 0.8 Mton CO_2 eq. for which a budget of 51 million euros is available. In addition, in *"het Klimaatakkoord"* it is agreed to reduce the emissions of the peat meadow area with 1 Mton CO_2 eq. by 2030 within a budget of 276 million euros (Ministerie van Economische Zaken en Klimaat, 2019). The PFF could play a role in both of these ambitions. A thousand ha PFF represents only 0.5% of the low peat areas in the Northern and Western part of the Netherlands. When a reduction of 3.5 Mg CO_2 eq/ha/a. is realized on these 1000 ha for the coming decade it accounts for 3.5% of the reduction aim for meadow areas. On top of this, the carbon sequestered by the PFF will account for up to 11.3% of the aim of *"de Bossenstrategie".* It shows that that agroforestry systems have the potential to significantly contribute to national climate policies, even on a relative small surface area. This potential was already stated by Montagnini and Nair (2004) and it might not be remarkable that the IPCC regards agroforestry to have the highest GHG reduction potential of all agricultural land-uses (IPCC, 2000). Contributions to other policies such as the Birds and Habitats directive in which the Dutch government is obliged to ensure a positive conservation status for characteristic species and habitats (Pouwel & Henkens, 2020), are unfeasible to quantify beforehand. However, it is likely that the PFF's contribution is positive for forest birds and negative for peat meadow birds. The preservation of both types of bird species demand different landscapes that can be both realized within the Dutch peat area. The area of peat swamp landscape the PFF is related to, is small compared to the total peat area. Therefore, the overall impact of a PFF on the habitat attractiveness is likely to be positive and contributes to the preservation of the characteristic peat swamp forest habitat.

Furthermore, the Netherlands depend heavily on the imports of protein rich agricultural products (LNV, 2020). The majority in the form of cattle feed but also products for consumption such as nuts. Since the Dutch nut sector with only 100 ha is small, the majority of hazelnuts is imported, mainly from Turkey (Baltissen & Oosterbaan, 2017). To become less dependent of imports a national protein strategy is being developed. The aim of this strategy is not only to produce protein rich crops domestically, but also to shift from animal to vegetable protein consumption (LNV, 2020b). Extending the production of hazelnuts by cultivating them in a PFF contributes to this aim (van Reuler et al, 2020).

As stated in the introduction, a farmer is becoming more than only a producer of food. It is becoming a profession of producing ecosystem services our society is demanding. As we are used to reward the farmer for his food, valuation schemes for other ecosystem services are debated in regard to the new European common agricultural policy at the moment (Erisman & Verhoeven, 2020; Lampkin et al, 2020). Regarding the national budgets for GHG emission reduction and the potential of a PFF, the value of a single ha PFF would be 9.660 and 5.763 euros for GHG emission reductions in peat areas and the *"Bossenstrategie"* respectively. Budget that is sufficient to construct a food forest (Buiter & de Waard, 2020) For farmers a (partial) transition to a PFF would diversify their agricultural activities. Making them less dependent on the production of only milk.

Further research

The results of this thesis indicate that the PFF is a promising concept. Further research however is necessary to develop it. This could be done by including other plant species and possibly fish. Exploring the introduction of native fresh water fish such as the in the Netherlands endangered Burbot *(Lota lota)* and Weatherfish *(Misgurnus fossilis)* to the ecosystem would be in line with the situation before the industrialisation of the agricultural sector (Wereld Natuur Fonds, 2020). Also the business model and investment costs could be modelled to get insight in the profitability of the PFF in which the valuation of ecosystem services should be included. The approach of comparing the PFF with other agricultural alternatives would improve when making a functional comparison in which the different stages of the PFF are considered by doing an LCA with system expansion. At the same time field experiments are necessary to validate the assumptions and estimates of this thesis. A field experiment would also allow for a complete analysis of the ecosystem services such as erosion prevention and water purification so that an integral consideration can be made.

Conclusion

Based on the research in this thesis a number of conclusions can be drawn. For the first time a food forest for the peat meadow area is designed and assessed on three ecosystem services. The food forest design is in compliance with the Dutch definition and the suitability of the proposed species are verified by an expert. In addition, the design proposes a combination of food production and peat restoration in one system.

The presented estimates of yield and carbon sequestration are within a similar range to the available literature. Compared to organic milk production, the assessment indicates that the PFF has a higher yield in dry matter, is likely to be a net carbon sink instead of a GHG emitter it currently is, and provides a habitat that is likely to attract more but different bird species than the current landscape, including a higher number of endangered species. However, PFF is only recommendable for peat soils with clay cover since the construction of ridges on peat soils without clay cover will result in increased GHG emissions.

The PFF design can contribute substantially to a number of national ambitions including the transition towards vegetable protein production, GHG reductions, and likely to contribute to the Birds and Habitats directive. At the same time, it can be concluded that a PFF could have a negative impact on peat meadow bird populations. It is well possible to mitigate these impacts by selecting the PFF locations to be in areas which will not likely be populated by peat meadow bird populations such as existing constructions or high-rising woody vegetation.

The first field experiment indicatively shows that a selection of plant species can grow under the environmental conditions of peat soil present at the Vrouwe Vennepolder. Overall, the concept of a food forest on peat soils can be seen as a promising concept for further development and field experiments.

Bibliography

Afzal, M., & Akhtar, A. M. (2013). Factors affecting carbon sequestration in trees. *J. Agric. Res*, *51*(1), 61-69. Retrieved from https://apply.jar.punjab.gov.pk/upload/1373835879_72_549__61p7.pdf.

Agrimatie. (2021). *Technisch resultaat, prijzen en saldo (bedragen excl. BTW) van de melkveehouderij - Biologische melkveebedrijven*. Retrieved July 7, 2021 from https://www.agrimatie.nl/binternet.aspx?ID=15&bedrijfstype=3.

Agrimatie. (2020a). *Melkproductie per bedrijf en per koe verder gestegen in 2018, maar melkproductie per hectare voedergewas gedaald.* Retrieved from https://www.agrimatie.nl/PublicatiePage.aspx?subpubID=2523&themaID=2756&sectorID=3534.

Agrimatie. (2020b). *Biologische bedrijven hebben afwijkende bedrijfsopzet, stabielere melkprijs, hoger inkomen per onbetaalde aje en gemiddeld hogere duurzaamheidsscore.* Retrieved from https://www.agrimatie.nl/ThemaResultaat.aspx?subpubID=2232&themaID=2267&indicatorID=2106.

Agroclub. (n.d) *Medlar*. Retrieved June 11, 2021 from https://www.agroklub.rs/sortna-lista/voce/musmula-344/.

Agroforestry Vlaanderen. (2021). *Informatiefiche hoogstamfruitbomen*. Retrieved June 4, 2021 from https://www.agroforestryvlaanderen.be/nl/nieuws/hoogstamfruitbomen.

Ah (n,d) *AH Munt*. Retrieved from https://www.ah.nl/producten/product/wi238969/ah-munt.

Alam, M., Olivier, A., & Paquette, A. (2016). Measurements and economics of carbon sequestration in temperate tree-based intercropping systems. *International Journal of Agricultural Resources, Governance and Ecology,* 12(2), 125-136. https://doi-org.tudelft.idm.oclc.org/10.1504/IJARGE.2016.076919

Anonymous (1946). Onderzoek naar de kostprijzen van appelen, peren en pruimen. *Landbouw-Economisch Instituut,* 51. Retrieved from https://edepot.wur.nl/272263.

Augère-Granier, M.L. (2020). *Agroforestry in the European Union*. Retrieved June 11, 2021 from https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/651982/EPRS_BRI(2020)651982_EN.pdf.

Baltissen, A., & Oosterbaan, A. (2016). Notenteelt in Nederland. *Wageningen Plant Research*, Rapport 2017-04.

Berendse, F., Van Breemen, N., Rydin, H., Buttler, A., Heijmans, M., Hoosbeek, M. R., & Wallén, B. (2001). Raised atmospheric CO2 levels and increased N deposition cause shifts in plant species composition and production in Sphagnum bogs. *Global Change Biology*, 7(5), 591-598. https://doi-org.tudelft.idm.oclc.org/10.1046/j.1365-2486.2001.00433.x.

Behre, K. E. (1999). The history of beer additives in Europe—a review. *Vegetation history and archaeobotany*, *8*(1), 35-48.

Besnard A.G., Fourcade Y., & Secondi J. (2016). Measuring difference in edge avoidance in grassland birds: the Corncrake is less sensitive to hedgerow proximity than passerines. *Journal of Ornithology.* 157(2), pp. 515–523. doi: 10.1007/s10336-015-1281-7. https://doi.org/10.1007/s10336-015-1281-7.

Boelter, D.H. (1968). Important physical properties of peat materials. In: Proceedings, third internationalpeat congress; 1968 August 18-23; Quebec, Canada. [Place of publication unknown]: Department of Engery, Minds and Resources and National Research Council of Canada: 150-154.

Biancalani, R. & Avagyan, A. (2014). Towards climate-responsible peatlands management. *Mitigation of Climate Change in Agriculture Series 9*. Food and Agiculture Organization of the United Nations (FAO).

Bol.com (n.d) *Gele kornoelje gedroogd 50g*. Retrieved July 12, 2021 from https://www.bol.com/nl/nl/p/gele-kornoelje-gedroogd-50g/9200000105763561/#product_specifications.

Boosten, M. & Snoep, M. (2021). Projecttype : Aanleg van nieuw bos en aanleg van boomweides en lijnvormige beplantingen buiten bosverband. Groningen, the Nehterlands: Stichting Nationale Koolstofmarkt. Retrieved from https://nationaleco2markt.nl/wp-content/uploads/2021/06/210603-Methode-Aanleg-bos-en-beplanting-buiten-bosverband.pdf.

Bosman, P. (1987). *Zomaar voor jou.* Tielt, Belgium: Uitgeverij Lannoo.

