DESIGN AND PERFORMANCE EVALUATION OF A 1HA PRODUCTIVE FOOD FOREST MODEL

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Yann Boulestreau with Realtime Landscape Architecture 2016©

Foreword – A forest for the future

Nature and agriculture are having an unhappy relationship. Production of food is causing huge decrease of biodiversity, is stimulating soil erosion and is contributing quite a lot to climate change. This rather dark picture can be seen when one looks at the nowadays dominant types of agriculture.

A food forest is meant to combine nature and agriculture. By mimicking essential parts of a natural forest, it is possible to create a system with perennial crops (many of them of course being trees and shrubs). A well designed food forest will produce food without needing fertilizers and pesticides. Our Food Forest Ketelbroek near Groesbeek in the Netherlands is still a quite recent attempt to realize such a system. However it is an interesting experiment, that might even contribute partly to a much needed 'reinvention of agriculture'.

We need many different insects for pollination (and many birds to prevent insects becoming a plague). We need healthy soil life to increase fertility of the soil. We need to grow biomass and plenty of organic matter for improvement of water management (since the soil of a forest will never be drowned or dehydrated). We need to sequester carbon. We notice this all happening right now, after planting a food forest on a bare field.

Of course, many questions still need to be answered. What about feeding the world? We know for sure a system based upon huge use of fossil fuels and meanwhile depleting soils (like modern agriculture) will not be able to feed the world in the future. But can we feed the world with shifting to agroecological systems such as food forests?

What about scaling up production to make the food forest system fit for farmers? Can harvests be rationalized? Will volumes reach reasonable levels?

Yann Boulestreau has showed to understand the importance of these questions. His internship at Food Forest Ketelbroek has been a period of inspiration. Together we co-designed a theoretical model of a food forest. Eventually Yann did an incredible job with gathering and checking relevant data. He combined available information to come up with calculations which are most interesting.

Happy relationships seem possible within a food forest, for nature and agriculture, for economy and ecology. Of course a model is not reality and more research needs to be done. However, this thesis of Yann was already convincing enough to start planting the designed model on some hectares on different places in the Netherlands. By planting and analyzing the evolution of these forthcoming food forests over the next years and decades, we will learn more about this system. Yann has been planting a seed in fertile soil.

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Please read: Notice to understand correctly this work ☺

This work is a result of the equivalent of 4 months of bibliographic research, thinking and modeling. Very scarce peer-reviewed scientific literature was available for complex Agroforestry systems in temperate climate. The sources used were then mainly coming from the practitioner community of food forest system such as Martin Crawford in the United Kingdom. The methodological approach was mainly coming from my head, using my background in engineering and agronomy, and exchanges with Wouter Van Eck from *Ketelbroek Food Forest* and Roos Nijpels from *Rich Forests*. The work has been done rigorously, every step and choice taken, every calculation being presented transparently in this report. **The values taken were conservative in order to avoid over-estimation of the food forests potential**.

In my opinion, this work can be considered as a **rough estimation of the yield, economical result and nutritional carrying capacity of a rationale food forest in a North European context, not more and not less.** My hope is that it can be useful to the community interested in Food Forestry as such but also that it can be used as a basis to develop a stronger and more precise scientific evaluation. Numerous ways to take in order to go in that direction are presented in the part 7 and 8 of this report: "Discussions" and "Prospective work". I think it can also be used as an inspiration for people who would like to set up a food forest in Northern Europe, who want to see from their home how it can look like and/or want a draft design as a basis for making their own.

This report is the outcome of the internship I did with the Farming Systems Ecology department of Wageningen University as part of the MSc Organic Agriculture-Agroecology.

If you have any questions, comments or remarks or want to contact me to use my work in another study or project, please send me an email to yannboulestreau@hotmail.fr.

Acknowledgements

I really enjoyed doing this work. I enjoyed it because I liked the topic but also because of my tutor and friend Wouter Van Eck. I want to give him many thanks for his kindness, his enthusiasm in sharing his enormous knowledge about plants and Food Forestry and his friendship. I also want to thank him and my supervisor from Wageningen University for their patience and their understanding of what priorities there are in life. I couldn't finish this work in due time because of health problems. They didn't put any pressure on me, trusting that I would resume my writing as soon as I could. I want also to give thanks to Kees Van Veluw for having given me the idea to contact Wouter for this internship and to Roos Nijpels for having taken the time to talk with me about the model they had developed at *Rich Forest* and given me support and inspiration for my work. Thanks to Egbert Latinga from Wageningen University for its administrative supervision and its grading. Thanks to Simon Legoupil, old friend who took the time when he had so little to proofread this document. Finally, I want to thanks Imke Harms, my dear friend, to have lent me her desk in her room to finish writing this report, even when she would have liked to use it.

