SUSTAINABILITY ASSESSMENT OF COMPLEX AGROECOSYSTEMS
a case study at Ketelbroek Food Forest

Name student(s): Matthijs Bakker

Period: April – November 2016

Farming Systems Ecology Group
Droevendaalsesteeg 1 – 6708 PB Wageningen - The Netherlands

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UNIVERSITY & RESEARCH

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Name student(s): Matthijs Bakker
Registration number: 910118-030-120
Course code: FSE-80436
Period: April – November 2016
Supervisor(s): Kees van Veluw
Professor/Examiner: Egbert Lantinga

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ABSTRACT

Originating in tropical regions of the world, agroforestry only recently started to gain popularity in Europe and the northern part of America. Recognized for its potential to be a more (bio)diverse, resilient and independent type of agriculture, a number of western agroforestry projects have emerged. Until now, only little scientific research providing insight in the performance and sustainability of this type of agriculture in European conditions has been done. In this study, the assessment of sustainability of complex agroecosystems is discussed. At three study systems (Food Forest Ketelbroek, Nature Area De Bruuk, conventionally managed permanent grassland) empirical data was collected for nine indicators of sustainability. This data was used to calculate sustainability scores for the different systems and serves as baseline data in further research at food forest Ketelbroek. Although it was intended to aggregate the sustainability scores of each system in one composite score of sustainability, this technique is demonstrated to be delicate and to possibly result in wrong conclusions. Alternatively, the indicators of sustainability were subdivided by the three aspects of agricultural sustainability they relate to (biology, soil quality and groundwater quality). Food Forest Ketelbroek was found to be most sustainable in light of biology (biodiversity and abundance). Nature Area De Bruuk was found to be most sustainable in terms of groundwater quality (contamination of groundwater). The permanent grassland was found to be most sustainable in relation to soil quality (carbon storage, cation exchange capacity, soil pH). Finally, recommendations for future research on sustainability assessment of complex agroecosystems and agroforestry systems in particular are given.

INTRODUCTION

Recognizing the (scientific) argumentation of modern ‘conventional’ agriculture being unsustainable in multiple ways, many alternatives for a more sustainable form of agriculture have been proposed. Subsequently, two important questions arise: ‘what is sustainable agriculture?’ and ‘how to recognize it?’ In reaction to the first question, multiple definitions of sustainability in agriculture have been formulated. These definitions differ in the considered timespan (sustainable for 50, 1000 or endless years…?) and the included dimensions of sustainability (ecological, social, economic). The second question, how to recognize sustainable agricultural practices, leads to a wide range of indicators that try to measure (parts of) the ecological, social or economic well-being of a farming system. Some indicators tend to focus on very specific processes while others work on a system-level evaluating the result of multiple interacting processes. However, they all aim to compare a measurable element of the system with an ideal value based on theories and context.

After years of increasing knowledge on the ecological, climatic and social influences of large scale conventional agriculture that follows an industrial approach towards food production, multiple alternative agricultural philosophies or mentalities arose. Anno 2016, most of these alternative agricultural styles are categorized as organic agriculture as they meet the conditions formulated in the principles of organic agriculture. However, diversity between organic agricultural styles is high; ranging from industrially organized monocultures to highly diverse food forestry systems.
This study is orientated towards this last category of food production strategies, referred to as agroforestry and food forestry. As the name implies, this agricultural approach or strategy is based on ecological characteristics of a forest and focusing on cultivation of perennial food producing plant species. In contrast to the classic tree orchard, a variety of annual and perennial edible plants (fruits, leaves, seeds, nuts, tubers) are combined in a design that is inspired by forest ecosystems. To what degree an agroforestry system is different from ‘normal’ agricultural systems varies. For instance , alley cropping agroforestry systems, designed to allow for mechanized harvesting techniques, are relatively species diverse but very homogenously designed (Figure 1). Food forest systems aim to implement vegetation patterns in its design as they can be seen in natural forest ecosystems (Figure 2).

FIGURE 1: EXAMPLE OF RELATIVELY HOMOGENOUS, MULTI SPECIES, AGROFORESTRY SYSTEM (SOURCE)

FIGURE 2 : EXAMPLE OF HIGHLY HETROGENOUS AND SPECIES DIVERSE FOOD FOREST SYSTEM (SOURCE)

Theoretically, agroforestry systems are argued to be more sustainable than conventional agriculture that focusses on annual crops cultivated in monocultures. This is for multiple reasons; higher and more nutritional yields, less need for fossil fuel inputs and less externalities per unit of produced food. Although scientific studies and practical agroforestry projects do find evidence to confirm aspects of these promises, it remains hard to understand the overall 'sustainability performance' of agroforestry systems and agriculture systems in general. A complicating factor in agroforestry research is the influence of time. In contrast with annual crops that are typically harvested within one growing season or one calendar year, agroforestry systems require an investment of much more time in order to produce significant amounts of food. Until now, agroforestry and especially food forestry is no common agricultural practice in Europe or North America. Consequently, only limited food forestry systems can be studied and only little empirical research has been done on the overall sustainability of a western, mature, food forest so far. Therefore, most available knowledge is based mainly on agroforestry practices in tropical areas where this type of agriculture is found more often.

PURPOSE OF STUDY

This master thesis reports on the conduct of the scientific monitoring and assessment of the sustainability performance of an agroforestry system, permanent grassland system and a nature area. The purpose of this study was to assess and compare these three systems on their sustainability.

Furthermore, this study has to function as baseline for further scientific research at Ketelbroek food forest in the Netherlands. The indicators 'surface water quality', 'base saturation' 'Visual Soil Assessment' and 'dry bulk density' have solely been included for this purpose.

During the first phase of this research project, a list of indicators for sustainability of an ecosystem was defined.

In the second phase of this study, empirical data for all indicators of sustainability was obtained for the three selected model systems.

During the third phase, the dataset was analysed quantitatively and qualitatively. Subsequently, the three model systems' sustainability was assessed per indicator.

The discussion section will encompass a reflection on

- the effectivity and meaningfulness of the different indicators of sustainability
- the difficulties I encountered interpreting the data and
- the meaningfulness of a multi-indicator based sustainability assessment

Concluding this thesis, the following research questions are answered

- Based on the selected indicators: which of the three model systems is the most sustainable?
- Does the list of selected indicators result in a good understanding of an agro-ecosystem's sustainability?
- Are more/less indicators needed? And if so, which indicator shave to be added?
- Provides the list of indicators a sufficiently objective outcome?

METHODOLOGY

LIST OF INDICATORS

An intensive literature study on 1) agricultural sustainability assessment and 2) scientific (epistemological) difficulties in sustainability assessment, was performed. Based on literature, a list of agricultural-sustainability indicators was composed. Three model systems were selected as study sites for the empirical part of the study; food forest De Ketelbroek, agricultural grassland and Natura 2000 nature reserve De Bruuk, Groesbeek, the Netherlands. Subsequently, a final list of indicators to be tested by field research was defined in association with an important stakeholder, the co- owner and manager of the Ketelbroek food forest. Wouter van Eck. Each indicator belongs to one of the most important dimensions of ecological sustainability of an agro-ecosystem, namely, biological quality, soil quality and groundwater quality. The objective of biological quality/sustainability is to maximize and maintain biodiversity. The objective of the soil aspect of sustainability is to facilitate optimal plant growth while storing carbon and minimizing nutrient losses. The objective of the (ground) water aspect of agro-ecological sustainability is to maintain clean groundwater suitable for human consumption. The indicators were selected on presumed relevance and feasibility (data collection, analysis and interpretation realizable within a time limit of circa 5 months). Basic assumptions on most sustainable values were formulated per indicator (Table 1).

TABLE 1 : SELECTED INDICATORS OF SUSTAINABILITY AND ASSUMED OPTIMUM VALUES

Indicator	Relation to Sustainability	Assumed optimum value
% Soil Organic Matter	Carbon sequestration, positive influence on soil quality	The higher, the better – more storage of carbon
Soil pH	Optimum values for plant growth, potentially more nutrient leaching at lower pH	Near neutral (pH 6-8)
Dry Bulk Density	Indicator of soil compaction	No signs of soil compaction
Earthworm density	Measure of soil quality, positive influence on soil structure	More earthworms indicate better soil management
Groundwater quality (nitrogen and phosphorus contamination, pH)	Indicating over-fertilization / nutrient leaching Groundwater quality should be sufficient to be used as drinking water	The lower, the better Neutral pH (7) optimal
Biodiversity (birds, beetles, butterflies, plants)	Higher biodiversity related to higher resilience of system Ecological function (pollination, pest control etc.) Cultural value	The more diverse, the better
Cation Exchange Capacity	Capability of soil to capture/hold cations and therefore minimize losses by leaching that possibly result in groundwater contamination	The higher the better
NDVI	Capability of vegetation to use photosynthetic active radiation – measure of chlorophyll density	The higher the better (as: more photosynthesis is more biomass production is more carbon sequestration and potentially food production)

STUDYSITES

Ketelbroek

The 'Ketelbroek' is a relatively young food forest located near Nijmegen, the Netherlands, on a piece of agricultural land that formerly was used to grow silage maize. In total, the land measures 2,42 hectares and houses an estimated 2000 introduced edible plants (around 420 different species, both indigenous and non-indigenous). Six years ago (2010), the first part of the food forest (Ketelbroek Food Forest, KFF) was realized, measuring around 0,8 hectares. The agroforestry part (Ketelbroek Agroforestry, KA) was realized four years ago (2012). This part of the system measures around 0,8 hectares as well. Next to the planted trees and shrubs and their offspring, mostly native plants live that settled without the (conscious) help of men. The remaining 0,8 hectares are uncultivated and treated as nature area (Ketelbroek Nature, KN).

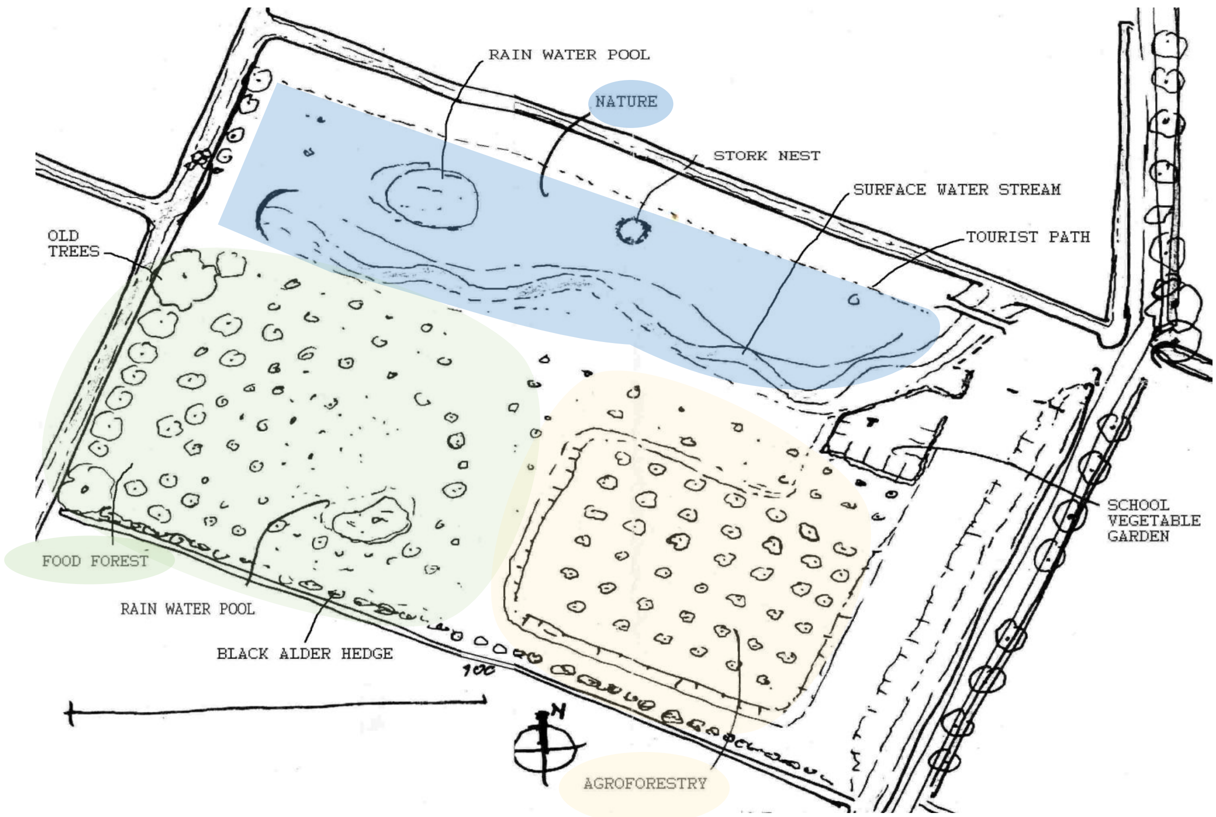


FIGURE 3 GENERAL DESIGN MAP OF FOODFOREST KETELBROEK ANNO 2014 (BY XAVIER SAN GIORGI - ADAPTATIONS BY ANASTASIA LIMAREVA)

The area is geographically interesting because of the land-shaping effects of glacier ice movement in the mid Pleistocene (Saalien, 0,239 – 0,126 Ma ago). During the late Pleistocene (Weichselien, 0,116-0,0117 Ma ago), the glacier ice retreated and löss deposition occurred in this area. The löss originated from the – at that time dry – North Sea and was transported by winds. Nowadays, a horizon of löss-soil is still present near the soil surface.

The food forest is located in the valley, surrounded by glacier moraines. Rainwater that infiltrates the land upwards the glacier moraines will move towards lower parts of the area through gravitation force driven groundwater flows (visualized in Figure 4). In the valley (referred to as discharge area), the groundwater is forced up in the soil profile and can reach the soil surface. This process is called ‘seepage’ (Dutch: kwel), resulting in a very high groundwater level that artificially must be lowered for land cultivation. Furthermore, the groundwater that is forced upwards is alkaline (pH of around 7,5) as it reacts with calcareous substances in the soil.

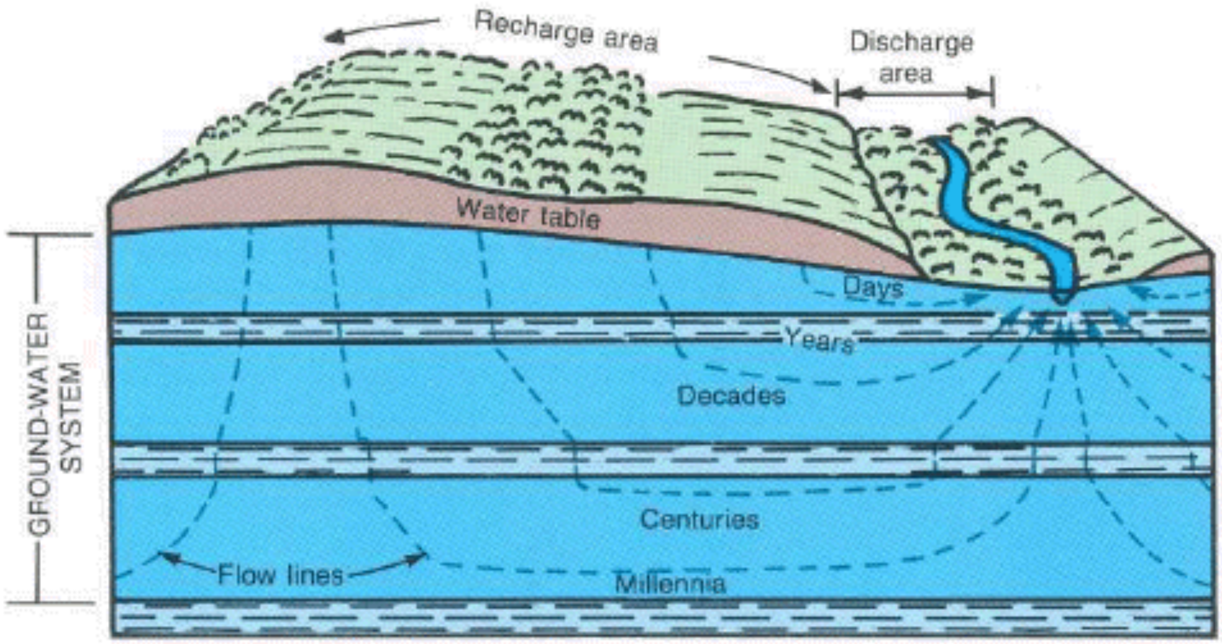


FIGURE 4 : VISUALISATION OF GROUNDWATER MOVEMENT PATTERNS AS PRESENT IN STUDY AREA. ALL STUDY SITES ARE LOCATED WITHIN THE DISCHARGE AREA AND SUBSEQUENTLY EXPERIENCE HIGH NATURAL GROUNDWATER TABLES.

Ketelbroek is surrounded by agricultural land (permanent pastures and silage maize – potato rotations) and is positioned next to a small road. Within around 500 meters, semi-nature area De Bruuk is situated.