Borren, W., Bleuten, W., & Lapshina, E. D. (2004). Holocene peat and carbon accumulation rates in the southern taiga of western Siberia. *Quaternary Research*, 61(1), 42-51.

Boulestreau, Y., & van Eck, W. (2016). Design and performance evaluation of a 1ha productive food forest model. [Intership report] *Wageningen University and Research Centre (WUR).*

Breidenbach, J., Dijkgraaf, E., Rooduijn, B., Nijpels-Cieremans, R., & Strijkstra, A. M. (2017). Voedselbossen van belang voor biodiversiteit. *De Levende Natuur*, 118(3), 90-93.

Brooker, R. W., Bennett, A. E., Cong, W. F., Daniell, T. J., George, T. S., Hallett, P. D., & White, P. J. (2015). Improving intercropping: a synthesis of research in agronomy, plant physiology and ecology. *New Phytologist*, *206*(1), 107-117. https://doi-org.tudelft.idm.oclc.org/10.1111/nph.13132.

Buiter, M., & de Waard, F.J. (2017). De kosten en baten van een voedselbos. *Stichting Voedselbosbouw Nederland*. . Lelystad, the Netherlands, Stichting voedselbosbouw Nederland. Retrieved from https://www.voedselbosbouw.org/artikelen.

Buiter, M., & de Waard, F.J. (2020). *Duurzame Schaalsprong Voedselbosbouw; een masterplan voor de realisatie van minimaal 1.000 hectare voedselbossen op Nederlandse landbouwgronden in de periode 2020-2030*. Lelystad, the Netherlands, Stichting voedselbosbouw Nederland. Retrieved from https://genaenhof.nl/docs/Masterplan%20voedselbosbouw.pdf.

Burgess, P.J. (1999). Effects of agroforestry on farm biodiversity in the UK. *Scottish Forestry*, 53(1), 24-27. Retrieved from http://dspace.lib.cranfield.ac.uk/handle/1826/1468.

Cardinael, R., Chevallier, T., Cambou, A., Beral, C., Barthès, B. G., Dupraz, C., & Chenu, C. (2017). Increased soil organic carbon stocks under agroforestry: A survey of six different sites in France. *Agriculture, Ecosystems & Environment,* 236, 243-255. https://doi.org/10.1016/j.agee.2016.12.011.

Carpentersherbal.com. (n.d). *Sweet Gale*. Retrieved June 11, 2021 from https://www.carpentersherbal.com/product/sweet-gale/.

Castaño-Santamaría, J., & Bravo, F. (2012). Variation in carbon concentration and basic density along stems of sessile oak (Quercus petraea (Matt.) Liebl.) and Pyrenean oak (Quercus pyrenaica Willd.) in the Cantabrian Range (NW Spain). *Annals of Forest Science*, 69(6), 663-672. https://doi-org.tudelft.idm.oclc.org/10.1007/s13595-012-0183-6.

CBS, PBL, RIVM, WUR (2021a). Fauna van het agrarisch gebied, 1990-2019 (indicator 1580, versie 05, 29 januari 2021). www.clo.nl. Centraal Bureau voor de Statistiek (CBS), Den Haag; PBL Planbureau voor de Leefomgeving, Den Haag; RIVM Rijksinstituut voor Volksgezondheid en Milieu, Bilthoven; en Wageningen University and Research, Wageningen. Retrieved from https://www.clo.nl/indicatoren/nl1580-trend-fauna-agrarisch.

CBS, PBL, RIVM, WUR (2021b). Trend van dagvlinders, 1992-2020 (indicator 1386, versie 18 , 7 juni 2021). www.clo.nl. Centraal Bureau voor de Statistiek (CBS), Den Haag; PBL Planbureau voor de Leefomgeving, Den Haag; RIVM Rijksinstituut voor Volksgezondheid en Milieu, Bilthoven; en Wageningen University and Research, Wageningen.

CBS, PBL, RIVM, WUR (2021c). Trend van boerenlandvogels, 1915-2019 (indicator 1479, versie 12 , 25 april 2021). www.clo.nl. Centraal Bureau voor de Statistiek (CBS), Den Haag; PBL Planbureau voor de Leefomgeving, Den Haag; RIVM Rijksinstituut voor Volksgezondheid en Milieu, Bilthoven; en Wageningen University and Research, Wageningen.

Clerkx, A. P. P. M., Van Dort, K. W., & Hommel, P. W. F. M. (1994). *Broekbossen van Nederland*. IBN-DLO 096.

College van Rijksadviseurs. (2020). *Landschap versterken met bomen en bos. Advies voor het ontwikkelen van een bossenstrategie*. College van Rijksadviseurs, Den Haag.

Cramp, S., & Perrins, C. M. (1994). *The Birds of the Western Palearctic*. Oxford, UK: Oxford University Press.

Crawford, M. (2010). *Creating a forest garden*. Cambridge, UK: Green Books.

Cushman, S. A., Mckelvey, K. S., Noon, B. R., & McGarigal, K. (2010). Use of abundance of one species as a surrogate for abundance of others. *Conservation Biology*, 24(3), 830-840. https://doi-org.tudelft.idm.oclc.org/10.1111/j.1523-1739.2009.01396.x.

De Graaf. (2019). Voedselbosbouw in het deltalandschap: Van bottom-up initiatief naar een duurzaam integraal landschap. *Paul de Graaf Ontwerp & Onderzoek*. Retrieved June 10, 2021 from http://pauldegraaf.eu/portfolio/voedselbosbouw-in-het-deltalandschap/.

De Jongh, L., de Jong, R., Schenau, S., van Berkel, J., Bogaart, P., Driessen, C., Horlings, E., Lof, M., Mosterd, R., & Hein, L. (2021). Natuurlijk Kapitaalrekeningen Nederland 2013-2018. *CBS-publication in corporation with Wageningen University & Research (WUR)*. Retrieved from https://www.cbs.nl/nl-nl/publicatie/2021/22/natuurlijk-kapitaalrekeningen-nederland-2013-2018.

De Vos, J. A., Hoving, I. E., Van Bakel, P. J. T., Wolf, J., Conijn, J. G., & Holshof, G. (2004*). Effecten van peilbeheer in de polders Zegveld en Oud-Kamerik op de nat-en droogteschade in de landbouw*. Wageningen, the Netherlands: Alterra.

De Vries, F. (2004). De verbreiding van veengronden. In: Kekem, A.J. (red.) *Veengronden en stikstofleverend vermogen. Wageningen*, the Netherlands: Alterra, 965.

Doomen, R., van Leeuwen, B., & Puhe, L. (2019). Food forest business models in the Nehterlands – Project report.

Van Dooren, N. (2018). The emerging practice of food forest-a promise for a sustainable urban food system?. In *European Agroforestry Conference-Agroforestry as Sustainable Land Use, 4th*. EURAF.

Engineering Toolbox. (n.d). *Liquids-Densities*. Retrieved July 6, 2021 from https://www.engineeringtoolbox.com/liquids-densities-d_743.html.

Erkman, S. (1997). Industrial ecology: An historical view. *Journal of Cleaner Production*, 5(1-2), 1–10. https://doi.org/10.1016/s0959-6526(97)00003-6.

FAO. (n.d). *Agroforestry*. Retrieved June 11, 2021 from http://www.fao.org/forestry/agroforestry/en/.

Fritz, C., Geurts, J., Weideveld, S., Temmink, R., Bosma, N., Wichern, F., & Lamers, L. (2017). Meten is weten bij bodemdaling-mitigatie - Effect van peilbeheer en teeltkeuze op CO2-emissies en veenoxidatie. *Bodem*, 20-22.

Jukema, G.D., Ramaekers, P., & Berkhout, P. (Red.) (2020). *De Nederlandse agrarische sector in internationaal verband*. Wageningen/Heerlen/Den Haag, the Netherlands: Wageningen Economic Research and Centraal Bureau voor de Statistiek, Report 2020-001.

Gardiner, B., Berry, P., & Moulia, B. (2016). Wind impacts on plant growth, mechanics and damage. *Plant Science*, 245, 94-118. https://doi.org/10.1016/j.plantsci.2016.01.006.

Geurts, J. J. M., & Fritz, C. (2018). *Paludiculture pilots and experiments with focus on cattail and reed in the Netherlands*. Retrieved from https://repository.ubn.ru.nl/bitstream/handle/2066/192628/192628pub.pdf.

Gori, A., Ferrini, F., & Fini, A. (2019). Reprint of: Growing healthy food under heavy metal pollution load: Overview and major challenges of tree based edible landscapes. *Urban forestry & urban greening*, 45, 126292. https://doi.org/10.1016/j.ufug.2019.02.009.

Gourmet-versand.com. (n.d-a). *Vlierbessen heel bevroren 1 kg.* Retrieved July 9, 2021 from https://www.gourmet-versand.com/nl/article7059/vlierbessen-heel-bevroren-1-kg.html.

Gourmet-versand.com. (n.d-b). Hawthorn purée mark, fine happened Retrieved July 9, 2021 from https://www.gourmet-versand.com/en/article21907/hawthorn-puree-mark-fine-happened-680-g.html.

Haines-Young, R., & Potschin, M.B. (2018). Common International Classification of Ecosystem Services (CICES) V5.1 and Guidance on the Application of the Revised Structure.

Harpenslager, S. F. (2015). *Growing peat*. [Doctoral dissertation], Radboud University Nijmegen.

Harpenslager, S. F., Lamers, L. P., van der Heide, T., Roelofs, J. G., & Smolders, A. J. (2016). Harnessing facilitation: Why successful re-introduction of Stratiotes aloides requires high densities under high nitrogen loading. *Biological conservation*, 195, 17-23. https://doi.org/10.1016/j.biocon.2015.12.031.