I hope the Food Forest community will strengthen in Europe, and will get more and more interest from the scientific community. I believe it is a very interesting farming system for the future and that scientists should get working on it to explore its possibilities and, if relevant, legitimate this system to the farming community.

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1. Introduction

Many alternative ways of farming are currently being developed in order to answer the urge of building sustainable societies. Many are inspired from natural ecosystem, best adapted to the local conditions. Mimicking those ecosystems is done for reaching comparably high resource use efficiency and resiliency. “Food Forest” systems mimic forest ecosystems. They mimic a forest ecosystem with its species diversity, its 3-dimension architecture capturing light energy, offering habitat to biodiversity and storing carbon while producing food for human consumption. The only change compared to a natural forest is that all the plant species are producing food resource for humans or supporting other species to do so. Autonomous by nature, they need very little management and investment after plantation but for the food harvest. They can be temperate (mimicking temperate forest ecosystem) or tropical (mimicking tropical forest ecosystems). They can also be considered as complex multilayer Agroforestry systems.

Ketelbroek is a Temperate Food Forest in the Netherlands with more than 300 species. Its design is complex and the Food Forest doesn’t produce a full income for its owner. Visiting farmers had concerns about the possibility to develop this kind of system to diversify their own production while keeping or increasing their revenue. To address these concerns, the designer and co-owner of *Ketelbroek*, Wouter Van Eck wanted to develop the design of a productive food forest, practical to manage and attractive for farmers.

The mission was then:

1. Selecting 13 species based on knowledge from similar project and species ecology data. The number 13 was an arbitrary limit to keep species diversity under a manageable number for farmers.
2. Realizing a 1ha food forest theoretical design in accordance with the ecology of each species and the idea of a typical Dutch ecosystem.
3. Evaluating the theoretical yield over 50 years of this 1ha food forest and giving an indication of the economic performance of this system and its nutritional carrying capacity. Here “Nutritional carrying capacity” is defined as the number of average humans whose yearly intake requirements are fulfilled in energy, carbohydrate, protein and fat by the 1ha food forest.

This report will follow the same order explaining the work done step by step.

2. Species pre-selection for further study

2.1. Material and methods

Based on literature concerning similar projects, species identified as interesting by the expert Wouter Van Eck and a series of criteria given in Table 1, 25 species of potential interest for a farmer food forest has been selected.

• Hardiness zone tolerance within the Netherlands' range, meaning 7 or below • Economic value • High economic potential, market opportunity foreseen • Occupy a free[1] ecological niche • Have a Special nutritional/health value

Table 1 - Species pre-selection criteria

2.2. Results

2.2.1. Species selected

The list of species selected with the criteria relevance associated is presented in the Appendix 1.

A list of the names of the species with the pictures of the most uncommon ones can be found below.

Hardi Kiwi *Actinidia arguta*	Autumn Olive *Eleagnus umbellata*	Apple *Malus domestica*	Peach & Nectarines *Prunus Persica (nucipersica)*	Red Currant *Ribes sylvestre*
Ramson / Wild Garlic *Allium Ursinum*	Strawberry *Fragaria spp.*	Apricot *Prunus armenica*	Japanese Plum *Prunus salicina*	Gooseberry *Ribes uva-crispa*
Chokeberry *Aronia spp.*	Day Lilies *Hemerocallis spp.*	Cherry Plum *Prunus cerasifera*	Poire Pyrus communis	Raspberry *Rubus spp.*
Chestnuts *Castanea spp.*	Sea Buckthorns *Hippophae rhamnoides*	European Plum *Prunus domestica*	Rhubarb *Rheum spp.*	Elderberrry *Sambucus canadensis*
Hazelnuts/ Filbert *Corylus spp.*	English Walnut *Juglans Regia*	Almond *Prunus dulcis*	Black currants *Ribes nigrum*	Grape *Vitis spp. (i.e. labrusca)*

Table 2 - Species pre-selected

Figure 1 - Hardy kiwi vine
Source: https://thefruitnut.com/tag/hardy-kiwi/

Autumn olive bush

Figure 2 - Autumn olive bush
Source : http://foragersharvest.com/autumnberry-autumn-olive/

[1] For instance, a climber can be set on the trunk of a tree without taking space of another plant (but another climber)

Figure 3 - Ramson (also called wild garlic)
Source : https://ukbushcrafters.wordpress.com/2012/05/11/a-jews-ramson/ and http://www.123rf.com/photo_27473733_bunch-of-fresh-ramson-food.html

Figure 4 - Chokeberry bush

Source: http://www.paghat.com/chokeberry.html

Figure 5 - Daylilies flowers
Source : https://gardencoachpictures.wordpress.com/tag/daylily/

2.2.2. Species rejected

The following species were all found in Savanna institute's list of species interesting to use and present in other similar systems however they were not suitable for our system aiming to be productive in the Netherlands. The reason for this choice can be found below.