De Bruuk

Nature area De Bruuk consists of around 100 hectares of wetlands and wet forests and is managed in a way that supports the unique and rare ‘bluegrasslands’ (“De Bruuk : Natuur in Nederland,” n.d.) . This means the grasslands are mown twice a year and the hay is removed. In this way nutrients are removed, a procedure that favors rare plant species adapted to nutrient-poor wetlands and forests. Nature area De Bruuk (NA) is included in this study as we argue it symbolizes a relatively constantly, passively, managed system that is argued to be in its successional climax state. Except for mowing and extraction of grasses from the system, it was not intensively used as agricultural land for centuries. Together with Staatsbosbeheer a study/sampling site (Figure 5) was selected and approval was given to enter this part of the nature area. For all samples, GPS coordinates are included in Appendix 1**.**

FIGURE 5 : MAP OF DE BRUUK NATURE AREA

Grassland

The third system that is included in this study (with exception for the work on biodiversity indicators, which was done by Emma Dijkgraaf and Jeroen Breidenbach) is a 2.02 hectares plot of permanent grassland (PG) used for fodder production at least since 2009 (based on publicly accessible governmental data). The plot is located directly next to Ketelbroek Figure 6. It is conventionally managed in the sense of fertilizer and pesticide application. Except for some weed contamination, it is a monoculture of English ryegrass (Lolium perenne). Next to fruit tree orchards, a permanent grassland is one of the few perennial farming activities commonly practiced in the Netherlands, making it an interesting farming strategy to include in this assessment study (conventionally managed perennial monoculture next to the 'naturally managed' perennial polyculture of the food forest).

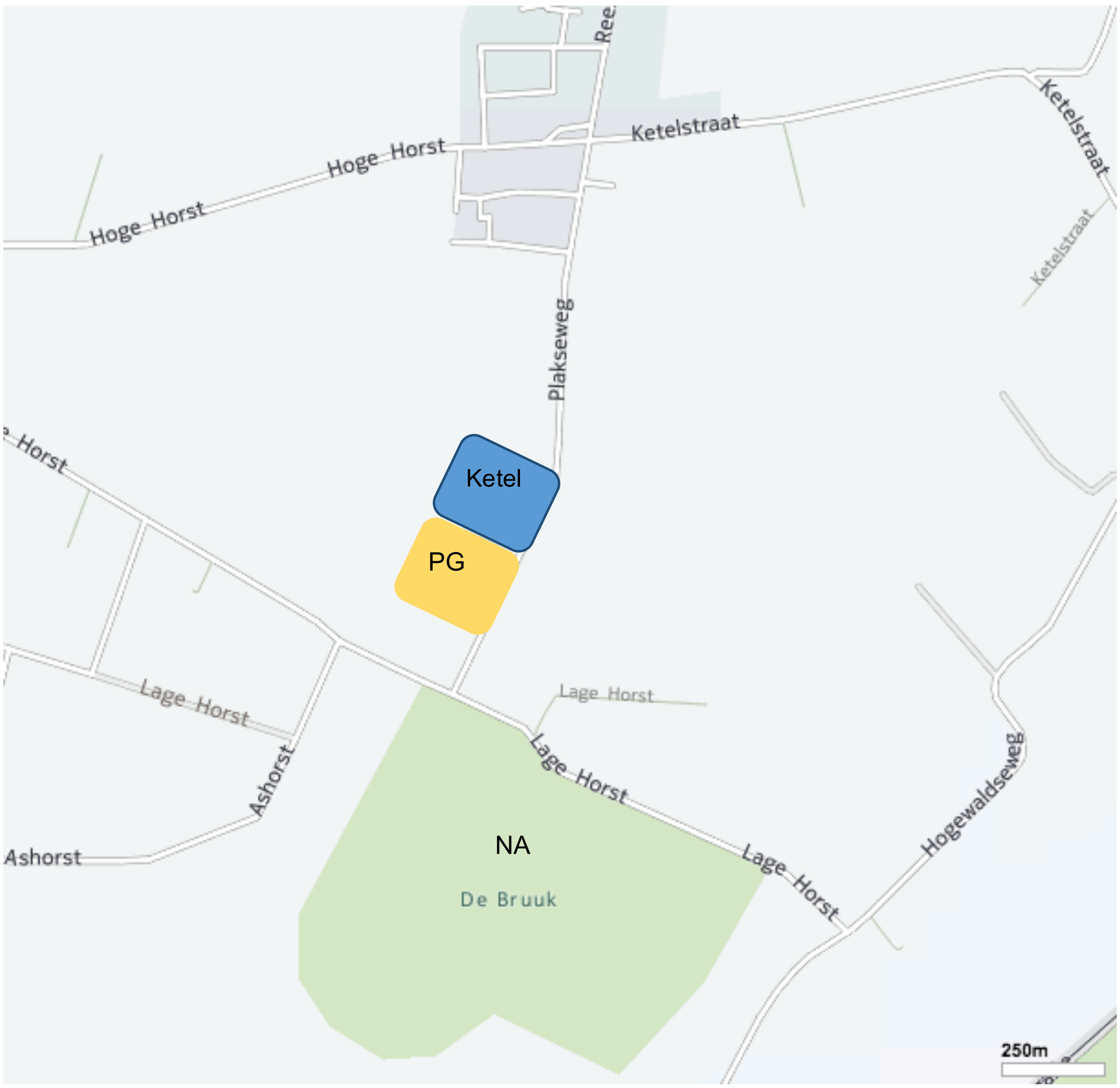


FIGURE 6 : RELATIVE LOCATION OF KETELBROEK, PG AND NA DE BRUUK

FIELD MEASUREMENTS

DRY BULK DENSITY

For each study site, soil bulk density samples were taken on the 14th and 15th of June 2016. Ten samples were taken per system, starting at the soil surface (sample depth ≈ 0-15 cm). Prior to sampling, ‘sampling zones’ were indicated on aerial maps of the study sites in a semi-regular systematic grid. In field, sample sites were chosen within the sampling zones, based on accessibility and local field conditions. Samples were taken with the Eijkelkamp Bulk Density Soil Sampler and the standard operating procedure (SOP) as described by California Department of Pesticide Regulation was followed (Department of Pesticide Regulation, n.d.).

SOIL CHEMISTRY

Soil samples were obtained on the 28th of June, 2016. Per study site, *five* soil samples (0-30 cm) were taken (see appendix 1 for exact locations) that were selected to cover spatial differences (vegetation types, soil moisture) within each study site. Following standard sampling techniques, the soil samples consisted of 10 subsamples to account for local variation and were taken in a 3 a 4-meter-wide circle around the groundwater sampling well (Figure 7). This standardized sampling technique is preferred over others as it levels out extremities. Samples were stored in airtight plastic bags, and within 6 hours after sampling, dried for 24h at 40 ℃ in a drying oven. After mechanical homogenization, samples were stored in plastic airtight containers.

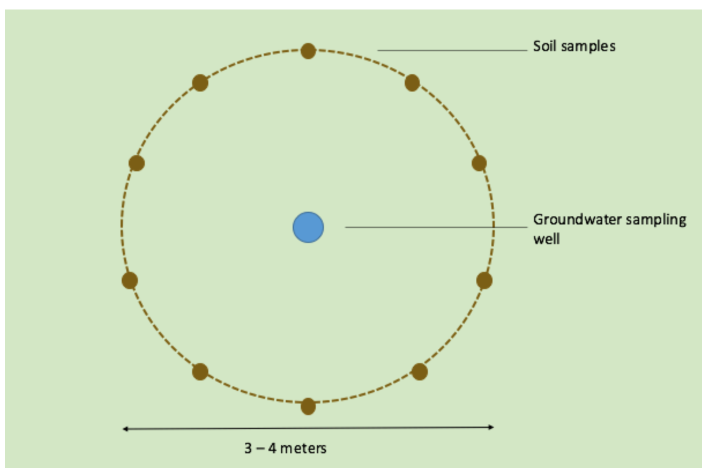


FIGURE 7 : SOIL AND GROUNDWATER SAMPLING ROUTINE

(GROUND) WATER CHEMISTRY

Ground- and surface water samples were obtained on the 28th of June, 2016. A standard soil drill/auger was used to make the groundwater wells. For most sample sites, groundwater started to fill the wells when a depth of only 100 to 150 cm was reached. For at least five minutes (starting from the moment at which the groundwater began to fill the well), the well was left alone to let debris settle and to allow groundwater to fill the well. A tube connected to a large syringe was used to obtain the groundwater samples from the well. Samples were stored in air and water tight containers and stored in the refrigerator.
Additionally to groundwater samples, two surface water samples were taken from the stream that crosses the food forest. Samples were taken from the culvert at which the stream enters the food forest and from the small bridge at the end of the stream (see Figure 8).

FIGURE 8 : SURFACEWATER SAMPLING POINTS AT ENTRY- AND EXIT- POINT OF WATERSTREAM RESPESPECTIVELY. WATER FLOW-DIRECTION INDICATED BY ARROWS.

EARTHWORM POPULATION SAMPLING

In this study, earthworm populations were assessed on their size (number and biomass of earthworms), the proportion of the population being adult or juvenile and to lesser extend their functional diversity. Worm population sampling was carried out on the 12th and 13th of July, 2016. Soil humidity was considered to be high, in some cases very high (permanent grassland). Per study site, five samples were taken. Soil blocks of 30x30x30 cm were manually excavated and transported in plastic bags to the base camp to be processed. To extract all earthworms, the soil blocks were manually broken apart until no more worms could be found. Earthworms were stored in aerated, soil filled plastic bags to be examined on biomass and ecotype in a controlled environment and were released afterwards.

Sampling of ground dwelling insects, macrolepidoptera (nocturnal butterflies) populations and breeding bird territories was carried out in the light of a biodiversity study in the period of the 18th of April till the first of July 2016 by bachelor students Emma Dijkgraaf and Jeroen Breidenbach of the Van Hall Larenstein University of Applied Sciences, Leeuwarden, the Netherlands. Data was shared for research purposes.

Ground beetle populations were sampled by pit trap sampling at the nature reserve and the food forest. One cultural and two agricultural typologies were discerned at the Ketelbroek food forest (food forest, agroforestry and nutrient depleted nature area) and analogies were found at the Bruuk nature reserve. For each typology and its analogy at the nature reserve, a series of five pit traps were placed semi-randomly. Once a week, pit traps were emptied and processed (species determination and quantification). For a comprehensive methodology and analysis regarding these three specific indicators of biodiversity, please be referred to the work by Dijkgraaf and Breidenbach (Emma Dijkgraaf and Jeroen Breidenbach HVHL Leeuwarden 2016).

Macrolepidoptera populations were studied weekly for 11 weeks in total. Two sample sites (one per study site) were chosen for their accessibility and their comparable vegetation type (grassland / herbaceous vegetation at the edge of the forest) (appendix 1). Specific sampling moments where chosen based on the weekly weather forecasting. Sampling was started after sunset and lasted five hours. A white projection screen was lit by a 250 watt construction lamp that was powered by a generator. Butterflies that were attracted to the light were actively caught using nets and stored for determination. Details on climatic conditions and other factors, known to influence macrolepidoptera' behaviour, were noted.

Breeding bird territories were inventoried following an adapted BMP (Broedvogel Monitoring Project; Breedingbird Monitoring Project) counting ("Broedvogelmonitoring (BMP) | Sovon.nl," n.d.). During eight counting sessions per study site (seven at sunrise, one at night), observers followed fixed routes within a fixed timeframe (2 hours) by foot. Observed territorial behaviour was marked on aerial maps of the study site. For a comprehensive description of the followed procedures, please be referred to Dijkgraaf and Breidenbach (Emma Dijkgraaf and Jeroen Breidenbach, HVHL Leeuwarden 2016).

To quantify and reflect on the species diversity in the three datasets that resulted from the above described population sampling series, Shannon-Wiener diversity indices (H') were calculated. In this case, this diversity index expresses how equally abundant species occur in a population of multiple species. Mathematically, the index expresses how difficult it is to correctly predict what species would be 'picked' from a population when this population is blindly sampled. For example, when a population exists of 100 individual animals (n=100) belonging to 5 different species (S=5) it would be easier to predict correctly what species is sampled if 96 individuals of that population belong to species X (n_x=96) than if all species are equally abundant (n=20 for all species).
The Shannon-Wiener diversity indices were calculated using the formula:

$$\mathrm{H}' = -\sum_{i=1}^{\mathrm{S}} (pi \ln pi)$$

With:

$$pi = \frac{ni}{N}$$

And:

$$ni = individuals\ of\ species\ i$$
$$\mathrm{N} = individuals\ in\ population$$
$$\mathrm{S} = number\ of\ species$$

NORMALISED DIFFERENCE VEGETATION INDEX (NDVI)

Yearly (2012, 2013, 2014, 2015, 2016) average NDVI values for three zones (KFF, KA, PG) were calculated for data obtained manually from the publicly accessible platform 'Groenmonitor' (Alterra Wageningen UR, 2016). This NDVI dataset is based on satellite images of three different types that all have their own spatial and temporal resolution as well as their own measuring techniques.

NDVI values in practice are within the range of 0 to 1, which (although simplified) can be interpreted as: what fraction of the photosynthetic active radiation is absorbed in the process of photosynthesis (ranging from none (0) to all (1)). The following equation is used to calculate normalized difference vegetation indices:

$$\mathrm{NDVI} = \frac{(\mathrm{NIR}-\mathrm{VIS})}{(\mathrm{NIR}+\mathrm{VIS})}$$

With

$\mathrm{NIR} =$ near infrared radiation

$\mathrm{VIS} = \text{visible radiation}$, photosynthetic active radiation

To calculate input values (NIR and VIS) for this simple equation, complex calculations on the 'raw' satellite dataset are necessary. As understanding the techniques behind these calculations is not strictly needed to work with NDVI values, elaborating on this topic is not relevant for this study. However, extensive descriptions on methods used by Alterra to disclose this dataset are available online (Alterra Wageningen UR, 2016).
Unfortunately, NDVI values are published only when suitable information could be gathered. Sometimes, satellites cannot function because of weather conditions or other influences. This results in slightly varying time intervals between data points. More NDVI data is available during summer as result of weather conditions, which potentially influences average values. Different methodologies that deal with the problem of varying time intervals between data points potentially result in slightly different results. In this study,) the NDVI value of the 1st of every month was used to overcome a 'varying data density' bias.. In some cases, this means that values were obtained by linear interpolation instead of actual measurements.

LABORATORY ANALYSES

SOIL ACIDITY

Soil acidity was measured using the H_2O extraction method. Soil pH-H_20 values were obtained following the standard as described in ISO/DIS 10390: (1994) Soil quality- Determination of pH.

SOIL ORGANIC MATTER

To assess the soil organic matter gravimetrically, the loss-on-ignition procedure was followed as described in the standard procedure (appendix 7).

CATION EXCHANGE CAPACITY (CEC)

Cation Exchange Capacities and base saturation were tested at the Wageningen UR laboratory, following all standard procedures as described in (Houba, van der Lee, & Novozamsky, 1997).

WATER CHEMISTRY

Groundwater samples were taken on the 28th of June and tested for their concentration of N-NH4, N-NO_3, P-PO_4 and their pH. N-NO_3, N-NH_4 and P-PO_4 were measured spectrophotometrically by means of segmented-flow analysis (Houba, Temminghoff, Gaikhorst, & van Vark, 2000). pH values were measured using a calibrated pH-meter and probe, following all standard procedures.

RESULTS

DRY SOIL BULK DENSITY

Dry soil bulk densities differ greatly per study site. Highest values were found at KFF (1.31 g/cm3) lowest at NA (0.645 g/cm3) clearly indicating topsoil in the food forest to be more compacted than in the nature area. Assuming all study sites have the same soil type (loam / sandy loam), differences in dry bulk density can be explained primarily by percentages soil organic matter, which indeed is negatively related to bulk density values (Table 2). Average dry bulk densities are within the optimum range for loamy or sandy loamy soils as described by USDA in ("Guides for Educators," n.d.). It should be noted that values presented here resemble the soil density of the topsoil layer (0-15 cm) and therefore contained high amounts of organic matter. Most likely (typically), soil density increases with distance from the soil surface.

TABLE 2 AVERAGE DRY BULK DENSITIES AND SOIL ORGANIC MATTER CONTENT

Indicator	Ketelbroek	PG	NA
Dry soil bulk density - average	1.31 g/cm3 (SEM=0.034)	1.08 g/cm3 (SEM=0.025)	0.645 g/cm3 (SEM=0.04)
% Organic matter - average	4.21 (SEM=0.28)	5.77 (SEM=0.22)	8.17 (SEM=1.095)

SOIL CHEMISTRY

SOIL PH-H20

On average, soil pH values are highest at Ketelbroek ($pH_{average}$ = 5.78) and lowest at the nature area ($pH_{average}$ = 4.48). Local variation in soil pH (variation within study site) is low, which is particularly interesting for the food forest, considering the differences in soil profile for KFF and KA.

TABLE 3 SOIL PH-H20 VALUES AND AVERAGES

Study site	Sample Nr	pH-H2O	Average
KA1	1	6.14	5.8
KA2	2	5.94	(SEM=0.16)
KFF3	3	5.58	
KFF4	4	5.28	
KN5	5	5.98	
PG11	11	5.41	5.5
PG12	12	5.58	(SEM=0.04)
PG13	13	5.56	
PG14	14	5.42	
PG15	15	5.6	
NA21	21	4.14	4.5
NA22	22	4.62	(SEM=0.13)
NA23	23	4.3	
NA24	24	4.43	
NA25	25	4.9	

In Table 2, the average percentage soil organic matter (%SOM) for each study site can be found. Data from different sample sites can be found in Table 4. Especially for NA, %SOM is highly diverse among different sample sites (ranging from 5.29% up to 11.28%). Likely, this results from different nature conservation strategies within this area. Lowest percentages of organic matter were found at Ketelbroek. Worth mentioning is sample 5 (KN), which was taken in the nature area of Ketelbroek. In this area, the soil was impoverished by turf stripping in 2012, removing all topsoil and subsequently its organic matter. This probably explains the low percentage of SOM that was found at this sampling site (KN-5).