Harpenslager, S. F., Overbeek, C. C., van Zuidam, J. P., Roelofs, J. G., Kosten, S., & Lamers, L. P. (2018). Peat capping: natural capping of wet landfills by peat formation. *Ecological Engineering*, 114, 146-153. https://doi.org/10.1016/j.ecoleng.2017.04.040.

Heijerman-Peppelman, G., & Roelofs, P. F. M. M. (2010). *Kwantitatieve informatie fruitteelt 2009/2010*. Wageningen, the Netherlands: Praktijkonderzoek Plant & Omgeving.

Hoogheemraadschap van Rijnland. (2020). *Nota Peilbesluit, De nota peilbeheer stelt kaders voor het opstellen en uitvoeren van peilbesluiten*. Retrieved June 3, 2021 from https://www.rijnland.net/plannen/extra-paginas-plannen/peilbesluiten.

Hoppenreijs, J. H. T., Beringen, R., Collas, F. P. L., Eeuwes, D. D. M., Odé, B., van Valkenburg, J. L. C. H., & Leuven, R. S. E. W. (2019). *Risicobeoordeling van voedselbosbouw als introductieroute voor invasieve plantensoorten*. Nijmegen, the Netherlands: Floron.

IPCC. (2000). *Land-Use, Land-Use Change and Forestry: Special Report of the Intergovernmental Panel on Climate Change.* Cambridge, UK: Cambridge University Press, p.375.

Jacke, D., & Toensmeier, E. (2005). *Edible forest gardens, volume II: ecological design and practice for temperate-climate permaculture* (Ed. 2). Chelsea, US: Chelsea Green Publishing.

Jurasinski, G., Günther, A., Huth, V., & Couwenberg, J. (2016). Greenhouse gas emissions. In W. Wichtmann, C. Schröder, & H. Joosten, *Paludiculture – productive use of wet peatlands* (pp. 79-93, Chapter 5.1). Schweizerbart Science Publishers.

Khanzadi, F. K. (2012). Free radical scavenging activity, phytochemical composition and nutrient analysis of Elaeagnus umbellata berry. *Journal of Medicinal Plants Research*, *6*(39), 5196–5203. https://doi.org/10.5897/jmpr11.1128.

Kentie R., Both C., Hooijmeijer J.C.E.W., & Piersma,T. (2015). Management of modern agricultural landscapes increases nest predation rates in Black-tailed Godwits. Limosa limosa. *Ibis 157*, 614-625. https://doi-org.tudelft.idm.oclc.org/10.1111/ibi.12273.

Goldewijk, K., Olivier, J.G.J., Peters, J.A.H.W., Coenen, P.W.H.G., & Vreuls, H.H.J. (2005). Greenhouse Gas Emissions in the Netherlands 1990-2003. National Inventory Report 2005. RIVM-report 773201009/2005.

KNMI. (n.d). *Windrozen van de Nederlandse hoofdstations*. Retrieved July 6, 2021 from https://www.knmi.nl/nederland-nu/klimatologie/grafieken/maand/windrozen

Lampkin, N., Stolze, M., Meredith, S., de Porras, M., Haller, L., & Mészáros, D. (2020). *Using Eco-schemes in the new CAP: a guide for managing authorities*. IFOAM EU, FIBL and IEEP, Brussels. Retrieved from https://www.organicseurope.bio/content/uploads/2020/06/ifoam-eco-schemes-web_compressed-1.pdf?dd.

Land van Ons. (2020). *Samenwerking met Universiteit van Leiden*. Retrieved June 10, 2021 from https://landvanons.nl/samenwerking-met-universiteit-van-leiden/.

Land van Ons. (n.d). *Oud Ade & PolderLab Vrouwe Venne.* Retrieved July 14, 2021 from https://landvanons.nl/perceel/oud_ade/.

Lehmann, L. M., Lysák, M., Schafer, L., & Henriksen, C. B. (2019). Quantification of the understorey contribution to carbon storage in a peri-urban temperate food forest. *Urban Forestry & Urban Greening*, 45, 126359. https://doi.org/10.1016/j.ufug.2019.06.002.

Lesbarrères D., & Fahrig L. (2012). Measures to reduce population fragmentation by roads: what has worked and how do we know? *Trends in Ecology and Evolution*, *27*(7), 374–380. doi: 10.1016/j.tree.2012.01.015.

Lindenmayer, D. B., & Likens, G. E. (2011). Direct measurement versus surrogate indicator species for evaluating environmental change and biodiversity loss. *Ecosystems, 14*(1), 47-59. https://doi.org/10.1007/s10021-010-9394-6.

LNV. (2019). *Realisatieplan Visie LNV Op weg met nieuw perspectief*. Retrieved June 9, 2021 from https://www.rijksoverheid.nl/binaries/rijksoverheid/documenten/publicaties/2019/06/17/realisatieplan-visie-lnv-op-weg-met-nieuw-perspectief/LNV+Realisatieplan_Juni_2019_WEB.pdf.

LNV. (2020a). *Bos voor de toekomst. Uitwerking ambities en doelen landelijke Bossenstrategie en beleidsagenda 2030*. Retrieved from https://www.rijksoverheid.nl/documenten/kamerstukken/2020/11/18/uitwerking-ambities-en-doelen-landelijke-bossenstrategie-en-beleidsagenda-2030.

LNV. (2020b) *Nationale eiwitstrategie*. Den Haag. Retieved from https://www.rijksoverheid.nl/binaries/rijksoverheid/documenten/kamerstukken/2020/12/22/nationale-eiwitstrategie/20298471.bijlage.pdf.

Lof, M., Schenau, S., de Jong, R., Remme, R., Graveland, C., & Hein, L. (2017). The SEEA EEA carbon account for the Netherlands. Den Haag, the Netherlands: Statistics Netherlands and Wageningen University.

Luske, B., Bestman, M.W.P., van Veluw, K., Prins, E., Rombouts, P. (2020). *Masterplan Agroforestry: Advies voor het realiseren van een schaalsprong van agroforestry in Nederland*. Bunnik, the Netherlands: Louis Bolk Instituut, Bunnik.

Marechal. (n.d). *Snoeien van rode, witte en zwarte bessen*. Retrieved June 11, 2021 from https://www.marechal.be/informatie/snoei-rode-witte-zwarte-bessen/.

Ministerie van Economische Zaken en Klimaat. (2019). *C4 Landbouw en landgebruik - Klimaatakkoord*. Retrieved from https://www.klimaatakkoord.nl/binaries/klimaatakkoord/documenten/publicaties/2019/06/28/klimaatakkoord-hoofdstuk-landbouw-en-landgebruik/klimaatakkoord-c4+Landbouw+en+gebruik.pdf.

Montagnini, F., & Nair, P.K.R. (2004). Carbon sequestration: an underexploited environmental benefit of agroforestry systems. *Agroforestry Systems, 61*, 281–295. https://doi.org/10.1007/978-94-017-2424-1_20.

Mooiemoestuin.nl. (n.d). *Zwarte bes*. Retrieved June 11, 2021 from https://www.mooiemoestuin.nl/fruit/zwarte-bes/.

Mosquera-Losada, M. R., Moreno, G., Pardini, A., McAdam, J. H., Papanastasis, V., Burgess, P. J., & Rigueiro-Rodríguez, A. (2012). Past, present, and future of agroforestry systems in Europe in agroforestry: the future of global land use. *Agroforestry-The Future of Global Land Use, 9*.

MVO NL. (2021) *Veelbelovende Agroforestry Product-Markt combinaties.* Recorded webinar, March 19 2021. Published at https://www.youtube.com/watch?v=3B4-ljWAtHQ&ab_channel=MVONederland.

Nair, P.K.R.(2012). Carbon sequestration studies in agroforestry systems: a reality-check. *Agroforestry Systems, 86* (2), 243–253. https://doi-org.tudelft.idm.oclc.org/10.1007/s10457-011-9434-z.

Norén, I. S., Keur, J., Vijn, M. P., Schoutsen, M. A., Cuperus, F., Slier, T., & Schrijver, R. A. M. (2019). Factsheet Agroforestry 3. Klimaatcompensatie met agroforestry, wat is mogelijk?: Handreiking voor agrarisch ondernemers die bomen willen planten op hun bedrijf. Retrieved from https://edepot.wur.nl/501459.

NSW. (n.d). *Quince growing*. Department op primary industries. Retrieved June 11, 2021 from https://www.dpi.nsw.gov.au/agriculture/horticulture/pomes/other/quince-growing.

Oosterveld E. (2011). *Weidevogels en predatie: een literatuuroverzicht*. Feanwâlden, the Nehterlands: Altenburg & Wymenga, ecologisch onderzoek.

Parmar, C., & Kaushal, M. (1982). Elaegnus umbellata. In *Wild Fruits* (pp. 23–25). New Delhi, India: Kalyani Publishers.

PBL. (2019). *Zorg voor landschap. Naar een landschapsinclusief omgevingsbeleid.* Den Haag, the Netherlands: PBL.

Permacultuurcentrum Den Haag. (n.d). *Voedselmoerasbos Den Haag!* Retrieved June 11, 2021 from https://permacultuur.nu/index.php/tuinprojecten/moerasvoedselbos.

Pijlman, J., Roelen, S., & van Eekeren, N. (2020). *Klimaatmaatregelen in het veenweidegebied in relatie tot biodiversiteit, bodem-en waterkwaliteit*. Bunnink, the Netherlands: Louis Bolk Instituut. Retrieved from https://www.louisbolk.nl/publicaties/klimaatmaatregelen-het-veenweidegebied-relatie-tot-biodiversiteit-bodem-en

Plantmaps. (n.d). *Netherlands Plant Hardiness Zone Map*. Retrieved April 16, 2021 from https://www.plantmaps.com/interactive-netherlands-plant-hardiness-zone-map-celsius.php.