Cherry:	Harvesting dangerous and harvest labour very expensive → Dutch production widely reduced
Oak:	Known by Dutch but not perceived as an edible products for humans → market foreseen as difficult to establish
Hickory:	Not known on Dutch market → less interesting than chestnut and walnut
Pecan:	Takes very long before starting bearing (10-20 years) → less interesting than chestnut and walnut
Hops:	Not perceived as a directly edible product in Netherlands

3. Species ecology database

3.1. Material and methods

The selection of 13 species and the design of the hectare were based on the ecological and socio-economic relevance of the species. An optimal complementarity of the species ecological niches was sought and species producing high market value products were favored. The information on the ecology of the different species were gathered in a database. The explanation of the database categories chosen and their relevance can be found below.

<u>Forest vertical layer (called “Storey” later)</u>

The choice here was made of a 7 layers classification inspired by the one imagined by Robert Hart (see Fig.6) and adapted to our situation. Among the plants selected, there was no root crop. Furthermore, the distinction between the soil surface layer and the herbaceous layer was not seen as a relevant distinction for the species pre-selected. However, we could distinguish 3 sizes of trees within our pre-selection:

- Small Trees : from 0.5 to 6m
- Medium Trees : from 6 to 12m
- Canopy Trees : above 12m

Then, similarly, a difference was made between the Small Schrubs (schrubs smaller than 2m) and the large ones (larger than 2m).

This was an important element to take into account in order to grasp the potential of niche complementarity of our 13 species selection, especially in regards to capturing the light.

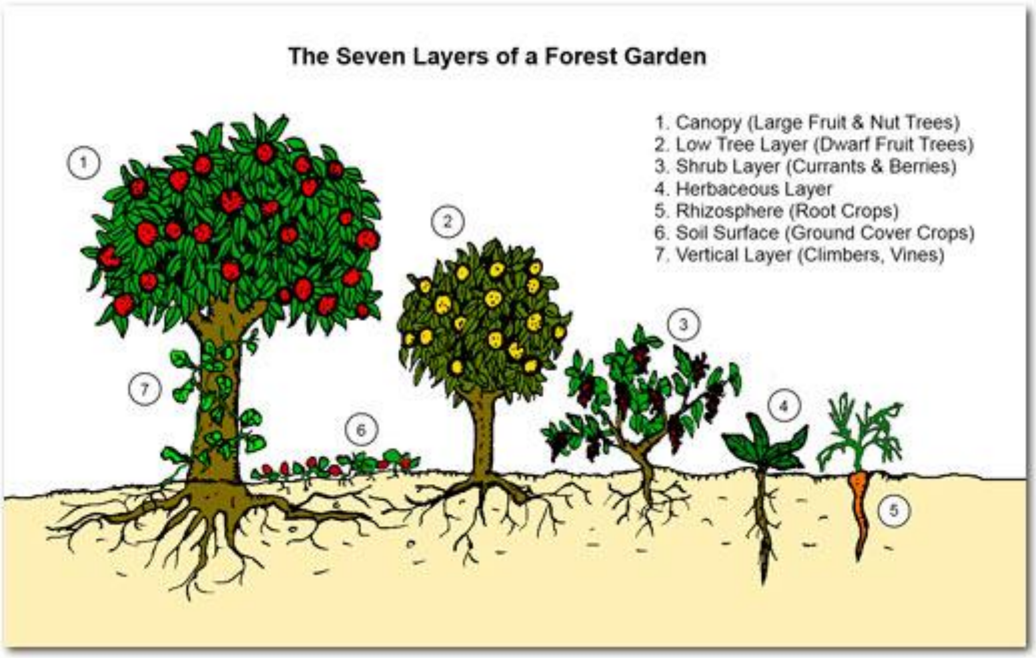

Figure 6 - The Seven Layers of a Forest Garden

Source: Permaculture a Beginner’s Guide, by Graham Burnett

Hardiness zones

The "Hardiness Zone" of a plant gives an indication of the minimum average winter temperature a plant can tolerate. It also represents a territory (a "zone") where the average minimum temperature is within a given range. This means that a plant zone 5 will very likely survive temperatures above -28°C (see Table 3) during winter but will likely die if the temperature goes below -28°C. Given that the other conditions for the plant survival are fulfilled, a plant of zone 5 (e.g. black currants) can survive in any place of the world being hardiness zone 5 or more. For instance, it can survive in Netherlands where the Hardiness zone is 8 or 7 for the center-east. This risk of dying from frost is the main shared limitation for mature perennial species to survive in a given environment. That is why it is a good criterion to look when choosing species for the food forest. Finally, micro-climatic conditions at the landscape or field scale can allow the survival of plants in lower hardiness zone or hinder their development within their hardiness zone tolerance range.