Cation exchange capacities highly differ per sample site, but on average seem to follow the same pattern (NA>PG>Ketelbroek) as average soil organic matter percentages (Table 4 & Table 5).

TABLE 4 PERCENTAGES SOIL ORGANIC MATTER AND C.E.C. VALUES

Sample	**C.E.C.** (cmol+/kg)	**%SOM**	**Average C.E.C.** (cmol+/kg)
KA1	7.24	4.00	5.18
KA2	7.21	4.63	(SEM=1.46)
KFF3	0.67	4.25	
KFF4	2.79	4.92	
1KN5	7.99	3.26	
PG11	13.05	6.24	6.88
PG12	8.37	6.34	(SEM=1.77)
PG13	4.18	5.62	
PG14	3.20	5.27	
PG15	5.60	5.38	
NA21	8.28	11.28	7.84
NA22	1.04	5.29	(SEM=1.74)
NA23	10.29	7.95	
NA24	10.16	9.9	
NA25	9.45	6.45	

In Table 5, cation exchange capacities and base saturation number are given per sample site. Although base saturation values will not be discussed in this study, they are included as reference data for future studies.

TABLE 5 : C.E.C. VALUES AND BASE SATURATION (CMOL+/KG)

Sample Site	**C.E.C.** (cmol+/kg)	**Na** (cmol+/kg)	**K** (cmol+/kg)	**Mg** (cmol+/kg)	**Ca** (cmol+/kg)
KA1	7.24	0.00	0.14	1.11	13.09
KA2	7.21	0.00	0.47	1.14	14.04
KFF3	0.67	0.00	0.43	0.52	11.33
KFF4	2.79	0.12	0.79	0.50	12.02
KN5	7.99	0.00	0.00	1.00	14.57
PG11	13.05	0.00	0.37	2.47	14.41
PG12	8.37	0.00	0.07	2.11	14.33
PG13	4.18	0.00	0.03	1.51	11.76
PG14	3.20	0.00	0.26	1.67	12.52
PG15	5.60	0.00	0.01	1.90	13.55
NA21	8.28	0.00	0.41	0.84	13.71
NA22	1.04	0.00	0.16	0.33	11.21
NA23	10.29	0.00	0.22	1.16	18.40
NA24	10.16	0.00	0.33	1.01	18.79
NA25	9.45	0.00	1.11	0.39	25.02

WATER CHEMISTRY

Concentrations of water soluble macro nutrients in groundwater are under influence of land use and agriculture in particular. Over-fertilization is the practice at which nutrient application (plant fertilizers) exceed nutrient demands of a crop and in certain conditions, may result in elevations of groundwater concentrations of nutrients by leaching. Additionally to over-fertilization, other agricultural practices can cause leaching of nutrients as well, such as tillage (increasing mineralization rates) or insufficient water management resulting in waterlogging. If nutrient concentrations in groundwater exceed limits (0.5 mg/L Ammonium, 50 mg/L Nitrate), intoxication of humans can occur when used as drinking water and therefore require purification when used for this purpose. Especially nitrates may cause problems, as their water solubility is high and application on agricultural land often large. Mainly infants are susceptible for nitrate intoxication.
Moreover, elevated concentrations of plant nutrients in groundwater resulting from agricultural practices potentially cause damage to other (non-) agricultural ecosystems. Also, an economic objective is to minimize over-fertilization, since all nutrients that are added in surplus can be considered a waste of resources and thus a waste of money). Because of both biological and economic arguments, elevated concentrations of plant nutrients in groundwater are considered to indicate potentially unsustainable farming practices in this study.

$N\text{-}NH_4$, $N\text{-}NO_3$, $P\text{-}PO_4$ AND PH

In Table 6, average concentrations of nitrate and ammonium present in groundwater samples (n=5 per study site) are presented per study site. For both $N\text{-}NH_4$ and $N\text{-}NO_3$, average concentrations were highest at Ketelbroek (0.35 mg/L, 1.14 mg/L respectively) and lowest at NA (0.03 mg/L, 0.01 mg/L). In one sample (KFF4), a remarkable high and inexplicable concentration of $N\text{-}NO_3$ was found (4.72 mg/L) (Table 7). When this sample is excluded (indicated as Ketelbroek* in table 6), an average of 0.24 mg/L nitrate is found in the groundwater samples reducing also the standard error of mean (SEM) (Table 6). Although this high concentration might have been caused by sampling errors, concentrations of 4.72 mg/L of n-nitrate (= 20.89 mg/L Nitrate-NO3) are still within safety limits for drinking water and far below the Dutch governmental directive of keeping groundwater nitrates below 50 mg/l. ("NITRAAT - NRC," n.d.) (Buis, E., van den Ham, A., Boumans, L.J.M., Daatselaar, C.H.G., Doornewaard, 2010).

Average ammonium ($N\text{-}NH_4$) levels measured at Ketelbroek are relatively high, although below the Dutch norm formulated for ammonium concentrations in drinking water. Compared to the Dutch and international norms ("Drinkwaterbesluit," n.d.; WHO, 1996), groundwater concentrations of 0.35 mg/L are above the national average, although higher values can be found in natural conditions as well. The most specific ammonium limit is found in the official European drinking water standards, which recommend maximum concentrations of 0.5 mg/L. The maximum accepted concentration is slightly more than the average concentrations found at Ketelbroek (concentrations in sample KA 1 do exceed this norm).

In the groundwater or surface water samples, concentrations of phosphate were below the detection limit.

TABLE 6 AVERAGE $N\text{-}NH_4$, $N\text{-}NO_3$ & PH GROUNDWATER

Study site	$N\text{-}NH_4$ (mg/L)	$N\text{-}NO_3$ (mg/L)	pH
Ketelbroek	0.35 (SEM=0.18)	1.14 (SEM=0.90)	5.96
PG	0.07 (SEM=0.07)	0.13 (SEM=0.04)	5.99
NA	0.03 (SEM=0.02)	0.01 (SEM=0.01)	5.93
Ketelbroek*		0.24 (SEM=0.13)	

TABLE 7 PH, N-NH4 & $N\text{-}NO_3$ GROUNDWATER CONCENTRATIONS

Sample site	pH	N-NH4 (mg/l)	N-NO3 (mg/l)	P-PO4 (mg/l)
KA1	6.04	1.01	0.08	<0.00
KA2	5.97	0.07	0.11	<0.00
KFF3	6.07	0.25	0.64	<0.00
KFF4	5.77	0.01	4.72	<0.00
KN5	5.93	0.41	0.14	<0.00
PG	5.93	0.35	0.12	<0.00
PG	6.10	<0.00	0.02	<0.00
PG	6.04	0.00	0.20	<0.00
PG	5.97	0.01	0.07	<0.00
PG	5.93	0.00	0.24	<0.00
NA	6.05	<0.00	0.01	<0.00
NA	5.92	0.07	0.03	<0.00
NA	5.91	0.06	0.01	<0.00
NA	6.02	<0.00	<0.00	<0.00
NA	5.73	0.01	<0.00	<0.00

In contrary to pH_{soil}, only slight differences in $pH_{groundwater}$ were found for the different study sites.

SURFACE WATER QUALITY KETELBROEK

At Ketelbroek food forest, surface water was sampled at two locations to test the hypothesized water filtering capacity of the stream and its vegetation that crosses Ketelbroek (Figure 8).. A slight reduction in surface water N-Nitrate was measured (Table 8).

TABLE 8 : SURFACE WATER NUTRIENT CONCENTRATIONS KETELBROEK

	$N\text{-}NH_4$ mg/L	$N\text{-}NO_3$ mg/L	$P\text{-}PO_4$ mg/L
Ketelbroek in	<0.00	2.45	<0.00
Ketelbroek out	<0.00	2.36	<0.00

EARTHWORM POPULATIONS

In all samples, the absolute number of juveniles exceeded the absolute number of adult earthworms. However, the total biomass of juveniles was less than the biomass of adults in most cases (Table 9). This might be relevant when considering the 'agro-ecological' services provided by earthworms such as mineralization of organically bound nutrients, improvement of soil structure and soil aeration. On average, the earthworm population size was found to be largest at Ketelbroek and smallest in the nature area (both in terms of weight and in absolute number).

TABLE 9 WORM POPULATION DATA PER SAMPLE SITE

Sample site	Plot	Individuals juvenile	Individuals adult	Juvenile biomass (gram)	Adult biomass (gram)	Total individuals / sample	Total individuals m^{-2}	Total biomass (gram) / sample
Ketelbroek	1	10	7	0.38	3.2	17	189	3.58
Ketelbroek	2	12	3	1.3	1.8	15	167	3.1
Ketelbroek	3	12	5	1.4	1.79	17	189	3.19
Ketelbroek	4	11	4	2.44	1.76	15	167	4.2
Ketelbroek	5	17	6	1.77	1.75	23	256	3.52
PG	11	11	7	1.12	2.35	18	200	3.47
PG	12	11	5	1.44	3.36	16	178	4.8
PG	13	12	1	1.67	0.42	13	144	2.09
PG	14	12	3	1.1	1.09	15	167	2.19
PG	15	3	1	0.43	0.48	4	44	0.91
NA	21	3	1	0.11	0.45	4	44	0.56
NA	22	15	8	1.93	3.94	23	256	5.87
NA	23	0	1	0	0.07	1	11	0.07
NA	24	1	0	0.07	0	1	11	0.07
NA	25	6	1	0.65	0.4	7	78	1.05

TABLE 10 TOTAL SIZE WORM POPULATION PER STUDY SITE (ALL SAMPLES COMBINED)

Study site	Total individuals	Total worm biomass (gram)
Ketelbroek	87	17.59
PG	66	13.46
NA	36	7.62

According to their behavior and niche, adult earthworms were divided in three ecological groups, the ecotypes, epigeic/compost earthworms, endogeic earthworms and anecic earthworms.

Earthworms that live above the soil surface, in the layer of organic litter, are called epigeic or compost worms. Their main agrological function is to ingest organic material and digest it. Hereby, the surface area of the organic material is increased which facilitates microbial digestion and as a result, mineralisation.
Endogeic earthworms live below soil surface, typically in horizontal burrows. This class of worms improves soil structure by ingesting soil, mixing different types of soil particles and adding mucus from their digestive track. By doing so, small aggregates are formed, increasing soil porosity.
Anecic earthworms live below soil surface in vertical burrows up to 2 meters deep from soil surface. This class of worms feeds on organic material that is found on the soil surface and stored in burrows. By doing so, organic material is integrated in deeper soil layers, increasing its permeability for water and air. Additionally, plant roots can use these burrows to reach deeper soil layers.

In Figure 9, the physiological characteristics of earthworms from the three different ecotypes and their behavior in the soil profile are displayed. It should be noted that the specific species mentioned in this illustration are representing common species of New-Zealand. However, their behavior and physiology are equal to the most common species in Europe.

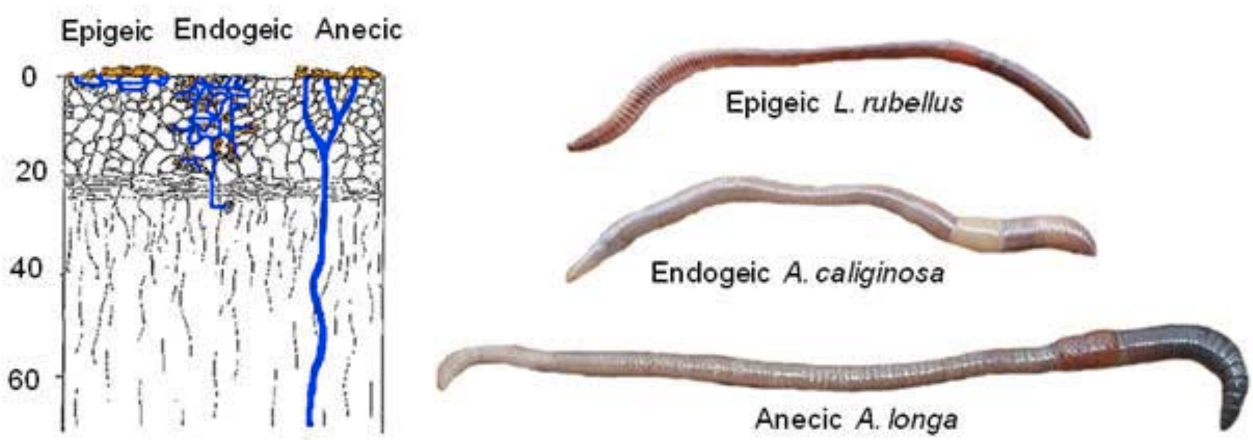


FIGURE 9 : DIFFERENT TYPES OF EARTHWORM ECOTYPES AND THEIR NICHES (SOURCE)

Of the epigeic/compost earthworm ecotype, only one adult earthworm was positively identified (PG). A lot of the juveniles that were found were expected to belong to this ecotype as well, but missed the swollen ‘saddle’ (reproductive organ) that is key in species determination.
High numbers of worms from the endogeic ecotype were found (Ketelbroek n=34, PG n=15, NA n=7) less of the anecic ecotype (Ketelbroek n=10, PG n=4, NA n=3) (

Table 11). In this study, no clear relations between earthworm population sizes, pH and %SOM were found (
Figure 10). These indicators were tested for their relation, as they are often argued to be of high importance in shaping earthworm populations. Interestingly, the average worm population size at NA was much lower than average population sizes at Ketelbroek and PG. However, the absolute number of worms was very high at sample site 23 and 24 and very low at sample site 21; indicating huge local variation which might be caused by different management strategies in this nature area.
Soil management like tillage regimes, fertilizer application, pesticide application (silage grassland) and nutrient depletion by biomass allocation (nature reserve) are suggested to have effect on

earthworm population sizes that could explain this dataset, but were not included as variables in this study.

TABLE 11 EARTHWORM ECOTYPE ABUNDANCE

Sample site	plot	Endogenic ecotype	Anecic ecotype	Epigeic ecotype
Ketelbroek	1	11	3	0
Ketelbroek	2	7	2	0
Ketelbroek	3	7	2	0
Ketelbroek	4	4	3	0
Ketelbroek	5	5	0	0
Ketelbroek average		6.8 (SEM=1.2)	2 (SEM=0.55)	0
PG	11	2	2	0
PG	12	3	1	0
PG	13	0	0	1
PG	14	7	1	0
PG	15	0	0	0
PG average		2.4 (SEM=1.29)	0.8 (SEM=0.58)	0.2
NA	21	1	0	0
NA	22	4	3	0
NA	23	0	0	0
NA	24	0	0	0
NA	25	2	0	0
NA average		1.4 (0.75)	0.6 (SEM=0.33)	0

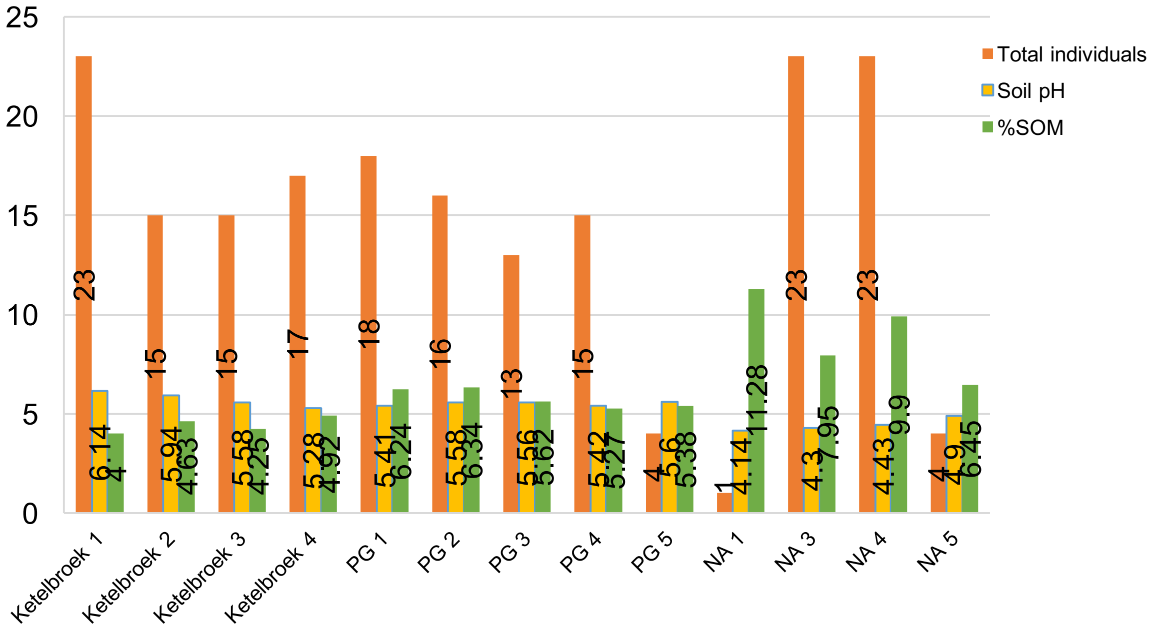


FIGURE 10 : WORM POPULATION SIZE, %SOM AND SOIL PH PER SAMPLE SITE

FLORA AND FAUNA: BIODIVERSITY

GROUND BEETLE POPULATIONS

At Ketelbroek, 497 individual ground beetles, from 35 species of the Carabidae family were found, of which 22 unique for this study site. These 22 species were not found at the nature reserve. At NA, 284 ground beetles were caught, belonging to 27 species of the Carabidae family, of which 14 unique for the nature reserve (and of which 2 were recognized to be rare species: Harpalus signaticornis and Trechus rubens). 13 species were found at both study sites, of which one was recognized to be rare (Bembidion mannerheimii). The Shannon-Wiener diversity index of the ground beetle population was found to be highest at Ketelbroek (H'=2.86) and lowest at the nature reserve (H'=2.58) (Table 12). Within the study sites, spatial differences in species occurrence and abundance is clearly visible. This is in line with the expectations as species of this family are known to occur only in specific niches and (micro)-climates. However, species occurrence and abundance did not match (whatsoever) between the different sampling sites that were selected for their analogies. This demonstrates that carefully chosen sampling sites, that are analogues in many aspects, in reality are sufficiently dissimilar to clearly influence population composition in terms of species occurrence. Please see Appendix 2 for the complete dataset on pit trap sampled Carabidae populations per sample site.