Plants for a future. (n.d) *Database plant search page*. Retrieved May 21, 2021 from https://pfaf.org/user/Default.aspx.

Poore, J., & Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. *Science, 360*(6392), 987-992. DOI: 10.1126/science.aaq0216.

Pouwel, R., & Henkens, R. J. H. G. (2020). *Naar een hoger doelbereik van de Vogel-en Habitatrichtlijn in Nederland. Een analyse van de resterende opgave na 2027 voor het bereiken van een gunstige staat van instandhouding van alle habitattypen en VHR-soorten*. Wageningen, the Netherlands: Wageningen Environmental Research.

RIVM. (n.d). *Nederlands voedingsstoffenbestand*. Retrieved July 23, 2021 from https://nevo-online.rivm.nl/ProductenDetailsGetabt.aspx?tabid=4

Schafer, L. J., Lysák, M., & Henriksen, C. B. (2019). Tree layer carbon stock quantification in a temperate food forest: A peri-urban polyculture case study. *Urban Forestry & Urban Greening, 45*, 126466. https://doi.org/10.1016/j.ufug.2019.126466.

Schekkerman H., Teunissen W., & Oosterveld E. (2009). Mortality of black-tailed godwit Limosa limosa and northern lapwing Vanellus vanellus chicks in wet grasslands: influence of predation and agriculture. *Journal of Ornithology, 150*(1), 133–145. doi: 10.1007/s10336-008-0328-4.

Schreuder, R., & Hendriks-Goossens, V. J. C. (2010). *Kwantitatieve informatie akkerbouw en vollegrondsgroenteteelt 2009*. Lelystad, The Netherlands: PPO AGV.

Skrøder, J. L., & Henriksen, C. B. (2019). Sustainable food production in a temperate climate – a case study analysis of the nutritional yield in a peri-urban food forest. *Urban Forestry and Urban Greening, 45*, 126326. https://doi.org/10.1016/j.ufug.2019.04.009360(6392), 987-992.

Statistics Netherlands & WUR. (2021). *Natural Capital Accounting in the Netherlands –Technical report*. Den Haag, the Netherlands: Statistics Netherlands (CBS) and Wageningen University and Research (WUR).

Stichting Voedselbosbouw Nederland. (n.d). *Start Programma Duurzame Doorbraak Voedselbosbouw*. Retrieved June 4 2021 from https://www.voedselbosbouw.org/single-post/2019/09/09/Start-Programma-Duurzame-Doorbraak-Voedselbosbouw.

Tabele kalorii. (n.d). *Owoce derenia*. Retrieved July 9, 2021 from https://www.tabele-kalorii.pl/kalorie,Owoce-derenia.html

Teunissen, W., Schekkerman, H., & Willems, F. (2005). *Predatie bij weidevogels; op zoek naar de mogelijke effecten van predatie op de weidevogelstand*. Nijmegen, the Netherlands: Sovon vogelonderzoek Nederland.

The pollinators. (2017). *Met deze bloemen doe je bijen en hommerls een plezier in de herfst.* Retrieved from https://www.thepollinators.org/blog/bloemen-voor-bijen-en-hommels-in-de-herfst.

Thomassen, M. A., van Calker, K. J., Smits, M. C., Iepema, G. L., & de Boer, I. J. (2008). Life cycle assessment of conventional and organic milk production in the Netherlands. *Agricultural systems, 96*(1-3), 95-107. https://doi.org/10.1016/j.agsy.2007.06.001.

Torralba, M., Fagerholm, N., Burgess, P. J., Moreno, G., & Plieninger, T. (2016). Do European agroforestry systems enhance biodiversity and ecosystem services? A meta-analysis. *Agriculture, Ecosystems & Environment, 230*, 150–161. https://doi.org/10.1016/j.agee.2016.06.002.

Van de Riet, B., van den Elzen, E., Hogeweg, N., Smolders, F., & Lamers, L. (2018). *Omhoog met het Veen: Herstel van een veenvormende veenmosvegetatie op voormalige landbouwgrond in veenweidegebieden*. Nijmegen, the Netherlands: B-WARE Research Centre.

Van den Akker, J. J. H., Kuikman, P. J., De Vries, F., Hoving, I. E., Pleijter, M., Hendriks, R. F. A., & Kwakernaak, C. (2010). Emission of CO2 from agricultural peat soils in the Netherlands and ways to limit this emission. In *Proceedings of the 13th International Peat Congress After Wise Use–The Future of Peatlands*, Ed. 1 Oral Presentations, Tullamore, Ireland, 8–13 June 2008 (pp. 645-648).

Van den Born, G.J., Kragt, F., Henkens, D., Rijken, B.C., van Bemmel, B., van der Sluis, S.M., Polman, N., Bos, E.J., Kuhlman, T., & Kwakernaat, C. (2016). *Dalende bodems, stijgende kosten: mogelijke maatregelen tegen veenbodemdaling in het landelijk en stedelijk gebied: beleidsstudie*. Den Haag, the Netherlands: Planbureau voor de Leefomgeving.

Van den Born, G.J., Brouwer, L., Goosen H., Hoekstra R., Huitema D., & Schrijver R. (2002). *Klimaatwinst in Veenweidegebieden. Beheersopties voor het veenweidegebied integraal bekeken*. Amsterdam, the Netherlands: IVM.

van der Wal, J., & Teunissen, W. (2018). *Boerenlandvogels en predatie: een update van de huidige kennis*. Nijmegen, the Netherlands: Sovon Vogelonderzoek Nederland.

Van Duin, F.C.M. (2021). *Facilitating a regime shift from agricultural grasslands to species rich hay meadows*. [Unpublished Master thesis]. Leiden University.

Van Eeden, N. (2020). *Agroforestry in the Netherlands, The production potential and environmental advantages of a temperate food forest*. [Master thesis] Leiden University.

van Kleunen, A., Foppen, R., & van Turnhout, C. (2017). *Basisrapport voor de Rode Lijst Vogels 2016 volgens Nederlandse en IUCN-criteria*. Nijmegen, the Netherlands: Sovon Vogelonderzoek Nederland.

van Reuler, H., Schoutsen, M., Cuperus, F., Groot, M., Keur, J., Ravesloot, M., ... & Ruigrok, T. (2020). *Nederlandse notenteelt: Kennis en innovatie ten behoeve van de ontwikkeling van notenteelt in Nederland*. (No. WPR-843). Wageningen, the Netherlands: Stichting Wageningen Research, Wageningen Plant Research, Business unit Open Teelten.

van Turnhout, C., Foppen, R., & Zoetebier, D. (2019). *Recente trends van weidevogels in relatie tot beheer*. Nijmegen, the Netherlands: Sovon Vogelonderzoek Nederland.

Varah, A., Jones, H., Smith, J., & Potts, S. G. (2013). Enhanced biodiversity and pollination in UK agroforestry systems. *Journal of the Science of Food and Agriculture, 93*(9), 2073–2075. https://doi.org/10.1002/jsfa.6148.

Voedingswaardetabel (n.d). *Voedingswaarde van voedingsmiddelen.* Retrieved from https://www.voedingswaardetabel.nl/voedingswaarde/.

Voedingscentrum. (n.d). *Wat is de voedingswaarde van mispel*. Retrieved July 9, 2021 from https://www.voedingscentrum.nl/nl/service/vraag-en-antwoord/gezonde-voeding-en-voedingsstoffen/hoeveel-voedingswaarden-zitten-erin/mispel.aspx.

Wendel, B.A.G. (2021). *Carbon sequestration in young temperate food forests*. [Unpublished MSc thesis]. Leiden University.

Wereld Natuur Fonds. (2020). *Living Planet Report Nederland. Natuur en landbouw verbonden*. Zeist, the Netherlands: WNF. Retrieved from https://www.rijksoverheid.nl/documenten/rapporten/2020/04/17/bijlage-rapport-living-planet-report.

Whittingham M.J., & Devereux C.L. (2008). Changing grass height alters foraging site selection by wintering farmland birds. *Basic and Applied Ecology, 9*(6), pp. 779–788. doi:10.1016/j.baae.2007.08.002.

Wiebes, E., van Veldhoven, S., Schouten, C., Mackus, H. J. H., Meijer, A., de Waard, F., & Kooistra, K. J. (2016). *Green Deal Voedselbossen.* Retrieved from https://www.greendeals.nl/sites/default/files/downloads/GD219-dealtekst-Voedselbossen.pdf.

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., & Murray, C. J. (2019). Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. *The Lancet, 393*(10170), 447-492. https://doi.org/10.1016/S0140-6736(18)31788-4.

Winsemius, P., Crone, F., It Fryske Gea, de Friese Milieu Federatie & Vogelbescherming Nederland. (2020). *Aanvalsplan Grutto.* Retrieved from https://www.natuurenmilieufederaties.nl/wp-content/uploads/2020/11/aanvalsplan-Grutto.pdf.

Woets, D. (1990). Roofvogels en uilen als broedvogel in noordwest Overijssel tussen 1950 en 1990. *Het Vogeljaar 38*.

WUR. (2012). *Opbrengst biologisch geteelde gewassen wereldwijd 20% lager dan in gangbare landbouw*. Retrieved May 21 from https://www.wur.nl/nl/show/Opbrengst-biologisch-geteelde-gewassen-wereldwijd-20-lager-dan-in-gangbare-landbouw.htm.