Zone number	Average min temp (°C)
1	Below -46
2	-46 to -40
3	-40 to -34
4	-34 to -29
5	-29 to -23
6	-23 to -18
7	-18 to -12
8	-12 to -7
9	-7 to -1

Table 3 - Hardiness zones temperatures

Figure 7- Hardiness zones Europe

Source: https://uk.pinterest.com/pin/355221489336908995/

Light requirement

As it is not being applied to a specific case or region of the Netherlands, the design can't take into account soil properties. Besides, assuming that mycorrhiza will eventually give trees rather easy access to nutrients even tens of centimeters away, light will be the main competition element between the plants in our system. Therefore, to optimize niche complementarity, the "Sun/Shade preference" and "Shade tolerance" are of major importance.

The “Sun/Shade preference” indicates the light conditions a plant prefers and will thrive in. Conversely, the “Shade tolerance” indicates the shadiest condition in which a plant will thrive in. The data given in the database is for UK climate which is close from the Dutch one. In place with hotter and drier summer like in the South of France, slightly shadier condition will likely be preferred. Conversely in places with cooler summer like in mountains or higher latitudes, slightly sunnier conditions are preferred. Soil moisture also has an influence. Plants on moist soil will tolerate more sun than plants on drier soil.

pH range, soil type and moisture let us know if the species selected are compatible in the sense that they can be grown and cropped efficiently on the same soil.

Root structure is important to foresee niche complementarity between different species (e.g. apple shallow root system and rhubarb deep root system).

Plant dimension and spacing were sought in literature in order to know where to place which plant relatively to the others.

Main yield is important to know the productive potential of one species and then forecast the yield, the sales and the nutritional carrying capacity of the whole system.

Secondary yield indicates to what extend the species can give secondary products, this often being potential niche products for the farmer to (process and) sell.

Service indicates if the species provides services that enhance ecosystem conditions for growing and cropping. Four services have been selected: nitrogen fixation, hedging species, pollination species and ground litter enhancer.

Vulnerability to frost, need for shelter and vulnerability to wind are all important in order to know how to place species regarding the microclimates available or that can be created in the design.

Macronutrients need indicates which species have a strong need in which macronutrients in order to include plants providing those macronutrients nearby.

Phenology

A phenology table has been created gathering the data per species about:

- The flowering period and the potential of the species to provide food to insect pollinators. This was to be able to select species with temporal complementarity of food provision for pollinators. Indeed, for the health and the good productivity of the system, it is important to ensure a strong pollinator population. This can be later complemented with hedges species.
- The harvest period. Here as well, the temporal complementarity is of importance. Spreading the harvesting period allows spreading the workload for the farmer and then making the harvest of the food forest manageable for him at relatively low labour cost.
- Late frost resistance/vulnerability. This is important as it is a major cause of damages to perennial plants leading to their unproductivity (for a year or permanently). This has to be confronted with the occurrence of late frost in the area the food forest would be planted.

<u>Lifecycle</u>

A lifecycle table gives 3 age intervals on the 50 years timespan chosen:

- when the plant species should start cropping
- when it should reach its maximum cropping potential
- when its production should decrease below the level of interest for the producer

Not all information for the each species could be found in literature. Those periods can extend on several months cause they depend on the variety and the local conditions

<u>Additional notes</u> give important details for the design phase, e.g. bearing of the plant for spatial complementarity, need of thinning to foresee the workload, humidity vulnerability to foresee the need of good air flow in the system, etc.

When the information couldn't be found in literature, Wouter Van Eck completed with his experience. Those data are in *italic*.

At this stage, the **<u>economical value potential</u>** of the different products was informally estimated based on our knowledge as consumers of sustainably produced fruits.