TABLE 12 GROUND BEETLE DATA OVERVIEW

Sample site	Individuals	Species	Shannon-index (H')
NA	284	27	2.58
Ketelbroek	497	35	2.86

MACROLEPIDOPTERA DIVERSITY

Nocturnal butterflies of the macrolepidoptera group, belonging to the insect order of Lepidoptera, resemble a wide variety of butterflies and moths. Although not commonly studied as potential ecological indicator, knowledge on their contribution to pollination, their position in the food chain (being predated in all life stages) and their host plant specificity, were reason to include this group of animals in the biodiversity study conducted by (Emma Dijkgraaf and Jeroen Breidenbach, HVHL Leeuwarden 2016). However, for the purpose of (a sustainability assessment of complex agro-ecosystems, only data on population sizes and species diversity is considered relevant. Dijkgraaf and Breidenbach conducted a comprehensive analysis on macrolepidoptera diversity and interpreted data on individual species found. The complete dataset on macrolepidoptera populations is provided in Appendix 3.

The number of individuals from the macrolepidoptera group that were found at Ketelbroek was considerably higher compared to De Bruuk NA (Ketelbroek n=2375, Nature area n=1411). Interestingly, the number of different species that were found was almost equal (170 at Ketelbroek, 168 at the nature reserve). The Shannon diversity index was highest for NA (H'=4.32) and lowest for Ketelbroek (H'=4.0). This indicates that the population at Ketelbroek is larger but less diverse. Table 13 and Table 14 present the five most common (highest amounts of individuals) species and their host plants. Interestingly, only one species is found in high quantities at both study sites. Most commonly found species at NA prefer perennial deciduous trees as host plants, while the most common species found at Ketelbroek prefer (bi)-annual herbaceous plants. Therefore, it can be argued that macrolepidoptera populations reflect ecological successional stages and dominant vegetation types.

Considering the equal amount of breeding bird territories and the higher amount of predatory ground beetles found at Ketelbroek (potentially resulting in a higher predation pressure at Ketelbroek), it can be argued that the nutritional value (digestibility, nutrient density) of the vegetation at the food forest must be higher in order to allow for such large population sizes. Further research is needed to confirm this theory, however. Monitoring of macrolepidoptera population sizes and changes in species composition would be interesting as food forests are by definition designed to provide a (very) high nutritional value.

TABLE 13 LIST OF FIVE MOST COMMON MACROLEPIDOPTERA SPECIES NA

NA Species	n	Hostplant
Lomaspilis marginata	118	willow and poplar, other deciduous trees
Idaea biselata	84	herbaceous plants, organic litter
Oligia fasciuncula	51	grasses
Eilema sororcula	51	lichens (beech, oak)
Deltote pygarga	48	moor-grass, false broom, tufted hairgrass

Table 14 list of five most common macrolepidoptera species Ketelbroek

FF species	Nr	Hostplant
Hypena proboscidalis	291	nettles
Agrotis exclamationis	155	herbaceous plants
Axylia putris	135	plantain, nettle, sorrel, bedstraw
Lacanobia oleracea	105	nettle, st. Johns wort, hazel, willow, hop
Lomaspilis marginata	87	willow and poplar, other deciduous trees

BREEDING BIRD TERRITORIES

The amount of breeding bird territories was found to be the same for both study sites (n=49) (see Appendix 4 for the complete dataset). Of 9 species territories were found at both study sites, 14 species were found solely at NA or Ketelbroek (Table 15 and

Table 16).

TABLE 15 BREEDINGBIRD TERRITORIES NA

Name	Dutch name	no. of territories	Feeding type
Fringilla coelebs	Vink	3	Omnivore
Erithacus rubecula	Roodborst	3	Insectivore
Anthus trivialis	Boompieper	2	Insectivore
Columba oenas	Holenduif	2	Seeds
Columba palumbus	Houtduif	2	Seeds
Gallinula chloropus	Waterhoen	1	Herbivores
Certhia brachydactyla	Boomkruiper	1	Insectivore
Cyanistes caeruleus	Pimpelmees	1	Omnivore
Dendrocopos major	Grote bonte specht	1	Insectivore
Sturnus vulgaris	Spreeuw	1	Omnivore
Cuculus canorus	Koekoek	1	Insectivore
Poecile palustris	Glanskop	1	Insectivore
Strix aluco	Bosuil	1	Carnivore
Buteo buteo	Buizerd	1	Carnivore

TABLE 16 BREEDINGBIRD TERRITORIES KETELBROEK

Name	Dutch name	no. of territories	Feeding type
Sylvia communis	Grasmus	7	Insectivore
Hippolais icterina	Spotvogel	5	Insectivore
Acrocephalus palustris	Bosrietzanger	3	Insectivore
Acrocephalus scirpaceus	Kleine Karekiet	3	Insectivore

Emberiza citrinella	Geelgors	2	Seeds
Carduelis carduelis	Putter	2	Seeds
Corvus corone	Zwarte Kraai	1	Omnivore
Ciconia ciconia	Ooievaar	1	Carnivore
Sylvia borin	Tuinfluiter	1	Insectivore
Phasianus colchicus	Fazant	1	Seeds
Linaria cannabina	Kneu	1	Seeds
Chloris chloris	Groenling	1	Seeds
Emberiza schoeniclus	Rietgors	1	Insectivore
Saxicola rubicola	Roodborsttapuit	1	Insectivore

The Shannon-Wiener diversity index was slightly higher for Ketelbroek (H'=0.3615) compared to the nature area (H'=0.3600). Interestingly, except for the stork (*Ciconia ciconia*) nest, no territories of higher predatory birds were found at Ketelbroek. The relatively young, and therefore less dense and high, vegetation might be of influence as well as the noted territorial behavior of the adult storks (other predatory birds are spotted foraging in the food forest except during the stork' breeding season). In the nature area, multiple territories of predatory birds were found to coexist. In general, a wider range of bird feeding types was found at NA (6 insectivores, 3 omnivores, 2 seed eating birds, 1 herbivore, 2 carnivores) than at Ketelbroek (8 insectivores, 5 seed eating birds, 1 carnivore, 1 omnivore), considering *only* the unique species of each sampling site. These differences in population types, might relate to differences in vegetation succession between the two ecosystems. At the nature reserve, opportunistic (generalist) feeding habits (omnivores) and specialist feeding habits co-exist. This indicates that food availability is high: birds specialized in one type of food and birds that eat anything they can find, are able to raise offspring in this area. Moreover, seed eating birds are found less, indicating that most plant niches are filled. Mass production of tiny seeds apparently does not result in more offspring; investing energy in higher quality seeds or nuts might do. At the food forest, annual herbaceous plants occur in abundance because of the successional strategy that is followed, providing a reliable source of seeds. Annual plants are more easily eaten by herbivory insects, resulting in high numbers of insectivorous birds as well. When these two important types of bird food are both present in abundance, having a generalist lifestyle does not result in higher amounts of offspring, explaining the low number of omnivores at Ketelbroek. However, to test whether these theories are truly explaining differences in breeding bird population composition, further research in nutrient dynamics and other factors affecting feeding strategies in these ecosystems would be needed.

FLORAL DIVERSITY

In the mentioned sampling period, for both the food forest and the nature reserve a detailed list of occurring plant species was made, summing up plant species by both their Dutch and Latin names (appendix 5). It should be noted that some of the plants found at the food forest were introduced for their edibility. However, not all deliberately planted shrubs and trees could be determined and were thus not included on the list, that therefore is not complete. Nonetheless, more plant species were found at the food forest (n=168) than at the nature reserve (n=131).
This inventory does not contain information on population sizes and is unsuitable to calculate diversity indexes and to check whether or not all species occur in significant amounts. Nevertheless, the qualitative information included is interesting. Only six years after abandoning a monoculture based agriculture on the land now known as Ketelbroek, a very high number of plant species populate the land without any help. In addition to these naturally occurring plants, hundreds of edible

plant species, possibly over a thousand of individual plants, were introduced by man and thrive as well. Indeed, certain amounts of food are harvested already, increasing every year. Although it remains to be seen what role wild or spontaneous occurring plants will have in a rather mature food forest, in the current stage of development, natural occurring vegetation and food production do not seem to be mutually exclusive. In this study, larger (worms, ground beetles and nocturnal butterflies) and more diverse (ground beetles, breeding birds, plants) populations of indigenous organisms were observed in the food forest.

VISUAL SOIL ASSESSMENT

On the 30th of September 2016 , one visual soil assessment (VSA) was conducted for the Ketelbroek site. Following results can be used as reference values in future studies at Ketelbroek. The standard VSA was conducted as described in VSA Field Guides 'orchard assessment guide', FAO 2008. Interestingly, only one zone within the oldest part of the food forest was found to be moist enough to perform this experiment. Most likely resulting from the (relatively) extreme drought and high temperatures in the weeks prior to the experiment, the soil surface was too hard to penetrate with an ordinary shovel. The soil quality index of 31,5 representing a good quality) found for the only sample, cannot be considered representative for the average soil quality at the food forest. It rather represents the best zone anno 2016. For the filled in VSA score sheet, see Appendix 6.

NORMALISED DIFFERENCE VEGETATION INDEX (NDVI)

For all tested locations, normalized difference vegetation indexes (NDVI) were lowest in 2012 (first measured year) and increased over time (Table 17). In the period end of 2009 - beginning of 2010, the first trees and shrubs were planted in the romantic food forest. Two years later, in 2012, the second part of the food forest was planted. This was also the first year NDVI data was collected and got published. The fact that the two parts of the food forest were not planted in the same year explains the differences in NDVI values around the year 2012 and 2013. In general, average NDVI values are highest for the permanent grassland. Note that the relatively high NDVI values in the year 2016 are somewhat misleading, as the average was calculated early October (missing data on three months of fall/winter, typically low NDVI values).

TABLE 17 YEARLY AVERAGE NDVI VALUES

YEAR	KFF	KA	PG
2012	0.51	0.46	0.60
2013	0.58	0.54	0.63
2014	0.59	0.55	0.66
2015	0.58	0.53	0.58
2016	0.60	0.57	0.65

In the first phase of this study, assumptions on optimum values and arguments why these values are optimal were formulated for each indicator. In this assessment, these optimum values are assumed to be correct and used in a process called the normalization of the scale of each indicator/variable. Normalization is needed to allow comparison of different indicators without scale effects (Gómez-Limón & Sanchez-Fernandez, 2010; Munda, 2005).

Per indicator, the precise normalization/standardization technique is described to ensure reproducibility. Unless indicated differently, study system averages are used. Dry bulk densities were not assessed, as all systems scored within the theoretical most sustainable range of soil densities ("Guides for Educators," n.d.).

SOIL PH-H_2O

Optimum soil pH values were assumed to be near neutral (pH 6-8) since this range is suitable for most food producing plants. Although pH follows a logarithmic (non-linear) scale, a linear scoring will be used for this assessment, as exact pH-related soil and plant responses are unknown for these study sites. This means that pH values per study site are expressed as percentages of the most sustainable pH (7): Ketelbroek: **83%**, PG: **79%**, NA **64%** as presented in Table 18.

TABLE 18 : SOIL PH-H2O (AVERAGES) AND SUBSEQUENT SUSTAINABILITY SCORE

Study site	Soil pH-H_2O (average)	Sustainability score
Ketelbroek	5.8	83%
PG	5.5	79%
NA	4.5	64%
Assumed optimum	7.0	100%

SOIL ORGANIC MATTER

An important aspect of sustainability is fighting climate change. From this perspective, the higher the mass of organic matter per volume unit of soil, the better as more carbon is stored.
In this study, the average percentage soil organic matter, expressed as a fraction of the soil's mass was highest for NA and lowest for Ketelbroek . However, bulk densities expressing soil mass/volume were found to differ greatly for Ketelbroek, PG and NA. When %SOM (mass fraction of soil) is used to indicate how much OM is present in a soil, this may result into incorrect conclusions regarding the carbon storage of the agro ecosystem. To correct for this, the following equation is used:

$$Mass\ soil\ organic\ matter\ per\ unit\ of\ volume = DBD * \%SOM$$

With

$$DBD = dry\ bulk\ density\ (gcm^{-3})$$
$$\%SOM = soil\ mass\ fraction\ organic\ matter$$

The resulting sustainability scores corresponding to the mass of soil organic matter per unit of volume (gcm^{-3}) are presented in Table 19

TABLE 19 : SUSTAINABILITY SCORES RELATED TO SOIL ORGANIC MATTER

Site	Organic matter (gcm^{-3})	Sustainability score
Ketelbroek	0.055	88%
PG	0.062	100%
NA	0.053	85%

This means that (based on available information) carbon storage is, in descending order, PG>Ketelbroek>NA. This means that PG is the most sustainable (**100%), **Ketelbroek is **88%** sustainable and NA is **85%** sustainable.

CATION EXCHANGE CAPACITY (C.E.C.)

Prevention of nutrient losses by leaching does not only comprises a good fertilization regime, but also management of soil pH and organic matter. Soil pH determines to what extend cations (positively charged ions) are bound to negatively charged parts of the soil. Soil organic matter contains a lot of negatively charged parts and potentially fixates substantial amounts of cations: the cation exchange capacity. A lower soil pH results in less fixated cations. To prevent leaching, soil pH can be increased by liming and the cation exchange capacity can be increased by increasing levels of soil organic matter.
In light of sustainability, we argue the higher the cation exchange capacity (C.E.C.), the more sustainable the system is. The average C.E.C. was highest at the nature area NA (7.84 cmol+/kg) followed by the permanent grassland (6.88 cmol+/kg) and Ketelbroek (5.18 cmol+/kg). Therefore, NA is most sustainable (**100%**) followed by PG (**87.75%**) and Ketelbroek (**66%**) as presented in Table 20.

TABLE 20 : SUSTAINABILITY SCORE BASED ON AVERAGE CATION EXCHANGE CAPACITIES

Site	C.E.C. (cmol+/kg)	(%)
Ketelbroek	5.18	66
PG	6.88	87.5
NA	7.84	100

GROUND WATER QUALITY

Sustainable agro-ecosystems should not cause ground water pollution to an extend where 1) other ecosystems are harmed and 2) concentrations reach levels that are toxic when used as drinking water, we argue. European standards for ammonium (0.5 mg/L) and nitrate concentrations (50 mg/L) are used as reference maximum values, concentrations of 0 mg/L as optimum for both groundwater ammonium and nitrate. To calculate the sustainability percentage, the following formula is used:

$$Sustainability\ percentage = \left(1 - \frac{average\ measured}{maximum}\right) * 100$$

The sustainability scores that were calculated using this formula are presented in Table 21.

TABLE 21 : SUSTAINABILITY SCORES BASED ON AVERAGE GROUNDWATER QUALITY

Site	Ammonium (NH_4^+)	Nitrate (NO_3^-)
Ketelbroek	30%	97.72%
PG	86%	100%
NA	94%	100%

EARTHWORM POPULATIONS

Although earthworm presence is commonly recognized to be important in agriculture, no absolute number of earthworms per unit of soil is argued to be generally optimal. Moreover, earthworm population sizes are dynamic in time and space. For instance, in, the soil underneath a manure patch, worm densities can increase to over a thousand individuals per m^2 while earthworm densities in the surrounding soil most likely decrease. For this reason, total earthworm counts per study site are compared to assess earthworm population sizes,. Highest amounts of earthworms were found at Ketelbroek (**100%**) followed by PG (**76 %** and NA (**41 %**) as presented in Table 22.

TABLE 22 : SUSTAINABILITY SCORES BASED ON EARTHWORM ABUNDANCE

Site	Total number of earthworms	Sustainability score (%)
Ketelbroek	87	100
PG	66	76
NA	36	42

BIODIVERSITY

In agro-ecology, a higher biodiversity is often related to a more resilient ecosystem (Peterson, Allen, & Holling, 1998). If a system is better able to overcome damaging events, such as influences of pests, climate or social events (so, more resilient) it is by definition more sustainable. Moreover, a higher biodiversity potentially results in more ecosystem services, such as pest control, pollination, seed dispersal and nutrient recycling, which lower the required input of pesticides, fertilizers and other external inputs. Based on these considerations, a higher biodiversity is assumed to be more sustainable in this assessment.

Ground beetle diversity (as well as population size) was highest at Ketelbroek (H'=2.86 (**100%**)) compared to the nature area (H'=2.58(**90%**)).