Appendix

A. Plant selection criteria

Indicator	Scale pfaf	Threshold used	VVP	Reference
Soil acidity tolerance	Acid/Neutral/Base	Acid	pH 5,4 (mean)	van Duin 2021
Moist tolerance	Wet/Moist/Dry	Moist/Wet	71% at 60cm	van Duin 2021
Hardiness zone (USDA	1-13	8	8	Plantmap (n.d.)
Edibility	1-5	4		Personal demarcation

B. Nutrient balance variables

Type of plant	N and K demand	N deliverance	K deliverance
	(g/m2)	*(g/m2)*	*(g/m2)*
High productive	8	10	
Medium productive	2	5	
Low productive	0	3,6	
Symphytum officinale		3,6	71

C. Plant list

Scientific Name	Family species	Common Name	Dutch name	Hight	Width	n/ha	pH	Moisture	Light preferenc	Shade tolerenc	Edibility	Productivity
				m	*m*		*A/N/B*	*D/M/We*	*1/4*	*1/4*	*1/5*	*L/M/H*
Corylus avellana	Betulaceae	Common Hazel	Hazel / lambertsnoot	6	3	56	ANB	M	1	4	5	H
Crataegus arnoldiana	Rosaceae	Arnold Hawthorn	Vruchtmeidoorn	7	7	4	ANB	DMWe	1	3	5	M
Cydonia oblonga	Rosaceae	Quince	Kweepeer	6	6	8	ANB	M	1	2	4	H
Mespilus germanica	Rosaceae	Medlar	Mispel	6	6	8	ANB	M	1	3	4	H
Prunus domestica	Rosaceae	Plum, European plum	Pruim	6	6	8	ANB	M	1	2	5	H
Malus Domestica	Rosaceae	Apple	Appel	10	10	12	ANB	M	1	2	5	H
Pyrus communis sativa	Rosaceae	Pear	Peer	15	8	12	ANB	M	1	2	5	H
Alnus glutinosa	Betuaceae	Black Alder	Zwarte Els	15	10	28	ANB	MWe	1	2	0	
Cornus mas	Cornaceae	Cornelian Cherry	Gele kornoelje	5	5	28	ANB	M	1	2	4	M
Sambuccus Nigra	Caprifoliaceae	American Elder	Vlier	4	4	28	ANB	M	1	3	4	M
Staphylea colchica	Staphyleaceae	Bladdernut	Pimpernoot	4	4	28	ANB	M	1	3	4*	M
Elaeagnus x ebbingei	Elaeagnaceae	Silverberry	Zilverbes	5	5	28	ANB	DM	1	4	5	
Elaeagnus umbellata	Elaeagnaceae	Autumn olive	Herfst olijfwilg	4.5	4	80	ANB	DM	1	2	4	
Ribes nigrum	Grossulariaceae	Black currant	Zwarte Bes	1,5	1,5	56	ANB	M	1	2	5	H
Rubus idaeus	Rosaceae	Raspberry	Framboos	2	1,5	28	ANB	M	1	3	5	H
Vaccinium corymbosum	Ericaceae	High-Bush Blueberry	Trosbosbes	2	2	80	A	M	1	2	4	H
Myrica gale	Myricaceae	Bog Myrtle	Wilde gagel	2	1	320	ANB	MWe	1	2	2	M
Actinidia arguta	Actinidiaceae	Tara Vine	Kiwibes	15	1	28	ANB	M	1	3	5	H
Rheum × hybridum	Polygonaceae	Garden Rhubarb	Rabarber	1,5	1,5	160	ANB	M	1	3	4	H
Symphytum officinale - L.	Boraginaceae	Comfrey	Smeerwortel	1,2	0,6	80	ANB	M	1	3	3	
Stratiotes aloides	Hydrocharitaceae	Water soldier	Krabbescheer	1	1	2000	ANB	MWe	1	2	0	

Legend		
pH	A	Acid
	N	Neutral
	B	Alkaline
Moisture	D	Dry
	M	Moist
	We	Wet
Light preference	1	prefers full sun
	2	prefers light shade
	3	prefers considerable shade
	4	prefers full shade (only indirect light)
shade tolerance	1	Does not tolerate shade
	2	Tolerates light shade
	3	Tolerates considerable shade
	4	Tolerates full shade

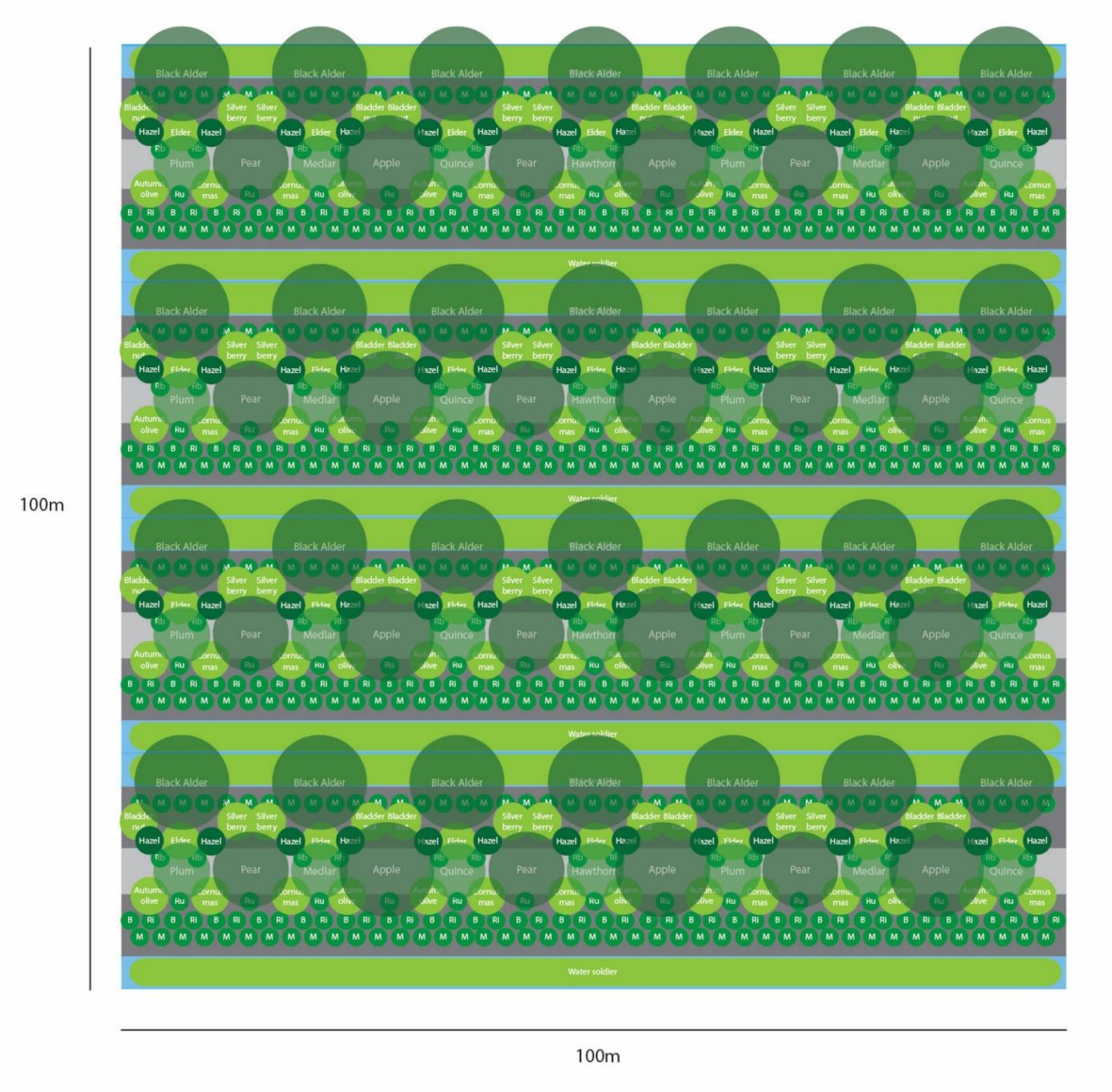
D. Blossom arch

Species		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Okt	Nov	Dec
Corylus avellana	Common Hazel	■	■	■	■								
Crataegus arnoldiana	Arnold Hawthorn					■							
Cydonia oblonga	Quince					■							
Mespilus germanica	Medlar					■	■						
Prunus domestica	Plum, European plum		■	■									
Malus Domestica	Apple				■	■	■						
Pyrus communis sativa	Pear				■	■							
Alnus glutinosa	Black Alder				■	■							
Cornus mas	Cornelian Cherry,		■	■									
Staphylea colchica	Bladdernut					■	■						
Elaeagnus x ebbingei	Silverberry										■	■	
Elaeagnus umbellata	Autumn olive					■	■						
Ribes nigrum	Black currant			■	■								
Rubus idaeus	Raspberry						■	■	■				
Sambuccus Nigra	Elder						■	■					
Vaccinium corymbosum	High-Bush Blueberry,					■	■						
Myrica gale	Bog Myrtle			■	■	■							
Actinidia arguta	Tara vine						■	■					
Rheum × hybridum	Garden Rhubarb												
Symphytum officinale - L.	Comfrey						■	■	■	■			
Stratiotes aloides	Water soldier						■	■	■				

E. Nutrient balance

Species		A/n	n/ha	Total A	Nutrient demand		Nutrient provision	
					N / K (g)		N (g)	K (g)
Corylus avellana	Common Hazel	7	56	396	3165,12			
Crataegus arnoldiana	Arnold Hawthorn	38	4	154	307,72			
Cydonia oblonga	Quince	28	8	226	1808,64			
Mespilus germanica	Medlar	28	8	226	1808,64			
Prunus domestica	Plum, European plum	28	8	226	1808,64			
Malus Domestica	Apple	79	12	942	7536			
Pyrus communis sativa	Pear	50	12	603	4823,04			
Alnus glutinosa	Black Alder	79	28	2198			21980	
Cornus mas	Cornelian Cherry,	20	28	550	1099			
Staphylea colchica	Bladdernut	13	28	352	703,36			
Elaeagnus x ebbingei	Silverberry	20	28	550			2748	
Elaeagnus umbellata	Autumn olive	13	28	352			3517	
Ribes nigrum	Black currant	2	80	141	1130,4			
Rubus idaeus	Raspberry	2	56	99	197,82			
Sambuccus Nigra	Elder	13	28	352	703,36			
Vaccinium corymbosum	High-Bush Blueberry,	3	80	251	502,4			
Myrica gale	Bog Myrtle	1	320	251			1884	
Actinidia arguta	Tara vine	0	28	0	0			
Rheum × hybridum	Garden Rhubarb	2	160	283	2260,8			
Symphytum officinale - L.	Comfrey	0	80	23			81	1605
Stratiotes aloides	Water soldier	1	2000	1570				
			Total balance		27855		30210	1605
			Net result				2355	-26250