3.2. Results

Table 4 - Pre-selected plant species ecology

Name	Storey	HZ	Light Requirement				pH										Soil type										
			●	◐	◑	○	3.5						7			8.5	C	Si C	Si C L	C L	Sa C L	Si L	Sa Si L	Sa L	L Sa	Sa	other char.
Hardi Kiwi ***Actinidia arguta***	L 7	2																									
Ramson / Wild Garlic ***Allium Ursinum***	G 6	4															N D	N D	N D	N D	N D	N D	N D	N D	N D	N D	+ humus rich
Chokeberry ***Aronia spp.***	SS 5	4																									
Chestnuts ***Castanea spp.***	C 1	4-6																									- heavy soil. + well-drained loamy soils
Hazelnuts/Filbert ***Corylus spp.***	LS 4	4																									Highly fertile soil decre

																											ases yield @ calcareous to acid loam & clay
Autumn Olive ***Eleagnus umbellata***	LS 4	3																									Salt resistant. @ poor soil
Strawberry ***Fragaria spp.***	G 6	3-6																									
Day Lilies *Hemerocallis spp.*	G 6	4																									
Sea Buckthorns *Hippophae rhamnoides*	LS 4	3																									Salt resistant. @ poor soil
English Walnut ***Juglans Regia***	C 1	4-5																									- heavy soil and light sandy soil
Apple ***Malus domestica***	ST 3	2-5																									f° roosto

																											ck
Apricot *Prunus armenica*	MT 2	5-6																									+ deep soil. Salt tolera nt
Cherry Plum *Prunus cerasifera*	MT 2	3-4																									
European Plum ***Prunus domestica***	ST3/MT 2	5																									f° roosto ck
Almond *Prunus dulcis*	MT 2	6-7																									@poo r soil + highly fertile deep loamy soil
Peach & Nectarines *Prunus Persica (nucipersica)*	ST 3	P.5 N.6																									+ rich OM & deep
Japanese Plum *Prunus salicina*	ST 3	4-5																	N D	N D	N D	N D	N D	N D	N D	N D	N D	N D	More tolera nt for heavy soil/ot her stone fruits
Poire Pyrus communis	MT 2	4-5																									- Thin chalk

Rhubarb ***Rheum spp.***	G 6	3/6															N D	N D	N D	N D	N D	N D	N D	N D	N D	N D	+ humus rich soil
Black currants *Ribes nigrum*	SS 5	5																									
Red Currant ***Ribes sylvestre***	SS 5	6																									
Gooseberry *Ribes uva-crispa*	SS 5	5																									
Raspberry *Rubus spp.*	SS 5	3																									
Elderberrry ***Sambucus canadensis***	LS 4	5															N D	N D	N D	N D	N D	N D	N D	N D	N D	N D	
Grape *Vitis spp. (i.e. labrusca)*	L 7	5																									

Name	Moisture			Root structure	Dimension and spacing (m)	Yields			Wind & Frost resistance/ Shelter needed	Macronutrient needed
						Main Yield at maturity per plant (kg) (performance rating)	2nd Yield	Service		
Hardi Kiwi					H 30 into	22.5-90	+			

Actinidia arguta					trees	(+++)				
Ramson / Wild Garlic ***Allium Ursinum***					H&W&S 0.3	0.175/m^2 (++++)	0	P		
Chokeberry ***Aronia spp.***					H3/2/2.5 W1.5/3/2.5 S 1*3.5	*10* (++++)	0	H/P		
Chestnuts ***Castanea spp.***				Deep, up to 2,5m	H30 S12-15	5y old : 5-8 8y : 6-20 10y+ : 25-34 20% is shell weight (++++)	0	P+/-		N, K
Hazelnuts/Filbert ***Corylus spp.***				Small taproots. Plenty of shallow roots. No deep roots.	H 3.5-6 W 3.5-4.5 S 4.5-5or 3.5*6 (allows use of blueberries harvester)	9-11 50% is shell weight (+++)	+	GL/H	F	
Autumn Olive ***Eleagnus umbellata***					*H 6* *W 4.5*	>10 (++++)	+	P/N/GL/H	W	
Strawberry ***Fragaria spp.***				50-90% roots in first 10-15cm of soil	H 0.15-0.25 W 0.3-0.375 S 0.45-0.6 0.8-1.1*0.25-0.5	0.2-0.7 (++++)	+	P+/-		