Macrolepidoptera diversity was highest for NA (H'=4.32 (**100%**)) compared to Ketelbroek (H'=4.0 (**92.6%**)). For breeding birds, differences in diversity were not significantly big and therefore will not be scored. Plant diversity at Ketelbroek (168 species) exceeded plant diversity at NA (131 species). However, as no information on population sizes is available, it cannot be concluded whether or not diversity is truly higher at Ketelbroek.

TABLE 23 : SUSTAINABILITY SCORES BASED ON SHANNON-WIENER BIODIVERSITY INDICES OF CARABIDAE AND MACROLEPIDOPTERA POPULATIONS

Site	Ground beetle diversity (H'; %)	Macrolepidoptera diversity (H'; %)
Ketelbroek	2,86; **100%**	4.0; **92,6%**
NA	2.58; **90%**	4,3; **100%**

NORMALISED DIFFERENCE VEGETATION INDEX (NDVI)

In this study, a higher normalised difference vegetation index (NDVI) is related to a more sustainable system, as more photosynthesis theoretically results in more CO_2 extraction from the atmosphere, reducing the atmospheric concentration of this greenhouse gas. The highest possible NDVI is 1 indicating that 100% of the photosynthetic active radiation is absorbed and will be considered optimal, although in reality NDVI values do not exceed 0.9.
Average NDVI values are calculated from five yearly averages (Table 17). For Ketelbroek, values measured at the Food Forest and the Agroforestry plot are combined.
The overall average NDVI of the permanent grassland is 0.62 (**62%** of the optimum) and 0.55 at Ketelbroek (**55%** of optimum) as presented in Table 24.

TABLE 24 : SUSTAINABILITY SCORES BASED ON NDVI

Site	NDVI	Sustainability score (%)
Ketelbroek	0.55	55
NA	0.62	62
Assumed optimum	1.00	100

The different indicators for sustainability are expressed in totally different units, for example mg/L, individuals/m^2. Calculation of the sustainability percentage for each base indicator is a very simple and straight forward normalization method that allows for comparison of the transformed variables (Gómez-Limón & Sanchez-Fernandez, 2010).
In this study, percentages were calculated by dividing the measured values by theoretically optimum values. Inherent to this technique lies the assumption that the scale between the most and least sustainable value is linear. Aggregating these linear functions, we also allow for compensation among different indicators. For example, when groundwater quality is extremely low, but biodiversity very high, the average score is neutral. This is not necessarily a bad thing, but it should be kept in mind when working with this data.

This normalization technique enables for calculating average sustainability scores per study system, based on scores for multiple indicators. This average score, often referred to as the composite indicator, is logically depending on what data is used as input. In Figure 11, an overview of all sustainability scores is given and corresponding composite indicators are presented in Figure 13. This set of indicators contains all information that was obtained in this study. However, the indicators of biodiversity were not tested for PG and NDVI data is missing for NA. Therefore, composite indicators corresponding to this dataset are based on an unequal number of sustainability assessment scores per study system. One of the possibilities to overcome this problem is to include only those indicators that were measured for all study sites. An overview of the resulting set of indicators is presented in
Figure 12, corresponding composite indicators in Figure 13. Important to note is the fact that 1) the selection of indicators influences the composite indicator score and 2) the effect of selecting indicators is not equal for the different study systems (figure 13).

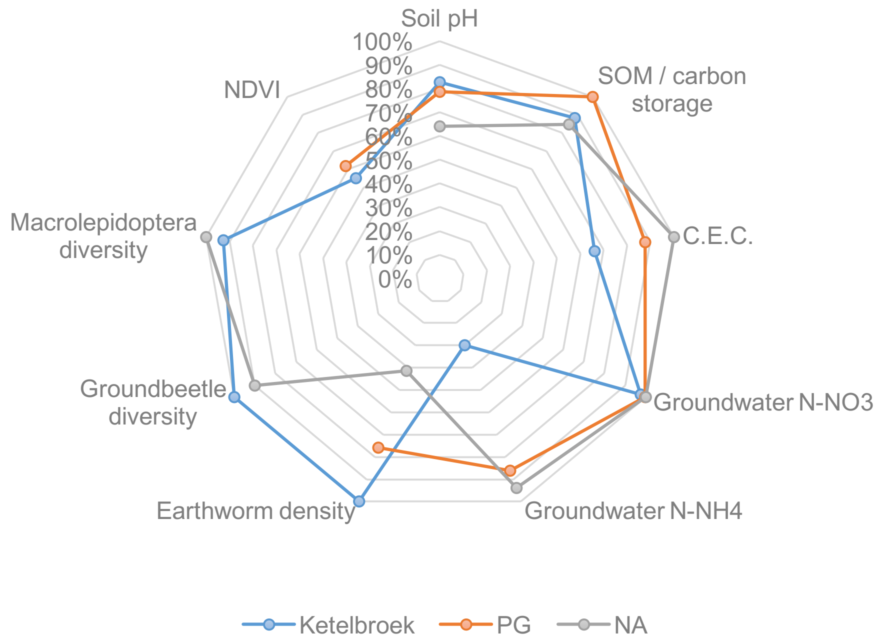


FIGURE 11 : PER INDICATOR OF SUSTAINABILITY, THE NORMALIZED (PERCENTUAL) SUSTAINABILITY SCORE IS PRESENTED FOR EACH STUDY SYSTEM.

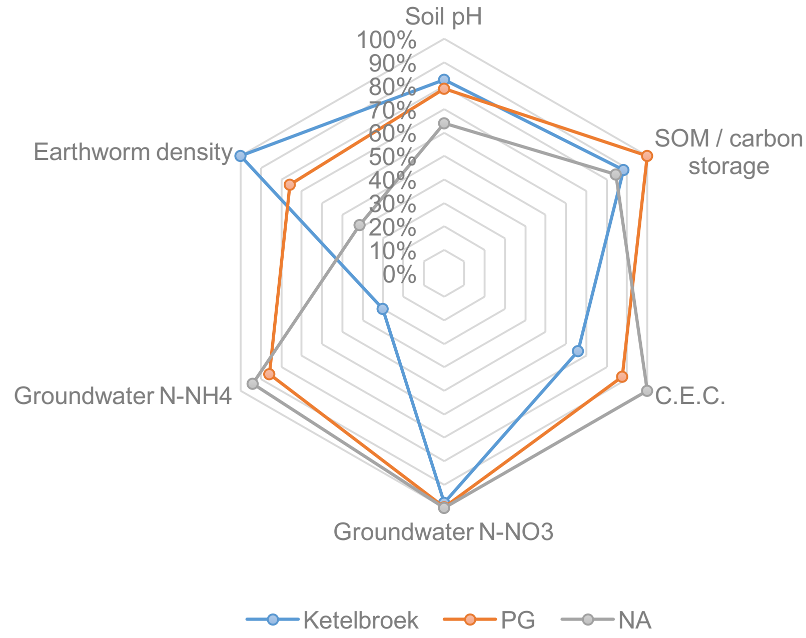


FIGURE 12 : SUSTAINABILITY SCORES: SHARED INDICATORS OF SUSTAINABILITY

***Figure 11**,*
***Figure** 12 **& Figure 13**:*
In figure 11 and 12, sustainability scores are presented for two sets of indicators of sustainability. The first set (figure 11), includes all indicators of sustainability that were considered in this study. As not all indicators were measured for all study sites, data density is uneven distributed over the different study sites resulting in an uneven number of assessment scores. The second set of indicators (figure 12) contains only those indicators measured for all study sites. The composite indicator scores corresponding to both sets of indicators (figure 13) are strongly influenced by the composition of the indicator set. Although both sets contain interesting and valuable information about the same study sites, the selection of indicators clearly determines the studies outcome. Obvious as this may sound, this simple example demonstrates the significance of the

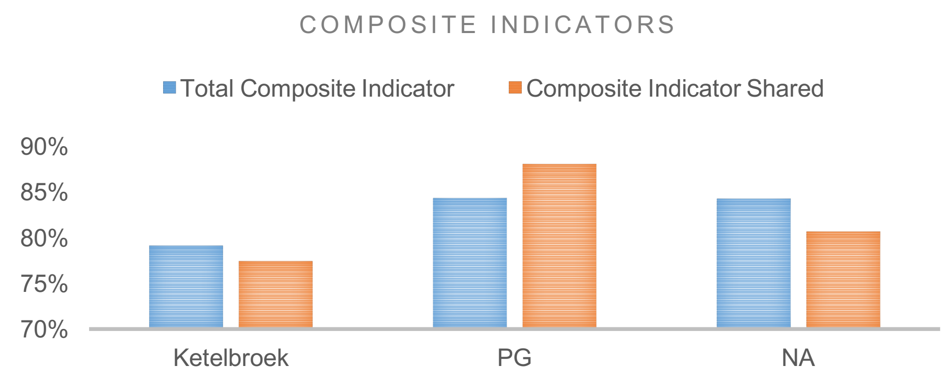
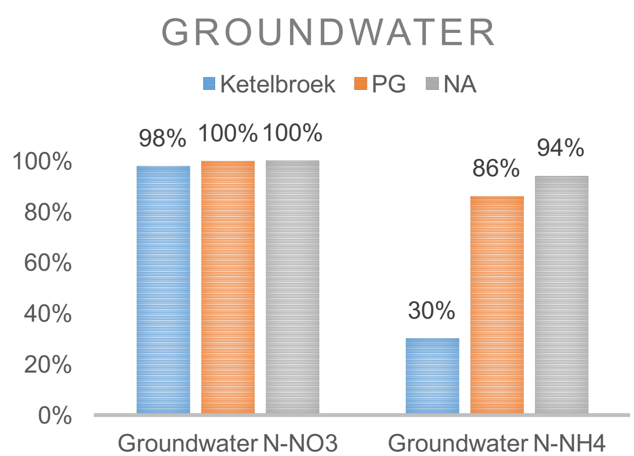


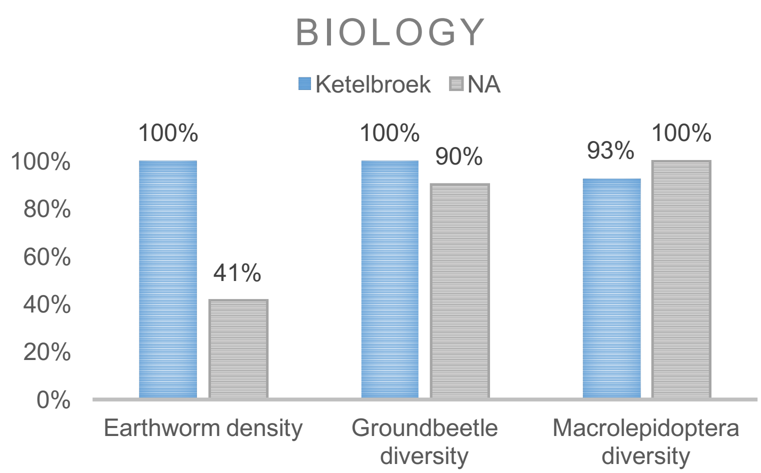
FIGURE 13 : BY AGGREGATION OF SUSTAINABILITY SCORES FOR MULTIPLE INDICATORS OF SUSTAINABILITY, COMPOSITE INDICATORS ARE CALCULATED. THE SUSTAINABILITY OF A SYSTEM ACCORDING TO THESE COMPOSITE INDICATORS STRONGLY DEPENDS ON THE SELECTION OF INDICATORS THAT ARE INCLUDED AND THEREFORE IS NOT TRUELY OBJECTIVE.

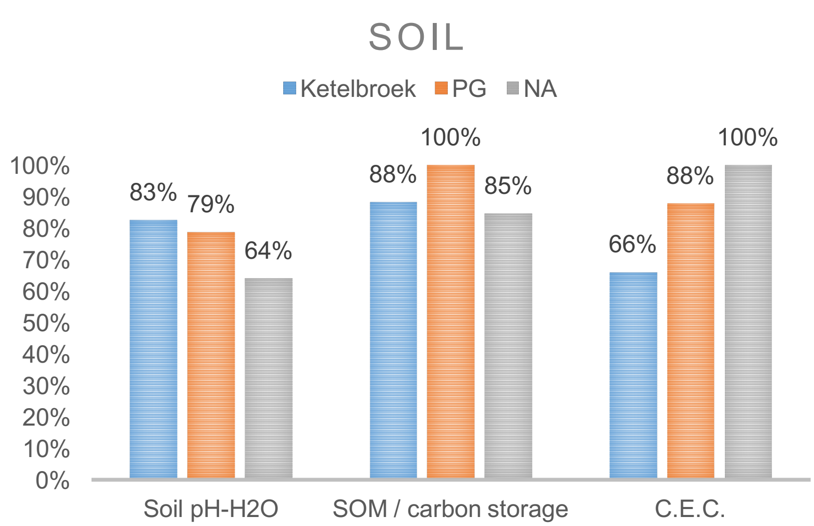
As the selection of indicators that are aggregated in the 'composite indicator' determines the outcome of the composite indicator, this technique needed to express sustainability of a system in one single value is not truly objective. More important is the fact that the composite indicator does not provide any information on what methodological choices were made in calculating its value. Consequently, when only composite indicator values are used to compare different systems, important details might be missed. Therefore, it might be undesirable to aggregate different indicator scores with the aim of expressing sustainability as one single score.

A different approach is to distinguish different categories of indicators based on the aspect or dimension of sustainability they relate to. Following this approach, data on indicators belonging to the same sustainability dimension are combined and the study results expressed in the sustainability dimensions Biology, Soil and Groundwater.

This method improves clarity without compromising details and shows each study system outperforms the other systems for one dimension. Ketelbroek scores highest for indicators on Biology, PG scores highest on indicators of soil, NA scores highest on indicators of groundwater quality.







Discussion

INDICATORS OF SUSTAINABILITY

SOIL ORGANIC MATTER

In the first phase of this study, soil organic matter was selected to function as an indicator of sustainability since it . relates to sustainability without doubt. However, no clear evidence exists on what a sustainable concentration of organic matter in the soil is. The optimum concentration partly depends on what role organic matter has in a specific agro-ecosystem. For example: in a region with high precipitation, a high groundwater table and relatively short periods of drought, improving water availability will not be the main reason to care for the percentage soil organic matter. Instead, improvement of soil structure, increasing the cation exchange capacity of a soil and the storage of carbon (lowering atmospheric CO_2 concentrations), will be more evident reasons to care about soil organic matter. Setting an ideal percentage soil organic matter (%SOM) in light of the sustainability of an (agro)ecosystem is not commonly done. Interestingly, in discussions on agricultural sustainability, the assumption is often that the highest possible amounts of soil organic matter is the optimum. This might be right when soils are considered to be a place to store carbon solely. However, when people should be able to live from a land, mineralization of organic matter is also necessary. Taking this into account, one could argue that the 'natural' steady state in the SOM dynamics is the optimum, which is the state at which addition of organic matter equals removal. In this state, plant biomass production is limited by natural mineralization rates of organic matter. When more organic material is mineralized, fixed plant nutrients will be released and biomass production will increase. More organic material is added to the soil, increasing the SOM. In principle, this negative feedback loop will by definition sustain itself (being thus sustainable) as long as it is not too heavily disturbed. In conclusion, a sustainable percentage SOM should 1) be in a steady state, and 2) feed people.
Now the question arises what the sustainable percentage SOM exactly is. As the steady state is influenced by many factors such as temperature, humidity and soil fauna, the sustainable percentage SOM also highly depends on many factors. The amount of people that should be fed by the ecosystem makes it even more complicated. Moreover, the steady percentage SOM in the succession climax state of an ecosystem is likely influenced by the exact species composition, which is not static in time and strongly influenced by ecological processes and to some extend coincidences.
Considering all complicating factors, I argue it is impossible to point out 'the' percentage soil organic matter that indicates the most inherent sustainable (agro) ecosystem. In the light of this sustainability assessment, I therefore propose to adopt the first assumption that the higher the amount of organic material in a soil in terms of mass is, the more sustainable the system is. Reason to do so is the lack of information about the steady state soil organic matter percentage in the study area. The potential of soils to (indirectly) sequestrate significant amounts of atmospheric carbon for longer periods of time, is however very real and measurable. Promoting sequestration of atmospheric carbon in form of organic material into the soil, is argued to be a serious measure in fighting climate change. This idea is substantiated by the fact that an increase of 1% in soil organic carbon per hectare top soil (10 cm) accounts for hundreds of kilograms of carbon (Freibauer, Rounsevell, Smith, & Verhagen, 2004; Montagnini & Nair, 2004).

WATER CHEMISTRY

As mentioned, groundwater quality in terms of $N\text{-}NH_4$, $N\text{-}NO_3$, $P\text{-}PO_4$ concentrations and pH is for all studied systems (on average) high enough to function as drinking water. However, ammonium concentrations at Ketelbroek were remarkably high. Moreover, nitrate concentrations were significant, but far too low to cause problems when used for drinking. Nonetheless, $Ketelbroek_{N\text{-}NO3}$ was nearly 9 times higher than $PG_{N\text{-}NO3}$ and 114 times higher than $NA_{N\text{-}NO3}$. It is not very likely this results from methodological mistakes, as the same procedure was followed for all samples.

Considering the background of the studied systems, the outcome seems contradictory to theoretical considerations. No fertilizers were applied and no tillage was done in the food forest for at least six years while fertilizers were applied at the permanent grassland every year. According to scientific theories, the permanent grassland is more prone to nutrient losses through leaching, resulting in higher nutrient concentrations in the ground water. Looking at the results, the opposite seems to be true for the ecosystems in this study.