F. Rational hectare PFF



G. Yield information

Species		n/ha	Max. harvest/year/n	Max. harvest/year	Year max. harvest	Value	Max. potential value	Reference harvest	Reference value	Assumptions
			kg			*€/kg*				
Corylus avellana	Common Hazel	56	10 (50% edible)	560	7	12,0	6720	Boulestreau & Van Eck (2016)	agroforestry vlaanderen (n.d)	They take 700kg/ha as an estimate when planting 200 trees in an agroforestry context. The 700 kg is the nut still with its shell. 6 euros/kg is the mean value (5-7) of organic production. Harvests start from year 3
Crataegus arnoldiana	Arnold Hawthorn	4	7,5	30	15	10	300	Chokeberry used as proxy	gourmet-versand.com (n.d b) (taken half of the retail price)	
Cydonia oblonga	Quince	8	120	960	15	2,58	2477	NSW (n.d.)	Plum as proxy	Assuming 250 trees per ha generating 30 tons of harvest
Mespilus germanica	Medlar	8	120	960	15	2,58	2477	Agroclub (n.d.)	Plum as proxy	Same assumption as for the plums based on the size of the tree and is in line with agroklub
Prunus domestica	Plum, European plum	8	120	960	15	2,58	2477	Anonymous (1946)	KWIN 2009/2010 Fruitteelt (2010) p49 regular production (with an organic factor of 1,94)	Assumption is 100 trees/ha generating 12 tons of harvest
Malus Domestica	Apple	12	250	3000	15	0,9	2700	Anonymous (1946)	KWIN 2009/2010 Fruitteelt (2010) p119 organic production	Assumption is 64 trees/ha generating on average 16tons of harvest
Pyrus communis sativa	Pear	12	160	1920	15	0,64	1229	Anonymous (1946)	KWIN 2009/2010 Fruitteelt (2010) p33 regular production	Assumption is 100 trees/ha generating on average 16tons of harvest
Alnus glutinosa	Black Alder	28	0	0	0	0	0			Systemic species
Cornus mas	Cornelian Cherry,	28	6	168	15	15	2520	Elderberry used as proxy	bol.com (n.d) (taken half of the retail price)	
Staphylea colchica	Bladdernut	28	1	28	15	4,5	126	Personal estimate	Blueberry as proxy	
Elaeagnus x ebbingei	Silverberry	28	0	0	0	0	0			Systemic species
Eleagnus umbellata	Autumn olive	28	9	252	15	4,5	1134	van Eeden (2020)	Blueberry as proxy	
Ribes nigrum	Black currant	80	4	320	5	1,3	416	Boulestreau & Van Eck (2016) Marechal (n.d.) mooiemoestuin.nl (n.d.)	KWIN 2009/2010 Fruitteelt (2010) p77 (with an organic factor of 1,94)	Assumption is 9000 plants/ha generate max 8 tons of harvest in year 5 for black currant. From KWIN is regarded too low compared to other sources.
Rubus idaeus	Raspberry	56	1,7	95,2	2	19,4	1847	KWIN 2009/2010 Fruitteelt (2010) p91	KWIN 2009/2010 Fruitteelt (2010) p91 (average over 5 years) (with an organic factor of 1,94)	Assumption is 6670 plants/ha generate max 18 tons of harvest in year 2 until year 5
Sambuccus Nigra	Elder	28	6	168	15	5,5	924	Doomen et al. (2019) Boulestreau & Van Eck (2016)	gourmet-versand.com (n.d a) (taken half of the retail price)	
Vaccinium corymbosum	High-Bush Blueberry,	80	2,5	200	6	4,5	900	KWIN 2009/2010 (2010) p83 organic product	KWIN 2009/2010 (2010) p83 organic production	Assumption is 4000 plant/ha generate 10 tons of harvest per ha under open conditions with manual picking.
Myrica gale	Bog Myrtle	320	0,5	160	10	37,5	6000	Personal estimate	carpentersherbal.com (n.d)	30 euros for 230 dried Bog Myrlte with a dm content of 15%
Actinidia arguta	Tara vine	28	22,5	630	10	4,5	2835	Doomen et al. (2019)	Blueberry as proxy	
Rheum × hybridum	Garden Rhubarb	160	1,6	256	3	1,13	288	KWIN 2009 Vollegrondsteelten (2010)p212 Boulestreau & Van Eck (2016)	KWIN 2009 Vollegrondsteelten (2010) p212 (with an organic factor of 1,94)	assumption is 2466 plants/ha genarate 45 tons of harvest from year 3 (KWIN sais 40.5tons/ha but it seems to be too high.
Symphytum officinale - L.	Comfrey	80	0	0	0	0	0			Systemic species
Stratiotes aloides	Water soldier	2000	0	0	0	0	0			Systemic species

H. Peat emission calculations

	BAU no clay (-60)	**BAU VVP (-60)**	**Raised no clay (-20)**	**Raised VVP (-20)**	**PFF no clay (-20)**				**PFF VVP (-20)**			
Fraction MWL					*20%*	*60%*	*20%*	100%	*20%*	*60%*	*20%*	100%
MWL	-60	-60	-20	-20	*-70*	*-20*	*+30*		*-70*	*-20*	*+30*	
Calc FP	(60-0)/60	(60-47)/60	(20-0)/20	(20-20)/20	*(70-0)/70*	*(20-0)/20*	*0*		*(70-70)/70*	*(20-20)/20*	*0*	
FP	1	0,21	1	0	*1*	*1*	*0*		*0*	*0*	*0*	
Emissions CO2	27,09	5,76	9,09	0,09	6,32	5,45	*0,00*	11,77	*0,02*	*0,05*	*0,02*	0,09
Emissions CH4 NO2	1,80	1,80	1,90	1,90	*0,04*	*1,14*	*2,86*	4,04	*0,04*	*1,14*	*2,86*	4,04
Total emissions Mg CO2 eq./ha/a	28,89	7,56	10,99	1,99	*6,36*	*6,59*	*2,86*	15,81	*0,06*	*1,19*	*2,88*	4,13

I. Nutritional values

Species	Dry matter (fraction)	Energy (kcal/kg)	Fat (fraction)	Protein (fraction)	Carbohydrates (Fraction)	Source
Corylus avellana	0,96	670	0,630	0,164	0,048	RIVM (n.d)
Crataegus arnoldiana	N.a.	260	0,010	0,010	0,060	gourmet-versand.com (n.d)
Cydonia oblonga	0,19	690	0,001	0,005	0,155	voedingswaardetabel.nl (n.d)
Mespilus germanica	N.a.	500	0,002	0,005	0,106	voedingscentrum.nl (n.d)
Prunus domestica	0,16	400	0,000	0.008	0.02	RIVM (n.d)
Malus Domestica	0,17	560	0,002	0,003	0,120	RIVM (n.d)
Pyrus communis sativa	0,16	550	0,003	0,002	0,117	RIVM (n.d)
Cornus mas	0,11	520	0,000	0,009	0,105	tabele-kalorii.pl (n.d)
Staphylea colchica	N.a.	N.a.	N.a.	N.a.	N.a.	
Elaeagnus x ebbingei	0,29	908	0,023	0,040	0,136	Khanzadi (2012); Parmar & Kaushal (1982)
Elaeagnus umbellata	0,29	908	0,023	0,040	0,136	Khanzadi (2012); Parmar & Kaushal (1982)
Ribes nigrum	0,14	530	0,000	0,009	0,008	RIVM (n.d)
Rubus idaeus	0,14	370	0,003	0,014	0,045	RIVM (n.d)
Sambuccus Nigra	N.a.	540	0,017	0,025	0,065	gourmet-versand.com (n.d)
Vaccinium corymbosum	0,23	750	0,002	0,006	0,145	voedingswaardetabel.nl (n.d)
Myrica gale	N.a.	N.a.	N.a.	N.a.	N.a.	
Actinidia arguta	0,13	480	0,002	0,010	0,103	voedingswaardetabel.nl (n.d) (kiwi)
Rheum × hybridum	0,06	230	0,000	0,010	0,020	RIVM (n.d)
Raw milk	0,142	710	0,044	0,034	0,044	RIVM (n.d)

J. Variables

Variable	Value	Unit	Reference
Density milk	1,035	kg/l	Engineering toolbox (n.d)
m2/kg milk (organic)	1,8	m2/kg	Thomassen et al (2008)
Emissions organicmilk production	1,5	kg CO2 eq/kg milk	Thomassen et al (2008)
kg milk/ha (organic)	5555	kg/ha	Derived from Thomassen et al (2008)
Organic milkprice (€/kg)	0,55	€	Agrimatie (2020)
Conversion C to CO2	3,664		Derived from Alam et al (2016)
Peat density	0,16	ton/m3	Boelter (1968)
Carbon fraction peat	0,55	%	Borren et al (2004)
Thickness clay cover	0,47	m	van Duin (2021)