Day Lilies *Hemerocallis spp.*					H 0.45-0.6 W 0.3-0.45 S 0.45	ND (+++)	0			
Sea Buckthorns *Hippophae rhamnoides*					H & W 3-6 S 1*4	*10* (++++)	++	N/H/GL	W	
English Walnut ***Juglans Regia***				Tap root very large and strong. Few lateral when young	H 18-30 W 12-18 S 9-15	50-75 53% is shell weight (+++)	++	GL		N
Apple ***Malus domestica***				Shallow root system	H&W 1.2-10.5 S 1-1.5*3-4 Semi-dwarf H&W 3.5-6 About 80% edible	Dwarf: 14-23 Semi-dwarf: 27-54 Std: 45-108 (++++)	0	P	W, Sn when flowering	N, K
Apricot *Prunus armenica*					H&W 1.2-10 S 6*6	14-55 (++)	+	P		**N**, K
Cherry Plum *Prunus cerasifera*					H&W 4-9	ND (++++)	+	P/H	W	
European Plum ***Prunus domestica***					H&W 3-9 S 1.5-2.5*3.5-4.5	7-9 (++++) About 90% edible	0	P		N
Almond *Prunus dulcis*				If peach rootstock :	H 2.4-10 S 6-7.3	5-18 (++)	+	P early		N

				shallow root system If Almond roostock: deep taproot	W 2.4-10					
Peach & Nectarines *Prunus Persica (nucipersica)*					H 0.6-6 W 0.6-7.5 S 4.5-6	Fan: 9-13.5 Bush tree: 13.5 Standard: 25-36	++	P	W	K
Japanese Plum *Prunus salicina*					H 3-5 W 3-6 S 5 or 3-6*5.5-6	ND (+++)	+	P	Sn	
Poire Pyrus communis					H 1.2-12 W 1.2-7.5	Bush tree : 18/45 (+++)	ND	P	Sn	
Rhubarb ***Rheum spp.***				Tap root	H 1.5-2.5 W 1-1.5 S 0.8-1.2	1.35-1.8 (++++)	0	GL (mineral accumulator)		
Black currants *Ribes nigrum*				Shallow and fribrous	H2 max W1m max S 0.6-1.2*2.5-3	4-4.5 (++++)	+	P		
Red Currant ***Ribes sylvestre***				Shallow and fribrous	H2 max W1m max S 0.6-1.2*1.8-2.4	1.35-4.5 (++++)	0	P	F	
Gooseberry *Ribes uva-crispa*				Shallow and fribrous	H&W 1-1.5m S0.6-1.2*1.8-2.4	3.5-4.5 (++++)	0	P	F	

Raspberry *Rubus spp.*					H2 S0.05-0.1*0.3	0.45-0.675 (++++)	+	P	F	
Elderberrry ***Sambucus canadensis***				Shallow/flat	H1.8-5 (can go up to 10) W 1.8-5 S 1-1.5*2.5-3	6-8 (+++)	++	P		
Grape *Vitis spp. (i.e. labrusca)*					H30 S 1.5-2.5*3-4	4.5-7 (++++)	++	P+/-		

<u>Legend :</u>

Storeys :

C 1	Canopy trees
MT 2	Medium trees
ST 3	Small trees
LS 4	Large schrubs
SS 5	Small schrubs
G 6	Ground Cover
L 7	Lianes

Hardiness zone: see Table 1 above

Light requirement:

	Sun/Shade preference	Shade tolerance
●	Prefers fairly deep shade (no direct sun but some indirect light)	Tolerate fairly deep shade (no direct sun but some indirect light)
◐	Prefers moderate shade moderate shade (about 20% or an hour or two of direct sun per day)	Tolerates moderate shade (about 20% or an hour or two of direct sun per day)
◑	Prefers light shade (about 50% or 4-5 hours of full sun per day)	Tolerates light shade (about 50% or 4-5 hours of full sun per day)
○	Prefers full sun conditions	Doesn't tolerate shade

pH

pH Range	3.5-4.0	4.0-4.5	-5.0	-5.5	-6.0	-6.5	-7.0	-7.5	-8.0	-8.5
Color code										

	Tolerance (or data not making distinction between tolerance and preference)
	Preference

Soil type

C	Si C	Si C L	C L	Sa C L	SiL	SaSiL	SaL	L Sa	Sa
Clay	Silty Clay	Silty Clay Loam	Clay Loam	Sandy Clay Loam	Silt Loam	Sandy Silt Loam	Sandy Loam	Loamy Sand	Sand

	Type of soil suitable for the species
ND	No data found

Other characteristic

+	The best is	@	Adapted to
-	Can't stand	f°	Highly dependant on
OM	Organic matter		

Soil moisture

	Drought tolerant
	Tolerate wide range soil moisture from quite dry to moist but well-drained
	Tolerate waterlogging

Moisture

Drought tolerant	Medium range of soil from moist to somewhat dry. Would need watering in dry period and won't stand seasonal wet feet.	Can grow in wet or seasonnaly wet soil. Don't necessarily stand waterlogging.