Trying to understand what might cause these contradicting results, an important note must be made regarding the chosen sampling technique. Although permanent groundwater wells are present in Ketelbroek and NA, their low abundance and the absence of such permanent wells at PG forced us to look for an alternative sampling method.

This alternative was found in the sampling method as described in the methodology section of this report. In the chosen method, no physical barrier (tube) prevented water from the 'soil solution' fraction to mix with the groundwater that entered the hand drilled well. Water in the soil solution phase can (and will, when rain is percolated into the soil or when the groundwater table raises bottom up) mix with groundwater, but is inherently different from it as it is located in the root zone of plants, the zone where biological activity is highest. For a more comprehensive background on this topic, see (Lehmann & Schroth, n.d.; Schroth & Sinclair, 2002).
To what extend the groundwater and soil solution got mixed cannot be checked, and from which of the two the measured nutrients originated remains to be answered.

Biological activity determines to a large extend how much nutrients are present in the soil solution. This study clearly demonstrated that soil (macro) fauna is highest for Ketelbroek and lowest for NA. As contamination of the water samples might have occurred, it cannot be excluded that elevated ammonium and nitrate concentrations found at Ketelbroek, in fact reflect a higher biological activity in the root zone. This theory is supported by the fact that earthworm biomass and absolute individual earthworm numbers follow the earthworm abundance pattern (Ketelbroek>PG>NA).

Considering above reflection on the significance of the measured nutrients in groundwater in light of sustainability and the possible influence of used sampling techniques on the quality of the samples, the only possible conclusion is that 1) in this study some serious, but not directly unsustainable, groundwater pollution was found, 2) more research is needed to determine the effects of the chosen sampling methodology on measured nutrient concentrations in the water samples.
Regardless of the precise effect of the chosen sampling methodology, this study resulted in some interesting and contradicting information on nutrient concentrations in (ground)water samples. Although no fertilizers and minimal amounts of organic material originating from external sources were added to the food forest ecosystem, concentrations of dissolved nitrate and ammonium exceeded concentrations found at the conventionally fertilized permanent grassland. Unless these nutrients enter the system in dissolved form through upwelling of polluted groundwater or precipitation of polluted rain, they logically originate from organic matter and are released through mineralization. At the same time, soil organic matter at the food forest was found to be lower in absolute (kg/hectare) and relative terms (mass percentage) and a zero-tillage soil management is followed. Research is needed to understand and quantify nutrient dynamics and balances at the food forest. In theory, this dataset could confirm some of the fundamental assumptions where the 'food forest idea' is based on. In terms of nutrients, Ketelbroek was designed to be a self-sufficient system that permanently increases its own fertility (Wouter van Eck). Nitrogen enters the system through symbiosis mediated nitrogen fixation, which is stimulated by introduction of nitrogen fixating vegetation. Carbon in organic form enters the system through photosynthesis, which is highly stimulated by introduction of shrubs and trees and the abundance of self-introduced annuals and perennials. Together, this organic nitrogen and carbon form the most important part of soil biota's diet. Next to providing enough to metabolize, soil biota is stimulated to flourish by abandoning tillage, preventing soil compaction and stimulating dense soil covering vegetation growth. In theory, all these practices result in a higher soil biota biomass; which indeed was found to be true for earthworms and soil biota predating ground beetles. As result of stimulating soil biota, more organic material is metabolized, resulting in higher mineralization rates; possibly resulting in higher amounts of dissolved mineral plant nutrients; which can be argued to be true as well.

This interpretation is rather speculative and required scientific evidence is not complete enough yet to confirm all parts of it. Still it is worth mentioning, as it could be at the basis of an alternative paradigm regarding (ground)water quality and sustainability, as I will plead.

Now, when above speculated theory is correct, elevated concentrations of nutrients in (ground)water can also indicate *sustainable* agricultural practices. This, as the nutrients might originate from an inherent, fertility increasing, system that in fact stores energy while fertility increases. This can be true when *energy required to fixate nitrogen ≤ extra energy fixated due to this nitrogen*. In such a system, 1) energy is stored in form of organic carbon and organic nitrogen, and 2) energy is lost due to metabolizing these organic compounds.
When 2) < 1), net energy is stored in the system. This stored energy can be, sustainably, used in the process of 2) as long as it does not compromise the system's ability to recover. In practice this means that *for a certain period*, more soil organic matter can be mineralized/metabolized than formed, without compromising the systems sustainability on the long run.
In food forest theory, the principle at which more energy is stored than used is referred to as the principle of abundance (as the system stores energy in abundance). A system where energy is stored in abundance (in form of food and organic matter), an energy reserve is created which can be mineralized without causing irreversible

damage to the system. Plant-nutrient availability as a by-product of this reserve-mineralization might temporally exceed plant-nutrient demand, and therefore leach into the groundwater. This could have been what caused relatively high concentrations of dissolved nutrients in the (ground)water of the food forest.

EARTHWORM POPULATIONS

Following the same theory, earthworm abundance could be an indicator of how well a system is storing carbon and nitrogen (although this is not the only factor that determines worm presence of course) and therefore indicate how much of these types of organic compounds are created in abundance.
Interestingly, the studied nature area where organic carbon is highly available in form of a very acidic leaf litter (that stores high amounts of energy) but nitrogen is artificially removed, indeed houses only very limited amounts of earthworms. The permanent grassland system, that is designed to produce protein and carbon-rich grass in readily harvestable form and is in fact prevented to invest energy in nitrogen fixation and storage by addition of artificial fertilizers and application of herbicides that eliminate nitrogen fixating clover species, houses less worms as well. Still, permanent grasslands are known to have a positive effect on soil organic matter formation and indeed %SOM were relatively higher compared to Ketelbroek. More research is needed to understand the exact SOM dynamics and differences in nutritional value for earthworms for the different study sites (Coq, Barthès, Oliver, Rabary, & Blanchart, 2007; Nurhidayati, Arisoesilaningsih, Suprayogo, & Hairiah, 2012). Additionally, the earthworm inhibiting effects of fertilizer and pesticide application at permanent grassland systems should be considered.

NDVI

One of the strongest crop-growth-limiting factors in the Netherlands is the relatively low sunlight intensity during the largest parts of the year. Where light conditions in the tropics can be sufficiently high to provide seven growth layers with enough energy to photosynthesize, in the Netherlands only three or four plant layers seem to thrive. Therefore, to realize the highest possible food production in a Dutch agro-ecosystem, photosynthetic active light should be used as efficiently as possible to minimize losses. This is exactly what is theoretically done in agroforestry / food forestry systems by designing the system to have multiple layers of photosynthesizing food producing vegetation. The species forming each layer are selected to prefer naturally specific light conditions typically found in that vegetation layer. This is for instance done by studying vegetation patterns in 'wild' forest ecosystems containing wild ancestors or analogies of selected production varieties used in the system. Species that prefer full sunlight will be selected to form the canopy layer, species with preferences for partial shade will form the understory, etcetera, until all fractures of light are used in photosynthesis. According to this theory, monocultures consisting of physically identical plants having the same shape and same preferences for certain light conditions, will use sunlight less efficiently resulting in lower yields.

Although optimum usage of sunlight in photosynthesis in itself is not necessarily required for a system to remain sustainable, there are some arguments to consider light adsorption in the process of photosynthesis as indicator of sustainability. For instance, higher light absorption in photosynthesis can result in more biomass production (potentially edible biomass) and thus in more CO_2 extraction from the atmosphere.
Photosynthesis is shown to be influenced by plant health, and light absorption (NDVI) can be used to measure biotic and abiotic caused stress influencing plant growth. On large farms, this principle is already applied by observing plant performance in terms of NDVI values, making use of drones. If particular spots in the field have a lower NDVI value, the farmer can check what is causing these problems and in some cases directly respond (application of fertilizers or pesticides for instance). Bare soils that are prone to erosion and therefore are not very sustainable, by definition have very low photosynthetic activity. Whether or not NDVI values are a reliable indicator of photosynthetic efficiency in agroforestry systems is not clear, more research on this topic is needed. In contrast with monoculture crops, NDVI values are inherent spatial diverse for agroforestry systems as different plant species use slightly different fractions of the photosynthetic active radiation and differ in photosynthetic activity in general. Following the development of an agroforestry system over time and the related changes in NDVI values is recommended to gain more insight in the meaning and relevance of photosynthetic activity patterns in this species diverse type of agriculture.

NORMALIZATION AND ASSESSMENT OF INDICATORS

As mentioned in ‘

Sustainability Assessment: aggregation of indicators', normalization of the indicators of sustainability is required to allow for aggregation. For this study, a relatively simple normalization method was used where theoretical optimum values were used as reference value when these were clearly defined in literature. In all other cases, the highest test result was used as reference value. Although some more complicated methods for normalization are proposed by (Gómez-Limón & Sanchez-Fernandez, 2010; Munda, 2005) and others, these calculations require higher data input and are much more complex to use and interpret. Therefore, it was chosen not to include these techniques here, at the risk of missing different interpretations of the same dataset.

AGGREGATION OF INDICATORS

To compare the multi-dimensional sustainability of different agro-ecosystems, indicators that provide information about the 'state' of these different dimensions should be brought together in a composition indicator. The first step required is the normalization of different indicators. These normalized indicators can be aggregated to express one overall value of sustainability. Mathematical techniques to aggregate different indicators are available, allowing its users to adjust for instance the weight of each indicator and modify the subsequent relationships among indicators. For example, when there is reason to believe the soil organic matter percentage of a system is much more important when measuring that systems sustainability than for instance ground beetle diversity, the ground beetle score is counted only half.

To justify such modifications, some scientific evidence must be found suggesting that doing so would increase the composition indicators' validity in expressing a systems sustainability. In this study, no good arguments were found to adjust the weight of different indicators.

Three variations of the same aggregation technique were used and described, as all different techniques resulted in slightly different but relevant information.

Again, it is important to note that the choice of method of aggregation is subjective, and inherently effects a research its results.

DIRECTION OF GROUNDWATER MOVEMENT

As mentioned earlier, the study sites are located in an area with an interesting geographical history. Anno 2016, the direction of groundwater flows is still determined by the landscape that was formed by glacier movement. The study sites are located in the valley between glacier moraines and subsequently have a natural high groundwater table. It is artificial drainage that enables agriculture and inhabitation of this area.
In this study, remarkable low groundwater N-NO3 and P-PO4 concentrations were found for all study sites, especially in the context of agriculture. Moreover, N-NH4 concentrations in groundwater samples were low, with exception for the samples taken at Ketelbroek. One of the hypothesized explanations for these low concentrations of nutrients is that clean groundwater is upwelling from deeper soil layers and removed horizontally from the land into the drainage channels (schematically visualized in Figure 14). Consequently, nutrients are leached to the surface water in the drainage channels rather than the groundwater (as is normally the case). This effect is likely strongest at PG and lower for Ketelbroek and De Bruuk, as the drainage system of Ketelbroek is at least partially removed and drainage at De Bruuk is virtually absent.

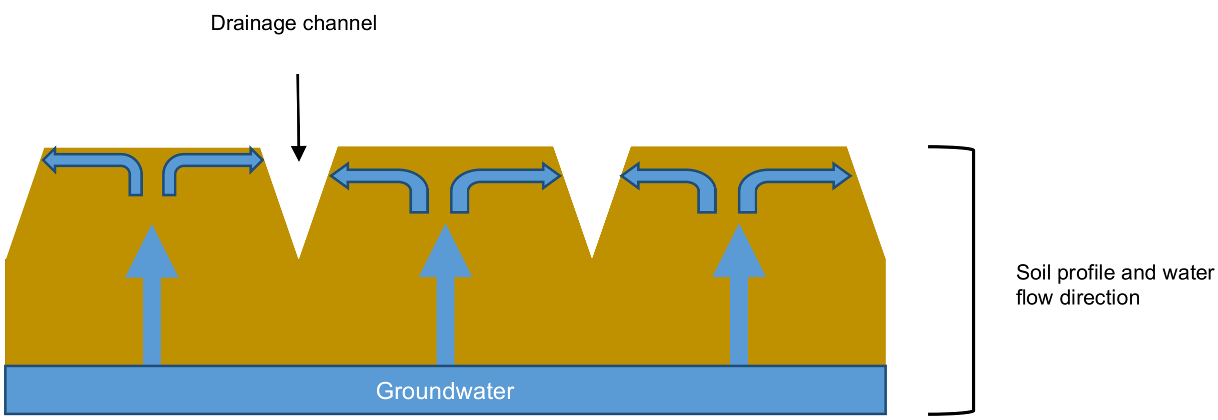


FIGURE 14 : VISUALIZATION OF GROUNDWATER FLOW IN SOIL PROFILE. AS GROUNDWATER IS FORCED UPWARDS IN THE SOIL PROFILE, WATER SOLUBLE NUTRIENTS ARE SOLVED AND REMOVED FROM SOIL THROUGH DRAINAGE OF WATER IN HORIZONTAL CHANNELS.

AGE OF SYSTEMS

In this study, the sustainability of three perennial based (agro)-ecosystems is compared based on different indicators of sustainability. Although the resulting information is interesting and valuable in the discussion whether or not nature and biodiversity can coexist with food production for human consumption, it is essential not to attenuate the weight of the simplification of reality needed to allow for comparison. One of the most profound simplifications lies in the assumed comparability of the three different system, regardless of their different age and specific state (in terms of for instance %SOM) at point zero. Although it was never our intention to deny the importance of these factors, it was chosen not to discontinue the study because of it. Rather, we argue this study to be a starting point for studies into the sustainability of Ketelbroek, instead of presenting the final sustainability score.

Although all indicators of sustainability that were considered in this study are rather resulting from and influenced by continuing processes, the influence of time (among other factors) is for example clear in soil organic matter dynamics. De Bruuk NA (multiple decennia) and the permanent grassland system (at least thirty years) considered in this study are both very old (that is; managed for a long time in a comparable manner as it is today). Ketelbroek, on the other hand, is only six years old and is located on agricultural soil that was intensively cultivated (potato and silage maize production) for years.

Therefore, it is rather interesting to compare soil organic matter dynamics per system in a continued study, than it is to compare data of a single measurement that reflects the state of a system instead of the direction of its development.

WEATHER CONDITIONS 2016

Data of all indicators of sustainability assessed in this thesis, was collected in the spring and early summer (April – July) of 2016. April 2016 was on average cold and wet ("KNMI - April 2016," n.d.). May 2016, on the other hand was on average relatively dry but characterized by short extreme weather events. During the last days of may and the first day of June, parts of the Netherlands as well as other European countries faced extreme precipitation events ("KNMI - Klimaatanalyse van extreme buien eind mei begin juni 2016," n.d.). Although the precise impact of these weather conditions on for instance groundwater and soil chemistry (samples taken on the 28th of June) remains uncertain, it does allow for speculation. The mentioned differences in drainage regimes for the different systems in combination with the extreme precipitation, likely resulted in (at least temporary) differences in groundwater level. If groundwater levels at Ketelbroek were sufficiently high to reach the root zone of plants and resulted in anoxic conditions, this might have resulted in ammonium production and explain the measured groundwater N-NH4 concentrations.

CONCLUSION

In this study on sustainability assessments for complex agroecosystems, existing (scientific) knowledge and theories and a practical case study at Ketelbroek Food Forest were combined to gain insight in the sustainability of Ketelbroek and sustainability assessments in general. One of the primary purposes of the study was to discover what study system (Ketelbroek Food Forest, permanent grassland, nature area De Bruuk) is the most sustainable, based on a set of indicators. In reality, however, the indicators of sustainability and their scores were found to be much more ambiguous than expected. Multiple assessment techniques were tested, all resulting in different conclusions. Moreover, when reflected on in the light of specific contexts, scores initially considered to indicate unsustainable conditions arguably indicated the opposite. When different indicators were aggregated into one average sustainability score of a system, details needed to understand the complexity of measuring sustainability was lost. Therefore, aggregation of indicators aiming to express the sustainability of a system in one single score, was (at least for this case study) found to be undesirable. Subdividing indicators by topic (biodiversity, soil quality, groundwater quality) in practice was found to be a useful strategy to improve the clarity of the data and provide insight in the relation between different elements of sustainability. For Ketelbroek, for instance, biodiversity was found to be highest/most sustainable. However, groundwater quality was suboptimal. When all indicators were aggregated, the overall sustainability appeared to be low, regardless of the fact that biodiversity was highest.
For the subdivision 'Groundwater', nature area de Bruuk scored highest. Soil quality appeared to be the highest for the permanent grassland. Concluding, the subdivision technique suggests all systems have sustainable and less optimal elements.

Although the selected indicators of sustainability provided interesting information on multiple aspects of sustainability while relatively easily measurable at low costs, improvement of the selection is desirable. Important is the absence of indicators on social and economic sustainability. Input/output ratios, expressing the needed inputs (labor, money, fuel, time) per unit of output (food, biomass, fuel, cultural value) provide highly interesting information on the efficiency of a system which arguably is an important part of sustainability. However, this type of indicator requires enormous amounts of data, resulting in a significantly more complicated study.