K. Field experiment food forest plant species

L. Occurrence red list species

Red list bird species			**Low peat swamp district**	**Peat polder district**
Scientific name	*Common name*	*Dutch name*		
Perdix perdix perdix	Partridge	Patrijs	x	x
Spatula querquedula	Garganey	Zomertaling	x	x
Spatula clypeata	Northern shoveler	Slobeend	x	x
Porzana porzana	Spotted crake	Porseleinhoen	x	
Zapornia pusilla	Baillon's crake	Kleinst Waterhoen	x	
Botaurus stellaris	Eurasian bittern	Roerdomp	x	
Limosa limosa	Black-tailed godwit	Grutto	x	x
Calidris pugnax	Ruff	Kemphaan	x	x
Gallinago gallinago	Common snipe	Watersnip	x	x
Tringa totanus	Common Redshank	Tureluur	x	x
Chlidonias niger	Black Tern	Zwarte Stern	x	
Asio otus	Long-eared owl	Ransuil	x	x
Circus pygargus	Montagu's harrier	Grauwe Kiekendief	x	
Falco tinnunculus	Common kestrel	Torenvalk	x	x
Falco subbuteo	Eurasion hobby	Boomvalk	x	
Oriolus oriolus	Eurasian golden oriole	Wielewaal	x	
Parus montanus	Willow tit	Matkop	x	
Hirundo rustica	Barn swallow	Boerenzwaluw	x	x
Delichon urbicum	Common house martin	Huiszwaluw	x	x
Alauda arvensis	Eurasian skylark	Veldleeuwerik	x	x
Locustella luscinioides	Savi's warbler	Snor	x	
crocephalus arundinaceu	Great reed warbler	Grote Karekiet	x	
Hippolais icterina	Mockingbird	Spotvogel	x	x
Luscinia megarhynchos	Nightingale	Nachtegaal	x	
Muscicapa striata	Spotted flycatcher	Grauwe Vliegenvanger	x	x
Passer domesticus	House sparrow	Huismus	x	x
Passer montanus	Eurasion tree sparrow	Ringmus	x	x
Motacilla flavissima	Western yellow wagtail	Gele Kwikstaart	x	x
Anthus pratensis	Meadow pipit	Graspieper	x	x
Carduelis cannabina	Linnet	Kneu	x	x

M. Interviews

Bastiaan Rooduijn/Paul de Graaf (19-04-2021)

Bastiaan: Owner of a Community Supported Agriculture (CSA) horticulture and biologist,

Paul: Landscape architect and member of Coöperation Ondergrond

With this research I want to research the possible ecosystem services of a food forest on peat soils. To what extent can you (NMVB) already make a statement about the ecosystem services that a food forest can provide?

Bastiaan: It is clear that certain food forests provide certain ecosystem services. However, this is not yet very well substantiated numerically. The best we have now is the ability to store carbon. We have now done a good study on this once and that gives an indication, but that is still very generic. What you actually want to know is which combinations are possible. And what the trade-offs are. It can't just be win-win-win. If your main goal is to protect biodiversity, you may have to sacrifice on productivity, for example. But these are still in the early stages, so I can't tell you much about that, especially not in the peat meadow area. There it is even more complicated, because much of the biodiversity occurs naturally. Well naturally you may ask. But those that have existed for a long time on the peat meadow area from culture, they are threatened by planting it full with trees. So that makes it even more complicated.

These are precisely the considerations that I want to put on paper with this study in order to give direction to the discussion whether a food forest as a niche can have a relevant impact on meadow birds in the area.

Bastiaan: In fact, before we started change the landscape on a large scale, it was one big forest. But then a swamp forest. Almost all peat is forest peat.

Paul: If you look a little more recently, you obviously have a whole coppice tradition. So there were woods and also duck decoys and things like that. Those were also small bushes. They were in the open country. And they were an integral part of the peat meadow landscape that we are trying to preserve, and where it has a certain rarity at European level. At the same time, around Rotterdam you notice a very strange dynamic around the open landscape near peat meadow. We are also going to create a food forest to the north of Rotterdam and there is a piece there, only half a hectare of forest may be placed on a piece of one hectare because otherwise it will become too large and then large birds will sit in it and that is dangerous for the aircraft who sit there. In that respect it is a very hybrid landscape. In any case, the entire peat meadow area is, because it is actually located in the middle of the Randstad. That also plays a part. In terms of CO2 storage, that is a lot more complex for a swamp food forest, also in relation to the entire methane issue, I think. Everything is going to be different on peat indeed.

Bastiaan: I think you can draw on from what is known for natural swamp forests. Just swamp forests. I mean the carbon cycle in swamp forests, many studies have been done on that. If you put everything underwater and that prevents the peat from evaporating, you do a lot. The question then is how much methane do you emit. And how does that relate to the CO2 you keep in the ground. I do not know that. There are also bacteria that use methane as an oxidizer under anaerobic conditions and still emit CO2. They are found in those kinds of areas. So you will have to dive into that. I think you can reasonably assume that the same applies to a food forest. Provided, of course, that the water level is high enough. But if you are going to do artificial interventions. I just saw your design where, for example, you want a back that is higher and then slopes slowly towards the locks. That will have an impact.

In previous discussions, the suggestion was made to use the natural differences in height in the existing landscape, how do you view this?

Paul: From a spatial point of view, that is what have also been proposed in the Delta landscape food forest plan. You also have creek ridges in the peat meadow area. Those are natural elevations. Because in any case, if you go up in peat, it also sinks again. So that's a reason not to create artificial ridges. From a landscape point of view, there is some logic in assuming in advance that the entire area will not become a swamp food forest, but that you will indeed look for places where you can.

Bastiaan: I wanted to respond to that. It is perfectly possible, if you wish, to create forest throughout the peat meadow area without artificial interventions. You just can't put all types. I seriously wonder whether we should want species that naturally grow poorly in a place where the groundwater is high to still put them there. And when I look at your species. And especially the large trees, then I only see one species that likes that and the rest absolutely do not want that. Namely the black alder. And there is really more possible than there are really species that produce food under those conditions, but Mulberry and Service tree are definitely not. Rather the opposite. They do well on dry soil. You have to look closely at that.

Are there any big trees that come to mind for these conditions?

Bastiaan: There isn't much of big trees. You do have nuts that come from America, pecans, hickories, which can handle high groundwater levels for quite a while. But not all year. Some arise from those fluvial areas that can flood and where standing water can be present for quite a few months. But after that it's done. At the same time, if the groundwater level is stable all year round, because it no longer needs to be pumped out in the winter, that also changes the story. There are more trees than you think that can cope with a high groundwater level as long as it is the same. Only if the groundwater level becomes high during the growing season. Wait I say that wrong. If the water table is low in the growing season and high in the dormant season, that won't work.

But aren't those exactly the natural water levels? High in winter and low in summer?

Bastiaan: Yes I understand that. You'd have to explore what that difference would naturally be if there wasn't widespread regulation. Because I don't know. This is of course done in the peat meadow area. So that should be your starting point. What would be the natural situation and how bad is that fluctuation, what is the difference between summer and winter. And based on that, you have to look at what you would like to grow here. But I wouldn't mind at all if the conclusion later is that actually we only have black alder. And again there is really more possible. Hazel, for example, can also be grown on very wet soils. Medlars can do that quite well. Fluttering elms fairly wet. Elm/Ash forests also grow in places where the river occasionally overflows its banks and can be standing water for quite some time. But white elm, you can eat the flowers and the young seeds, but you won't get a lot of high-quality food from it. But I think if you put Alder as backbone crown cover, because Alder can just get really thick and tall to really make your forest a forest and thus give all the ecosystem services that a forest ha, that's fine. And then you fill the rest with, I see here on your list: cranberries and blueberries and Bog myrtle. Things that we just know could do well here. Chokeberries, then you still have to pay attention to invasiveness. Because chokeberries are actually just a problem in the low moor area. So not everyone will jump on that. Well, apparently they are doing well there and they supply high-quality food. So that's a complicated decision. You can use climbers. And just to give you an idea, I already thought of that in my head, but never worked it out. old osier beds. That is a landscape with willow trees. Those willows have the property of becoming hollow as they get older. Especially if you knot them every time. And of course those willows can grow just fine when it's wet. Those cavities are slowly filling with soil. And so what you see is that old willows that have become hollow, other trees are sprouting in them. Which could not germinate in the ground. I've seen cherries there and all kinds of other trees that don't hold up at all when the water is too high. So if you start thinking creatively, you can use trees that can handle high groundwater levels as ecosystem engineers to create conditions where other trees can then grow. So I think we need to think a lot more that way instead of trying really hard to plant things that really don't want to grow there. You never know what the future will bring, so I think the whole idea of a food forest should be to create a resilient system. A robust system. You don't know exactly what the final image will be at any given moment, but you bet on multiple species and multiple tracks. This is important. And as much as possible on the natural dynamics. Who adjusts you as a human being to get just that little bit more production out of it. But you have to get it working.

Paul: That is also true for the research that I have done, I have tried to give a historical overview of landscape in three pages from zero to now. So you get a better sense of what you're talking about, the natural dynamic. But you might know that too.

<u>Wouter van Eck (23-04-2021)</u>

Chair Stichting Voedselbosbouw Nederland – owner of food forest Ketelbroek

Your suggestion was to go through the plant list as I have now prepared it. Is there anything else you would like to say in general?

Just see my feedback and input as from a plant nerd with some experience. So all comments about plant species and how well they are expected to thrive are mostly based on literature I've collected and field observations. And so I also have a lot of species in my basket for you that I want to give you that I expect to be promising in these kinds of circumstances. That is in addition to what you have already found yourself. You have made useful use of the plants for a future plant database. Let's run through those first.

Strawberry tree

The strawberry tree is a bit of a slow grower. It is dubiously hardy. So in a really cold winter it won't make it or you'll get a serious backlash. So I don't expect him to be very productive in this system. I don't know what the expected acidity will be. The Ericaceae family of this species likes acidity. So if it's not acidic enough with that clay, he won't be happy standing here.