Dimension and spacing

H Height
W Width/Diameter of the canopy
S Spacing. 1 value → distance needed in every direction. 2 values → distance needed in rows* distance needed between rows

Yield

Main yield

The performance rating is a qualitative indication of how well the species grows and crops in a food forest given by the worldwide forest garden expert Martin Crawford in his book *Creating a forest garden*:

+ Fair
++ Good
+++ Very good
++++ Excellent

2nd yield

Qualitative estimation of the potential of a species to produce other interesting products for human use (e.g. fuel, medicine, construction material, …):

0 No 2nd yield
+ 1 or 2 fairly interesting to interesting supplementary products
++ 2 or more interesting supplementary products

Service

N Nitrogen fixing plant
H Good hedge plant
P Producing resources for pollinators
GL Enrich soil with mineral rich leaves or roots

Wind & Frost resistance/ Shelter needed

W Wind resistance
F Frost resistance
Sn Shelter needed

Nutrients needed

N Nitrogen
P Phosphorus

Table 5 - Pre-selected plant species life-cycle

Name	Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Hardi Kiwi ***Actinidia arguta***																										
Ramson / Wild Garlic ***Allium Ursinum***																										
Chokeberry ***Aronia spp.***																										
Chestnuts ***Castanea spp.***																										
Hazelnuts/Filbert ***Corylus spp.***																										
Autumn Olive ***Eleagnus umbellata***																										
Strawberry ***Fragaria spp.***																										
Day Lilies *Hemerocallis spp.*																										
Sea Buckthorns *Hippophae rhamnoides*																										
English Walnut ***Juglans Regia***																										
Apple	Standard																									
Malus	**Semi-dwarf**																									
domestica	dwarf																									
Apricot *Prunus armenica*																										
Cherry Plum *Prunus cerasifera*	inc																									

European Plum ***Prunus domestica***																										
Almond *Prunus dulcis*	inc																									
Peach & Nectarine *Prunus* *Persica* *(nucipersica)*	Peach																									
	Nectarine																									
Japanese Plum *Prunus salicina*	inc																									
Poire Pyrus communis																										
Rhubarb ***Rheum spp.***																										
Black currants *Ribes nigrum*																										
Red Currant ***Ribes sylvestre***																										
Gooseberry *Ribes uva-crispa*																										
Raspberry *Rubus spp.*																										
Elderberrry ***Sambucus canadensis***	inc																									
Grape *Vitis spp. (i.e. labrusca)*																										

Name	Year	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	GR
Hardi Kiwi ***Actinidia arguta***																											
Ramson / Wild Garlic ***Allium Ursinum***																											
Chokeberry ***Aronia spp.***																											
Chestnuts ***Castanea spp.***																											
Hazelnuts/Filbert ***Corylus spp.***																											
Autumn Olive ***Eleagnus umbellata***																											
Strawberry ***Fragaria spp.***																											
Day Lilies *Hemerocallis spp.*																											
Sea Buckthorns *Hippophae rhamnoides*																											
English Walnut ***Juglans Regia***																											
Apple	Standard																										
Malus	**Semi-dwarf**																										
domestica	dwarf																										
Apricot *Prunus armenica*																											
Cherry Plum *Prunus cerasifera*																											
European Plum																											

Prunus domestica																										
Almond *Prunus dulcis*																										
Peach & Nectarines *Prunus Persica (nucipersica)*																										
Japanese Plum *Prunus salicina*																										
Poire Pyrus communis																									→	
Rhubarb ***Rheum spp.***																										
Black currants *Ribes nigrum*																										
Red Currant ***Ribes sylvestre***																										
Gooseberry *Ribes uva-crispa*																										
Raspberry *Rubus spp.*																										
Elderberrry ***Sambucus canadensis***																										
Grape *Vitis spp. (i.e. labrusca)*																									→	

Legend			
	Start cropping		Max cropping AND end of economic usefulness period
	Max cropping (maturity)		
	end of economic usefulness		
	Start cropping period AND max cropping period		end of economic usefulness of the plant over 50 years after germination
inc	Data incomplete	**Rhubarb**/ Grape	Species selected for the design/species not selected

Name	Phenology												Frost resistance	Additional Notes
	J	F	M	A	M	J	J	A	S	O	N	D		
Hardi Kiwi ***Actinidia arguta***													-	Protect when young from cats, slugs and snails. Pruning needed to keep it at manageable size.
Ramson / Wild Garlic ***Allium Ursinum***						* *							?	* Dies out in June -> no more ground cover
Chokeberry ***Aronia spp.***													++	Shade reduces fruiting. Flowering in Late Spring. Useful lifespan not clearly known. One source suggests 10 to 15 years, another suggests it can live (without mentioning the production) 100 years. The last one suggests that it is autoregenerating with suckering.
Chestnuts ***Castanea spp.***													?	Fruit to pick daily during a 10-12 days period. Can form an understory. Pollen producing tree need to be less than 40m away. About 1 out of 4 trees in any direction should be a pollen producer.
Hazelnuts/Filbert ***Corylus spp.***													++	Good hedging but exposure reduces yield. Need 2 to 3 varieties to ensure good pollination.