In this study, the set of studied indicators of sustainability was based on both gut feelings about relevance, monetary restrictions and limited availability of time. Although it was intended to include social and economic indicators of sustainability, data on these topics was found hard to acquire. The resulting absence of information on these elements of sustainability is conflicting objectivity. By acknowledging these facts, the aimed for objectivity might be doubted. As was demonstrated in this study, the outcome of a sustainability assessment is inherent to the selection of used indicators and the methodological choices that are made by the scientist and therefore is inherently subjective. Transparency about the choices that are made, specific contexts and the inherent ambiguity of sustainability, I conclude, determines whether or not the subjective character of (this type of) studies should be considered problematic.

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APPENDICES

APPENDIX 1 : GPS COORDINATES SAMPLE SITES

Dry Bulk Density	Lat	Long
1	51°46'8.33"N	5°57'56.56"E
2	51°46'7.73"N	5°57'58.95"E
3	51°46'6.33"N	5°58'3.98"E
4	51°46'8.74"N	5°57'57.10"E
5	51°46'8.69"N	5°57'57.83"E
6	51°46'8.33"N	5°58'0.92"E
7	51°46'7.47"N	5°58'5.29"E
8	51°46'11.27"N	5°57'58.55"E
9	51°46'10.79"N	5°58'0.72"E
10	51°46'8.92"N	5°58'3.84"E
11	51°46'3.09"N	5°58'1.64"E
12	51°46'3.59"N	5°58'2.47"E
13	51°46'4.83"N	5°58'3.23"E
14	51°46'3.75"N	5°57'58.62"E
15	51°46'4.44"N	5°57'59.01"E
16	51°46'5.24"N	5°57'59.86"E
17	51°46'4.69"N	5°57'54.87"E
18	51°46'5.43"N	5°57'55.62"E
19	51°46'5.92"N	5°57'56.44"E
20	51°46'4.12"N	5°58'0.51"E
21	51°45'50.33"N	5°57'51.91"E
22	51°45'50.64"N	5°57'52.04"E
23	51°45'49.88"N	5°57'54.76"E
24	51°45'50.03"N	5°57'53.96"E
25	51°45'48.93"N	5°57'56.47"E
26	51°45'49.86"N	5°57'57.81"E
27	51°45'50.81"N	5°57'56.40"E
28	51°45'49.39"N	5°57'52.10"E
29	51°45'55.04"N	5°57'54.05"E
30	51°45'55.24"N	5°57'57.20"E

Visual Soil Assessment	Lat	Long
	51°46'8.77"N	5°57'59.53"E

Macro Nightbutterfly sampling point	Lat	Long
Ketelbroek	51°46'6.33"N	5°58'3.98"E
Bruuk	51°45'50.81"N	5°57'56.40"E

Wormsamples	Lat	Long
1	51°46'9.92"N	5°57'58.47"E
2	51°46'8.24"N	5°57'56.35"E
3	51°46'9.43"N	5°58'1.68"E
4	51°46'7.83"N	5°58'2.20"E
5	51°46'6.70"N	5°58'4.31"E
11	51°46'4.54"N	5°58'2.38"E
12	51°46'3.40"N	5°58'1.52"E
13	51°46'4.35"N	5°57'58.95"E
14	51°46'4.85"N	5°57'56.18"E
15	51°46'5.95"N	5°57'57.34"E
21	51°45'49.30"N	5°57'57.28"E
22	51°45'49.60"N	5°57'54.18"E
23	51°45'50.05"N	5°57'50.84"E
24	51°45'51.07"N	5°57'50.89"E
25	51°45'55.83"N	5°57'54.54"E

Groundwater and Soil samples	Lat	Long
1	51°46'7.67"N	5°58'4.58"E
2	51°46'7.33"N	5°58'3.24"E
3	51°46'8.60"N	5°57'57.27"E
4	51°46'9.79"N	5°57'58.40"E
5	51°46'10.83"N	5°57'59.10"E
11	51°46'4.89"N	5°58'2.58"E
12	51°46'3.78"N	5°58'0.77"E
13	51°46'4.75"N	5°57'58.48"E
14	51°46'4.35"N	5°57'56.53"E
15	51°46'6.17"N	5°57'56.66"E
21	51°45'50.43"N	5°57'51.36"E
22	51°45'47.13"N	5°57'47.13"E
23	51°45'49.30"N	5°57'52.70"E
24	51°45'49.55"N	5°57'53.69"E
25	51°45'49.61"N	5°57'55.87"E

	Ketelbroek			De Bruuk		
Samplesite	**1**	**2**	**3**	**4**	**5**	**6**
Amara similata	57	0	4	0	0	0
Amara communis	45	2	64	0	0	0
Pterostichus strenuus	17	0	14	0	4	1
Notiophilus palustris	9	0	9	3	0	0
Harpalus latus	9	0	2	0	0	0
Clivina fossor	8	6	13	2	2	3
Poecilus versicolor	8	5	4	0	25	0
Harpalus rufipes	5	1	22	0	0	0
Pterostichus vernalis	5	2	17	0	1	1
Anisodactylus binotatus	2	0	11	0	0	0
Bradycellus harpalinus	2	0	1	0	0	0
Amara lunicollis	2	0	0	0	5	0
Amara aenea	2	3	0	0	0	0
Poecilus cupreus	1	21	9	0	9	0
Amara aulica	1	0	3	0	0	0
Pterostichus anthracinus	1	0	0	1	2	7
Bembidion properans/lampros	1	20	0	0	0	0
Trechus obtusus	1	0	0	0	0	0
Pterostichus melanarius	0	0	12	0	0	1
Trechoblemus micros	0	0	8	0	0	0
Anchomenus dorsalis	0	0	4	0	0	0
Agonum muelleri	0	12	3	0	0	0
Oodes helopioides	0	0	2	1	1	0
Loricera pilicornis	0	0	1	1	1	4
Bembidion mannerheimii	0	1	1	0	2	0
Amara ovata	0	0	1	0	0	0
Pterostichus niger	0	0	1	0	0	0
Limodromus assimilis	0	0	0	19	0	28
Carabus nemoralis	0	0	0	17	1	28
Carabus granulatus	0	0	0	16	12	20
Nebria brevicollis	0	3	0	2	3	14
Abax ater	0	0	0	16	0	6
Pterostichus nigrita	0	0	0	3	1	6
Pterostichus minor	0	0	0	0	2	3
Notiophilus rufipes	0	0	0	1	0	1
Harpalus laevipes	0	0	0	0	0	1
Trechus rubens	0	0	0	0	0	1
Bembidion guttula	0	0	0	2	0	0
Patrobus atrorufus	0	0	0	1	0	0
Pterostichus oblongopunctatus	0	0	0	1	0	0
Acupalpus exiguus	0	0	0	0	1	0
Harpalus signaticornis	0	0	0	0	1	0
Cicindela campestris	0	14	0	0	0	0
Notiophilus substriatus	0	10	0	0	0	0
Chlaenius nigricornus	0	6	0	0	0	0
Bembidion lunulatum	0	4	0	0	0	0
Harpalus affinis	0	3	0	0	0	0
Clivina collaris	0	1	0	0	0	0
Stenolophus mixtus	0	1	0	0	0	0
Aantal individuen	**176**	**115**	**206**	**86**	**73**	**125**

Total Ketelbroek	497	Total BRUUK	284

APPENDIX 3 : MACROLEPIDOPTERA DATA

Nr.	Species (Dutch)	Bruuk	Ketelbroek
1	Variabele Spanner	38	0
2	Witte Schaduwspanner	21	0
3	Tweevlekspanner	14	0
4	Vierstipbeertje	10	0
5	Melkwitte Zomervlinder	6	0
6	Grote Spikkelspanner	5	0
7	Naaldboombeertje	5	0
8	Hyena	4	0
9	Lichte Blokspanner	4	0
10	Kleine Herculesspanner	4	0
11	Kleine Wapendrager	4	0
12	Gele Tijger	4	0
13	Heidewortelboorder	3	0
14	Bruine Eenstaart	3	0
15	Geel Spannertje	3	0
16	Klein Visstaartje	3	0
17	Variabele Eikenuil	2	0
18	Ringelrups	2	0
19	Leverkleurige Spanner	2	0
20	Getande Spanner	2	0
21	Witvlekspikkelspanner	2	0
22	Kameeltje	2	0
23	Erwtenuil	2	0
24	Roesje	2	0
25	Slawortelboorder	1	0
26	Dennenpijlstaart	1	0
27	Groenige orvlinder	1	0
28	Berkenspikkelspanner	1	0
29	Schimmelspanner/Gehoekte Schimmelspanner	1	0
30	Zwartvlekdwergspanner	1	0
31	Klaverblaadje	1	0
32	Sleedoorndwergspanner	1	0
33	Lindeknotsvlinder	1	0
34	Drievlekspanner	1	0
35	Naaldboomspanner	1	0
36	Gestreepte tandvlinder	1	0
37	Kleine Hermelijnvlinder	1	0
38	Dromedaris	1	0
39	Gevlekte winteruil	1	0
40	Gewone Silene-uil	1	0
41	Paddenstoeluil	1	0
42	Sint-Jacobsvlinder	1	0
43	Zwarte-c-uil	0	57
44	Nunvlinder	0	19
45	Gekraagde Grasuil	0	11
46	Brede W-uil	0	8
47	Halmrupsvlinder/Weidehalmuiltje	0	6
48	Bleke Grasworteluil	0	6
49	Egale Stofuil	0	5
50	Variabele Breedvleugeluil	0	5
51	Komma-uil	0	5
52	Wegedoornspanner	0	4
53	Bosspanner	0	4
54	Volgeling	0	4
55	Zwartbandspanner	0	3
56	Geoogde Bandspanner	0	3
57	Bessentakvlinder	0	3
58	Geoogde worteluil	0	3
59	Sneeuwbeer	0	3
60	Gele Agaatspanner	0	2
61	Bruine wapendrager	0	2
62	Zilverstreep	0	2
63	Vogelwiekje	0	2
64	Wachtervlinder	0	2
65	Oranje o-vlinder	0	2
66	Eikendwergspanner	0	1
67	Fruitboomdwergspanner	0	1
68	Streepjesdwergspanner	0	1
69	Esdoorndwergspanner	0	1
70	Ligusterpijlstaart	0	1
71	Berkeneenstaart	0	1
72	Gele Eenstaart	0	1
73	Dennenspanner	0	1
74	Vroege blokspanner	0	1
75	Schaapje	0	1
76	Grote worteluil	0	1
77	Dubbelstipvoorjaarsuil	0	1
78	Schedeldrager	0	1
79	Levervlek	0	1
80	Zuidelijke Stofuil	0	1
81	Getekende Gamma-uil	0	1
82	Weidehalmuiltje	0	1
83	Witte-l-uil	0	1
84	Donsvlinder	0	1
85	Bruine Sikkeluil	0	1
86	Schildstipspanner	84	5
87	Geel Beertje	51	6
88	Braamvlinder	21	2
89	Zwartkamdwergspanner	12	1
90	Eikentandvlinder	20	2
91	Gevlekte zomervlinder	29	4
92	Boogsnuituil	15	2
93	Populierentandvlinder	9	1
94	Kroonvogeltje	9	1
95	Slakrups	8	1
96	Meriansborstel	29	4
97	Ringspikkelspanner	41	7
98	Variabele Spikkelspanner	12	2
99	Donker Klaverblaadje	14	4
100	Gewone Spikkelspanner	26	8
101	Kleine Groenbandspanner	38	13
102	Kleine Blokspanner	8	1
103	Appeltak	20	7
104	Bruine Breedvleugeluil	8	2
105	Voorjaarsdwergspanner	14	4
106	Vuursteenvlinder	21	10
107	Puntige Zoomspanner	13	6
108	Zwart Beertje	8	1
109	Gepijlde Micro-uil	6	1
110	Gerande Spanner	118	87
111	Schimmelspanner	4	1
112	Fijnspardwergspanner	4	1
113	Marmeruil	7	2
114	Gestreepte Rietuil	6	2
115	Zomervlinder	7	3
116	Peppel-orvlinder	4	2
117	Gestippelde oogspanner	3	2
118	Bosgrasuil	3	2
119	Wilgendwergspanner	3	2
120	Herculesje	3	1
121	Wederikdwergspanner	3	1
122	Jota-uil	3	1
123	Spitsvleugelgrasuil	2	1
124	Hopsnuituil	2	1
125	Blauwrandspanner	2	1
126	Brandvlerkvlinder	5	3
127	Snuitvlinder	5	4
128	Kleine Zomervlinder	43	43
129	Drielijnuil	9	9
130	Tweestreepvoorjaarsuil	5	5
131	Maantandvlinder	4	4
132	Taxusspikkelspanner	3	3
133	Goudvenstertje	3	3
134	Gewone Dwergspanner	2	2
135	Gemarmerd heide-uiltje	2	2
136	Groenbandspanner	2	2
137	Schijn-sparspanner/Sparspanner	2	2
138	Rietvink	1	1
139	Populierenpijlstaart	1	1
140	Papegaaitje	1	1
141	Schermbloemendwergspanner	1	1
142	Fraaie Walstrospanner	1	1
143	Varenspanner	1	1
144	Draak	1	1
145	Kleine Beer	1	1
146	Roomkleurige stipspanner	1	1
147	Grote groenuil	1	1
148	Gevlekte groenuil	1	1
149	Pauwoogpijlstaart	1	1
150	Agaatvlinder	18	19
151	Rondvleugelbeertje	7	8
152	Peper-en-zoutvlinder	6	7
153	Maanuiltje	2	3
154	Wapendrager	3	5
155	Lieveling	1	2
156	Koolbandspanner	1	2
157	Donker Brandnetelkapje	1	2
158	Berkenbrandvlerkvlinder	1	2
159	Gestreepte Goudspanner	1	3
160	Donkere Marmeruil	48	55
161	Oranjegeel Halmuiltje	51	64
162	Hagedoornvlinder	12	14
163	Grijze Stipspanner	9	11
164	Zilveren Groenuil	4	6
165	Populierenuil	1	5
166	Schaduwsnuituil	9	14
167	Bruine Grijsbandspanner	20	31
168	Haarbos	29	52
169	Groene dwergspanner	7	9
170	Schilddrager	5	7
171	Variabele Voorjaarsuil	7	10

172	Bruine Vierbandspanner	6	9
173	Vierbandspanner	3	6
174	Witte Grijsbandspanner	7	15
175	Driehoekuil	3	7
176	Bosbesuil	3	7
177	Witlijntandvlinder	3	7
178	V-dwergspanner	6	13
179	Gewone Bandspanner	4	11
180	Grijze dwergspanner	3	9
181	Mendicabeer	1	6
182	Vlekstipspanner	3	12
183	Groot Avondrood	3	16
184	Kleine Groenuil	1	7
185	Witte Tijger	26	57
186	Stompvleugelgrasuil	27	84
187	Stro-uiltje	14	53
188	Koperuil	9	40
189	Donker Halmuiltje	11	68
190	Vliervlinder	1	8
191	Wilgenschorsvlinder	1	8
192	Kweekgrasuil	1	8
193	Huismoeder	8	41
194	Witstipgrasuil	2	12
195	Gewone Breedvleugeluil	6	40
196	Puta-uil	1	9
197	Variabele Grasuil	2	18
198	Rietgrasuil	2	18
199	Gelobd Halmuiltje	5	43
200	Grauwe Grasuil	1	12
201	Morpheusstofuil	1	13
202	Stippelsnuituil	1	13
203	Groente-uil	13	105
204	Houtspaander	14	135
205	Bruine Snuituil	15	291
206	Meldevlinder	1	21
207	Moerasgrasuil	1	23
208	Gamma-uil	1	26
209	Graswortelvlinder	2	52
210	Gewone worteluil	3	155
211	Gewone Stofuil	1	86
		1411	2375

APPENDIX 4 : BIRD TERRITORIA

Species (Dutch)	Ketelbroek	Bruuk
Vink	0	3
Roodborst	0	3
Boompieper	0	2
Holenduif	0	2
Houtduif	0	2
Waterhoen	0	1
Boomkruiper	0	1
Pimpelmees	0	1
Grote bonte specht	0	1
Spreeuw	0	1
Koekoek	0	1
Glanskop	0	1
Bosuil	0	1
Buizerd	0	1
Grasmus	7	0
Spotvogel	5	0
Bosrietzanger	3	0
Kleine Karekiet	3	0
Geelgors	2	0
Putter	2	0
Zwarte Kraai	1	0
Ooievaar	1	0
Tuinfluiter	1	0
Fazant	1	0
Kneu	1	0
Groenling	1	0
Rietgors	1	0
Roodborsttapuit	1	0
Winterkoning	1	8
Zwartkop	3	6
Tjiftjaf	4	5
Merel	3	3
Zanglijster	1	1
Fitis	1	1
Grauwe Vliegenvanger	1	1
Heggenmus	2	1
Koolmees	3	2
	49	49