Hazel

I would put the hazel first for the peat meadow area, because it grows well and there are good productive culture selections with large nuts with a high filling percentage. There is already a market for it. According to the nutrition centre, we should all eat more nuts. And we are now importing from Italy and Turkey. It can even temporarily stand in the water. So it still grows in swamp forests. I actually think that we can convert half of the peat meadow area to hazel systems, but I don't think everyone agrees with me.

Rosaseae

You have rightly picked up several species from the Rosaseae family. And from them the fruit hawthorn from North America is the first one. If you manage to keep 25 cm of rootable space, and that is certainly the intention on those ridges, then they are interesting. Strangely enough even for the big trees. Because a pPar can grow up to 18 meters high, but only needs 25 cm of root space. It is a surface rooter, so it roots in width. The ridge itself will therefore have to be sufficiently wide. But then the botanically tasty rose family can be used relatively without problems. I think 4 to 6 meters wide will be sufficient. That's a bit of playing with the design. It also depends on how much opportunity you see to work with earthmoving or what your sales will eventually be. A fruit hawthorn on the other side needs a much narrower ledge of one and a half meters. If you make a wide back, just when that pear gets really high, you can put quince and fruit hawthorn as intermediate categories, at a smaller distance on the south side of that row of pears, creating a rising hem. While the hazel likes partial shade, so you can put it behind it on the north side and also a bit lower.

Specifically about the mulberry, I was told it needed more permeable soil than probably will be the case here. How do you see that?

I hear different things about that. It's almost what we have yet to test. Because at least it can bear fruit in partial shade. I have observed this for mulberries myself and found it in literature. While some books say, it must be sunny. But luckily he didn't read that. And specifically with the lesser-known crops, this is more common. That things are repeated on the internet, while it is actually not validated. Just because he gives fruits in the sun doesn't mean he doesn't in the shade. They did a bit of research to figure out what the root system is, but it conclude the Mulberry has tap roots. Tap roots is a risk zone for a swamp forests. Because they want to breathe in the soil. And that's why chestnut, walnuts and persimmons just fall off. But the Mulberry is an intermediate category, so I would secretly just include it. I would stick to the credo there: where it is plausible that it does not work, you do not do it, but where there is a chance that it will work, you try. So it's a bit like trying that chance.

Are there any other comments about the rose family that you would like to make?

One that is not listed and is well known in the Netherlands is the apple. Because that too is one of the rose family. Along with pear and plum that are there, there are so many different varieties in cultivation that there are also different rootstocks and varieties grafted on that rootstock. And then a vigorously growing rootstock actually seems better suited for this system, because a weak growing rootstock is less vital and less healthy. But they are all superficially rooting rootstocks, because they are in the rose family. So they go wide rather than deep. So that's why my preference would be to grab a sturdy growing rootstock for half-stem or standard trees. You get a tree that is healthier and does not give up completely or becomes susceptible to disease in the event of a minor setback.

Alder

The black alder belongs to the swamp forest that has created the low moor in the Netherlands. It just grows thirty meters high in the water and it is a nitrogen binder. As a system tree, it's super good. We cannot eat anything from its own leaves and fruits, but you could possibly use it as a climbing frame by placing kiwi berries along it, for example. And that's one tip I want to pass on. The kiwi berry has very superficial roots and likes moisture. Actinidia is the genus and the kiwi berry is the Actinidia arguta. It makes berries like grapes. I like that better than the regular kiwi. Several varieties have been developed in Poland and Hungary for which I see a bright future. Then the only drawback is that with a spring like the one with those warm days and the occasional frost, it sprouts too early and then freezes. Then it will come back later, but then you will hardly have any harvest that year. If the area where you are located is probably less affected by late night frosts due to the influence of the sea. One last thing about the black alder. You can also put them in the water on the north side of the ridge instead of on the back so that you create more wind shelter for the other trees in the bare plain of the landscape there. And if necessary, they can also plant in a fairly close connection to get the system up and running more quickly, to provide wind shelter and to produce organic material. Later you could thin out and possibly graft on the shiitake trunk. Then you can grow edible mushrooms on the wood as a follow-up cultivation.

Do you see any further use of the wood?

Funny enough Alder wood in Germany is much more common to use it though. The Netherlands almost exclusively uses pine and imported oak. But alder wood is very sturdy wood. Amsterdam is built on stilts and those are alder trees. Alder can also be used for furniture and floors. Has a bit of a nice red tint to it. But that market in the Netherlands is quite conservative so you almost have to bring it to Germany and then import it again when it's processed.

<u>Currant tree</u>

In itself a beautiful tree and on the back it will do, but it does not give a great harvest.

<u>Bud yew</u>

It really thrives under the other vegetation layers in a forest system, so is good for shade. It is a slow starter that you should only plant when there is some shade. Otherwise he is unhappy. Then you need a phaed planting. But then it is a special plant with special fruit.

<u>Cornelian cherry</u>

There are also fruit selections from Eastern Europe that produce thicker berries or plums. It is valuable to the system anyway because it flowers early in January February. This allows insect populations to settle, feel at home and also pollinate the later fruit. So giving it a place in the system is very useful.

<u>silverberry</u>

This one is not as productive, but it does have the advantage of being evergreen and can be shaded. The Elaeagnus umbellata is the insanely productive olive willow. It is therefore family of the Eleagnaceae, the olive willow-like. And then the Elaeagnus umbellata is undisputed topper in productivity, fast growth. Also insanely many flowers that are very popular with insects. The umbellata is about the same size as the ebbingei. That goes pretty quickly. The umbellata is actually a bit of a pioneer. He at least likes a sunny flank. It is a sun lover. The ebbingei can be grown in partial shade. So in principle it could be among the hazel trees. And then you basically have a bit of a system plant with that, but the productivity is nothing.

Ribes

There are several species of the ribes genus. You have the black currant here, but you also have the red currant, the gooseberry, and others. Like the Worcestershire berry, for example. I consider them all suitable, because they also grow traditionally in mixed swamp forests. Red currants and Gooseberries are actually native as well. Those forests are now gone. The last swamp forest was cleared in 1880 near Apeldoorn. And in descriptions you will find that there were alders of 35 meters high. You can't imagine that now. What we have now is all still very young.

Rubus

The same applies in principle to the raspberry. It doesn't like full sun at all and it likes moisture. So it will do well in such a system.

Ericaceae

Then two more come from the heather family, where if the soil is not acidic, their advantage is lost. And certainly the cranberry wants a sunny spot without competition, so I think that is quite difficult in polyculture. Although it is in a place in the Green Heart where they ensure that the water level is plus and minus two centimetres, it can start to feel good there. The bush blueberry grows more robust and can even stand a bit drier. And that's actually the American blueberry. There is a large nursery close to the Peel in Limburg or Brabant. They also have good conditions, but they have even something of an invasive character, because for a bog reserve this is an unwanted intruder. But there is no original nature anymore in peat meadow area, so that is not really an issue there.

Bog Myrtle

Bog Myrtle is actually a popular herb at the brewery. We also have him at Ketelbroek and he needs sufficient moisture and sufficient sun, but otherwise he is not that picky at all. So he can reach it and he is also a nitrogen binder.

Rhubarb

I find the rhubarb exciting because it is also semi taproot. Or he has to sit on the back and with his large leaves he is happier in the partial shade than in the full sun. But too soggy I suspect he's not doing it right. Then that taproot can rot away.

We're through my own list. You indicated that there were a number of plants that you considered suitable for this area. Which are they and why?

I have already mentioned the kiwi berry. The one that I would like to tip you further is bamboo of the genus Phyllostachys and then you will quickly find which varieties are hardy. Because some lose weight because they will freeze to pieces in a cold winter. And then bamboo is of course a bit notorious for its rapid growth and once established that it will proliferate. But what you harvest from the bamboo to eat are the young shoots. In Asian cuisine there are plenty of tasty recipes. The chef to whom we supply has of course also done so. So when people say oh but hey a rampant bamboo then they just didn't eat well, because they could have broken off more shoots in the spring. Then you take the plant's energy and limit the place where it grows and it doesn't get any further. So in the period when he throws shoots. That's late May, early June the sideways expansion starts, but that's also your harvest zone. And those young shoots also break very easily from the rhizome. It's one of the most efficient crops at getting carbon from the air into the soil because of its rapid growth, but that goes for the zone where you grow them and at the edge you take the harvest off. And its rhizome is very shallow so it can grow in swampy conditions.

Then a shrub that occurs in the old moist forests of Europe and probably also existed in the Netherlands, but which has never been demonstrated. That's the Bladdernut. It has a strong root system in the topsoil. It likes a moist growing spot. He likes partial shade. Little nuts are coming. They appear to be edible. But the funny thing is that the flower clusters, the buds and the young leaves are very edible early in the year. So you can harvest and eat the leaves and the flower clusters, there are a lot of them. That's what they learn from the field of ethnobotany. In Georgia, where it also occurs in humid forests, they all have recipes for it and they go into the forest to harvest in the spring to eat immediately or pickle for other seasons. It is perfectly hardy and likes a swampy spot and likes partial shade. So I see him as very suitable for this system. Those were the most important additions I wanted to give.

An aspect that we have not yet discussed in relation to a food forest in the peat meadow area is the meadow birds. How do you view that?

It's almost philosophical. There may be one and a half Lapwings. Does it outweigh the Stonechat, Redstart, Reed warbler and other birds that return to this system? That's a fascinating discussion.

Finally, is there anything else you would like to include for this project?

You are familiar with Jan Boulestreau's study on rational ha. It would be nice if you also translate the system about species and the ridge and the water into such a rational hectare with insolation. If you have any doubts about which species on which side or which size, just get in touch. That really helps people understand what it does in terms of productivity, harvestability, and species richness that you can amass. The disadvantage of Ketelbroek is that it is hyper-diverse, then it is mainly a beautiful picking paradise or edible jungle or whatever. But you should not be afraid to apply this system for the translation to large-scale systems on a landscape scale.