APPENDIX 5 : VEGETATION LIST

Vegetation list Bruuk

1 Zevenblad - Aegopodium podagraria
2 Moerasstruisgras - Agrostis canina
3 Gewoon struisgras - Agrostis capillaris
4 Kruipend zenegroen - Ajuga reptans
5 Zwarte els - Alnus glutinosa
6 Grote vossenstaart - Alopecurus pratensis
7 Bosanemoon - Anemone nemorosa
8 Gewone engelwortel - Angelica sylvestris
9 Gewoon reukgras - Anthoxanthum odoratum
10 Fluitenkruid - Anthriscus sylvestris
11 Kleine watereppe - Berula erecta
12 Ruwe berk - Betula pendula
13 Kleine veldkers - Cardamine hirsuta
14 Pinksterbloem - Cardamine pratensis
15 Scherpe zegge - Carex acuta
16 Zwarte zegge - Carex nigra
17 Hazenzegge - Carex ovalis
18 Oeverzegge - Carex riparia
19 Snavelzegge - Carex rostrata
20 Haagbeuk - Carpinus betulus
21 Dolle kervel - Chaerophyllum temulum
22 Wilgenroosje - Chamerion angustifolium
23 Akkerdistel - Cirsium arvense
24 Kale jonker - Cirsium palustre
25 Speerdistel - Cirsium vulgare
26 Haagwinde - Convolvulus sepium
27 Hazelaar - Corylus avellana
28 Eenstijlige meidoorn - Crataegus monogyna
29 Kamgras - Cynosurus cristatus
30 Kropaar - Dactylis glomerata
31 Gevlekte rietorchis - Dactylorhiza praetermissa subsp. junialis
32 Ruwe smele - Deschampsia cespitosa
33 Bochtige smele - Deschampsia flexuosa
34 Smalle stekelvaren - Dryopteris carthusiana
35 Brede stekelvaren - Dryopteris dilatata
36 Heermoes - Equisetum arvense
37 Holpijp - Equisetum fluviatile
38 Koninginnekruid - Eupatorium cannabinum
39 Speenkruid - Ficaria verna
40 Moerasspirea - Filipendula ulmaria
41 Es - Fraxinus excelsior
42 Gewone hennepnetel - Galeopsis tetrahit
43 Kleefkruid - Galium aparine
44 Glad walstro - Galium mollugo
45 Lievevrouwebedstro - Galium odoratum
46 Moeraswalstro - Galium palustre
47 Geel Nagelkruid – Geum urbanum
48 Hondsdraf - Glechoma hederacea
49 Mannagras - Glyceria fluitans
50 Liesgras - Glyceria maxima
51 Klimop - Hedera helix
53 Gewone berenklauw - Heracleum sphondylium
54 Lidsteng - Hippuris vulgaris
55 Gestreepte witbol - Holcus lanatus
56 Gladde witbol - Holcus mollis
57 Sint-Janskruid - Hypericum perforatum
58 Gele lis - Iris pseudacorus
59 Jakobskruiskruid s.l. - Jacobaea vulgaris
60 Veldrus - Juncus acutiflorus
61 Biezenknoppen - Juncus conglomeratus
62 Pitrus - Juncus effusus
63 Tengere rus - Juncus tenuis
64 Gele dovenetel s.l. - Lamiastrum galeobdolon
65 Witte dovenetel - Lamium album
66 Gevlekte dovenetel - Lamium maculatum
67 Paarse dovenetel - Lamium purpureum
68 Akkerkool - Lapsana communis
69 Veldlathyrus - Lathyrus pratensis
70 Wilde kamperfoelie - Lonicera periclymenum
71 Moerasrolklaver - Lotus pedunculatus
72 Grote veldbies - Luzula sylvatica
73 Wolfspoot - Lycopus europaeus
74 Penningkruid - Lysimachia nummularia
75 Grote wederik - Lysimachia vulgaris
76 Grote kattenstaart - Lythrum salicaria
77 Watermunt - Mentha aquatica
78 Bosgierstgras - Milium effusum
79 Pijpenstrootje - Molinia caerulea
80 Zompvergeet-mij-nietje - Myosotis laxa subsp. cespitosa
81 Moerasvergeet-mij-nietje - Myosotis scorpioides subsp. scorpioides
82 Gewone vogelmelk - Ornithogalum umbellatum
83 Rietgras - Phalaris arundinacea
84 Timoteegras - Phleum pratense subsp. pratense
85 Riet - Phragmites australis
86 Smalle weegbree - Plantago lanceolata
87 Grote weegbree + Getande weegbree - Plantago major
88 Straatgras – Poa annua
89 Veldbeemdgras - Poa pratensis
90 Ruw beemdgras - Poa trivialis
91 Ratelpopulier - Populus tremula
92 Tormentil - Potentilla erecta
93 Slanke sleutelbloem - Primula elatior
94 Gewone brunel - Prunella vulgaris
95 Gewone vogelkers - Prunus padus
96 Amerikaanse vogelkers - Prunus serotina
97 Zomereik - Quercus robur
98 Amerikaanse eik - Quercus rubra
99 Scherpe boterbloem - Ranunculus acris
100 Egelboterbloem - Ranunculus flammula
101 Kruipende boterbloem - Ranunculus repens
102 Sporkehout - Rhamnus frangula
103 Grote ratelaar - Rhinanthus angustifolius
104 Akkerkers - Rorippa sylvestris
105 Dauwbraam - Rubus caesius
106 Gewone braam - Rubus fruticosus
107 Framboos - Rubus idaeus
108 Vuurkambraam – Rubus rubrumcadaver
109 Veldzuring - Rumex acetosa
110 Ridderzuring - Rumex obtusifolius
111 Geoorde wilg - Salix aurita
112 Boswilg - Salix caprea
113 Grauwe wilg + Rossige wilg - Salix cinerea
114 Gewone vlier - Sambucus nigra
115 Knopig helmkruid - Scrophularia nodosa
116 Echte koekoeksbloem - Silene flos-cuculi
117 Bitterzoet - Solanum dulcamara
118 Late guldenroede - Solidago gigantea

119 Moerasmelkdistel - Sonchus palustris
120 Wilde lijsterbes - Sorbus aucuparia
121 Grasmuur – Stellaria graminea
122 Grote muur - Stellaria holostea
123 Vogelmuur - Stellaria media
124 Zeegroene muur - Stellaria palustris
125 Paardenbloem - Taraxacum officinale s.l. (incl. all sec.)
126 Rode klaver - Trifolium pratense
127 Grote brandnetel - Urtica dioica
128 Echte valeriaan - Valeriana officinalis
129 Beekpunge - Veronica beccabunga
130 Vogelwikke - Vicia cracca
131 Ringelwikke - Vicia hirsuta
132 Smalle wikke + Vergeten wikke + Voederwikke - Vicia sativ1

Vegetation list Ketelbroek

1 Spaanse aak - Acer campestre
2 Gewone esdoorn - Acer pseudoplatanus
3 Duizendblad - Achillea millefolium
4 Zevenblad - Aegopodium podagraria
5 Zilverhaver - Aira caryophyllea
6 Grote waterweegbree - Alisma plantago-aquatica
7 Look-zonder-look - Alliaria petiolata
8 Zwarte els - Alnus glutinosa
9 Grote vossenstaart - Alopecurus pratensis
10 IJle dravik - Anisantha sterilis
11 Fluitenkruid - Anthriscus sylvestris
12 Gewone klit - Arctium minus
13 Gewone glanshaver - Arrhenatherum elatius subsp. elatius
14 Bijvoet - Artemisia vulgaris

15 Madeliefje - Bellis perennis
16 Kleine watereppe - Berula erecta
17 Ruwe berk - Betula pendula
18 Zachte dravik - Bromus hordeaceus
19 Goudsbloem - Calendula officinalis
20 Ruig klokje - Campanula trachelium
21 Herderstasje - Capsella bursa-pastoris
22 Kleine veldkers - Cardamine hirsuta
23 Pinksterbloem - Cardamine pratensis
24 Ruige zegge - Carex hirta
25 Hazenzegge - Carex ovalis
26 Pilzegge - Carex pilulifera
27 Tamme kastanje - Castanea sativa
28 Knoopkruid - Centaurea jacea s.l.
29 Gewone hoornbloem + Glanzige hoornbloem - Cerastium fontanum
30 Wilgenroosje - Chamerion angustifolium
31 Melganzenvoet - Chenopodium album
32 Akkerdistel - Cirsium arvense
33 Speerdistel - Cirsium vulgare
34 Haagwinde - Convolvulus sepium
35 Smal vlieszaad - Corispermum intermedium
36 Rode kornoelje - Cornus sanguinea
37 Hazelaar - Corylus avellana
38 Eenstijlige meidoorn - Crataegus monogyna
39 Kropaar - Dactylis glomerata
40 Gevlekte rietorchis - Dactylorhiza praetermissa subsp. junialis
41 Grote kaardebol - Dipsacus fullonum
42 Slangenkruid - Echium vulgare
43 Gewone waterbies - Eleocharis palustris
44 Kweek - Elytrigia repens
45 Beklierde basterdwederik - Epilobium ciliatum
46 Harig wilgenroosje - Epilobium hirsutum
47 Heermoes - Equisetum arvense
48 Holpijp - Equisetum fluviatile
49 Zomerfijnstraal - Erigeron annuus
50 Gewone steenraket - Erysimum cheiranthoides

51 Koninginnekruid - Eupatorium cannabinum
52 Speenkruid - Ficaria verna
53 Moerasspirea - Filipendula ulmaria
54 Es - Fraxinus excelsior
55 Kleefkruid - Galium aparine
56 Moeraswalstro - Galium palustre
57 Ruw walstro - Galium uliginosum
58 Slipbladige ooievaarsbek - Geranium dissectum
59 Zachte ooievaarsbek - Geranium molle
60 Hondsdraf - Glechoma hederacea
61 Mannagras - Glyceria fluitans
62 Liesgras - Glyceria maxima
63 Gewone berenklauw - Heracleum sphondylium
64 Oranje havikskruid - Hieracium aurantiacum
65 Duindoorn - Hippophae rhamnoides
66 Gestreepte witbol - Holcus lanatus
67 Gladde witbol - Holcus mollis
68 Sint-Janskruid - Hypericum perforatum
69 Gewoon biggenkruid - Hypochaeris radicata
70 Jakobskruiskruid s.l. - Jacobaea vulgaris
71 Veldrus - Juncus acutiflorus
72 Zilte greppelrus - Juncus ambiguus
73 Platte rus - Juncus compressus
74 Pitrus - Juncus effusus
75 Paddenrus - Juncus subnodulosus
76 Kompassla - Lactuca serriola
77 Witte dovenetel - Lamium album
78 Paarse dovenetel - Lamium purpureum
79 Veldlathyrus - Lathyrus pratensis
80 Kleine margriet - Leucanthemum paludosum
81 Wilde liguster - Ligustrum vulgare
82 Engels raaigras - Lolium perenne
83 Moerasrolklaver - Lotus pedunculatus
84 Wolfspoot - Lycopus europaeus
85 Penningkruid - Lysimachia nummularia
86 Grote kattenstaart - Lythrum salicaria
87 Schijfkamille - Matricaria discoidea
88 Struisvaren - Matteuccia struthiopteris
89 Hopklaver - Medicago lupulina
90 Luzerne - Medicago sativa

91 Watermunt - Mentha aquatica
92 Akkervergeet-mij-nietje - Myosotis arvensis
93 Moerasvergeet-mij-nietje - Myosotis scorpioides subsp. scorpioides
94 Watermuur - Myosoton aquaticum
95 Witte waterkers - Nasturtium officinale
96 Grote klaproos - Papaver rhoeas
97 Perzikkruid - Persicaria maculosa
98 Rietgras - Phalaris arundinacea
99 Timoteegras - Phleum pratense subsp. pratense
100 Riet - Phragmites australis
101 Grove den - Pinus sylvestris
102 Smalle weegbree - Plantago lanceolata
103 Grote weegbree + Getande weegbree - Plantago major
104 Straatgras - Poa annua
105 Veldbeemdgras - Poa pratensis
106 Ruw beemdgras - Poa trivialis
107 Gewoon varkensgras - Polygonum aviculare
108 Ratelpopulier - Populus tremula
109 Zilverschoon - Potentilla anserina
110 Amerikaanse vogelkers - Prunus serotina
111 Sleedoorn - Prunus spinosa
112 Gevlekt longkruid - Pulmonaria officinalis
113 Vuurdoorn - Pyracantha coccinea
114 Zomereik - Quercus robur
115 Scherpe boterbloem - Ranunculus acris
116 Egelboterbloem - Ranunculus flammula
117 Kruipende boterbloem - Ranunculus repens
118 Blaartrekkende boterbloem - Ranunculus sceleratus
119 Sporkehout - Rhamnus frangula
120 Grote ratelaar - Rhinanthus angustifolius
121 Aalbes - Ribes rubrum
122 Kruisbes - Ribes uva-crispa
123 Robinia - Robinia pseudoacacia
124 Akkerkers - Rorippa sylvestris
125 Hondsroos - Rosa canina s.l.
126 Rimpelroos - Rosa rugosa
127 Dauwbraam - Rubus caesius
128 Gewone braam - Rubus fruticosus
129 Veldzuring - Rumex acetosa
130 Ridderzuring - Rumex obtusifolius
131 Moeraszuring - Rumex palustris
132 Liggende vetmuur - Sagina procumbens
133 Schietwilg - Salix alba
134 Boswilg - Salix caprea
135 Gewone vlier - Sambucus nigra
136 Dagkoekoeksbloem - Silene dioica
137 Echte koekoeksbloem - Silene flos-cuculi
138 Blaassilene - Silene vulgaris
139 Canadese guldenroede - Solidago canadensis
140 Akkermelkdistel - Sonchus arvensis
141 Gekroesde melkdistel - Sonchus asper
142 Gewone melkdistel - Sonchus oleraceus
143 Wilde lijsterbes - Sorbus aucuparia
144 Grote egelskop s.l. - Sparganium erectum
145 Moerasandoorn - Stachys palustris
146 Grasmuur - Stellaria graminea
147 Vogelmuur - Stellaria media
148 Zeegroene muur - Stellaria palustris
149 Gewone smeerwortel - Symphytum officinale
150 Boerenwormkruid - Tanacetum vulgare
151 Paardenbloem - Taraxacum officinale s.l. (incl. all sec.)
152 Zomerlinde - Tilia platyphyllos
153 Kleine klaver - Trifolium dubium
154 Inkarnaatklaver - Trifolium incarnatum
155 Rode klaver - Trifolium pratense
156 Witte klaver - Trifolium repens
157 Reukeloze kamille - Tripleurospermum maritimum
158 Klein hoefblad - Tussilago farfara
159 Grote lisdodde - Typha latifolia
160 Gladde iep - Ulmus minor
161 Grote brandnetel - Urtica dioica
162 Kleine brandnetel - Urtica urens
163 Echte valeriaan - Valeriana officinalis
164 Akkerereprijs - Veronica agrestis
165 Veldereprijs - Veronica arvensis
166 Draadereprijs - Veronica filiformis
167 Vogelwikke - Vicia cracca
168 Voederwikke - Vicia sativa subsp. sativa

FIGURE 1 Soil scorecard – visual indicators for assessing soil quality in orchards

Landowner: Wouter van Eck

Land use: Food Forest

Site location: Food Forest (romantical)

GPS ref:

Sample depth: 25 cm

Date: 1 oktober 2016

Soil type: Silt loam

Soil classification:

Drainage class: -

Textual group (upper 1 m): ☐ Sandy ☒ Loamy ☒ Silty ☐ Clayey ☐ Other

Moisture condition: ☐ Dry ☒ Slightly moist ☐ Moist ☐ Very moist ☐ Wet

Seasonal weather conditions: ☒ Dry ☐ Wet ☐ Cold ☐ Warm ☒ Average

Visual indicators of soil quality		Visual score (VS) 0 = Poor condition 1 = Moderate condition 2 = Good condition	Weighting	VS ranking
Soil texture	pg. 2	2	x 3	6
Soil structure	pg. 4	1,5	x 2	3
Soil porosity	pg. 6	1	x 3	3
Soil colour	pg. 8	1.5	x 1	1.5
Number and colour of soil mottles	pg. 10	1.5	x 2	3
Earthworms (Number =) (Av. size =)	pg. 12	0	x 3	0
Potential rooting depth (m)	pg. 14	1 (around 30 cm)	x 3	3
Surface ponding	pg. 18	2	x 2	4
Surface crusting and surface cover	pg. 20	2	x 2	4
Soil erosion (wind/water)	pg. 22	2	x 2	4
SOIL QUALITY INDEX (sum of VS rankings)				31.5

Soil Quality Assessment	Soil Quality Index
Poor	< 15
Moderate	15–30
Good	> 30

5. Determination of organic matter

5.1 Determination of organic matter by loss-on-ignition

1. Principle of the method

1.1 The organic matter of the soil and plant samples is assessed gravimetrically by dry combustion of the organic material in a furnace at 500-550 °C. the loss in the weight gives an indication of the content of organic matter in the sample.

However, at the high temperature used, several soil components are lost: $CaCO_3$ is decomposed (loss of CO_2), structural water is released from the crystal lattice and NaCl is volatilized.

No corrections are made for the losses of weight of these phenomena.

2. Apparatus

2.1 Dryingoven
2.2 Furnace, capable of producing and maintaining a temperature of at least 500°C.
2.3 Weighing balance

3. Procedure

7.1 Heat a crucible during 1 hour in a drying oven at 103°C. Weigh the empty crucible hot at three decimals (A).Then weigh out precisely about 5 g soil or 2 g plant material in the crucible (W).

Put the crucible into the drying oven at 103°C, for at least 8 hours. Weigh the hot crucible with the dry sample (B).

Put the put the crucible in the furnace and raise the temperature gradually from room temperature to 550°C. Maintain this temperature during at least 3 hours. Then cool off the furnace to about 150°C and put the crucible in the drying oven at 103°C, for about 1 hour.

Then weigh the hot crucible with the ash (C).

4. Calculation

First the dry matter content of the sample can be calculated in %:

$$\frac{B-A}{(A+W)-A} * 100\%$$

The organic matter content of the sample in % is:

$$\frac{B-C}{B-A} * 100\%$$