Table 6 - Pre-selected plant species life-cycle

Autumn Olive ***Eleagnus umbellata***	?	Growth of 60cm per year. No important pest and diseases known.
Strawberry ***Fragaria spp.***	?	Flowering April onward, Fruiting June onward. Function of species and varieties, 7 main species
Day Lilies *Hemerocallis spp.*	?	Need protection from slug at the beginning
Sea Buckthorns *Hippophae rhamnoides*	?	Shelter and food for biodiversity. Need 1 male for 6 females. Growth of 60cm per year, reach about 5m in 10 years. No significant pest and disease.
English Walnut ***Juglans Regia***	- -	Need to be picked daily. Need 1 out of 8 trees producing pollen upwind. Humid condition to be avoided → plantation need to allow the flow of wind.
Apple ***Malus domestica***	?	Flowering varying tremendously depending on the cultivar. Need about 6 different varieties for good pollination. Need shelter for good fruiting. Need pruning if not for juice.
Apricot *Prunus armenica*	-	Need to be picked daily. Need shelter against the wind during fruiting period. Very pest resistant compared to other stone fruits. Humid condition to avoid. May need thinning while. Free shape (no pruning and branches forcing) is good.
Cherry Plum *Prunus cerasifera*	0	Round headed. Sprouting. 40cm growth per year (4m in 10 years). Disease resistant.
European Plum ***Prunus domestica***	- (especially no-cooking variety)	Depending on the variety pass 2 to 3 times to harvest. Bearing upright, spreading or pendulum.

		Sprouting. Need thinning.
Almond *Prunus dulcis*	- -	Bearing habit upward then bushy with broad crown
Peach & Nectarines *Prunus Persica (nucipersica)*	?	Need good flow of air with, low humidity. Bearing upward overtopped. Fruit thinning needed. Better on a sunny wall.
Japanese Plum *Prunus salicina*	- -	Need thinning to get good fruit size. More resistant to disease than European plum.
Poire Pyrus communis	-	Flowering varying tremendously depending on the cultivar. Need a low humidity and warm spot.
Rhubarb ***Rheum spp.***	?	No maintenance needed.
Black currants *Ribes nigrum*	?	Flowering mid spring. Maintain distance from Hazel if not big bud mite resistant.
Red Currant ***Ribes sylvestre***	++	Flowering early to mid-spring.
Gooseberry *Ribes uva-crispa*	+	Flowering in spring. Shade reduces fruiting. Can pick up green berries from May for cooking.
Raspberry *Rubus spp.*	+	Flowering in spring. Forest edge plant. Let them move. For the design : let the canes arch and rest over other smaller shrubs or perennial -> hide the berries, no nested needed, neither tiding vertically. Summer fruiting varieties and Autumn fruiting ones. Better to use thornless variety

Elderberrry ***Sambucus canadensis***																									?	Shrub multi-stemmed. Best pollination when 2 different cultivars. Little affected by pest and disease
Grape *Vitis spp. (i.e. labrusca)*																									?	flowering mid-end spring

Legend			
	Flowering period	Raspberry	Pollinated by insects
	Harvest period	Chestnuts	Partly pollinated by insect
	Period of flower harvesting when the flower is the main product	English Walnut	Not pollinated by insects
		Rhubarb/ Grape	Species selected for the design/species not selected

When the information was « Late Spring », the period from the "2nd half of May and first half of June" was chosen, being the last month of Spring. Similarly, "Early Spring" and "Mid-Spring" were considered being respectively "2nd half of March to 1st half of April" and "2nd half of April to 1st half of May"

For all the tables above, for an ease of reading, the name of the species selected (cf part 4.) are in bold.

4. Species for design selection

4.1. Materials and methods

The species ecology database was used to make a list of pro and cons for each species. It has been the basis of the decision. This list for the species selected and rejected can be found in Appendix 3.

4.2. Results

The 13 plants list can be found below.

Hardi Kiwi *Actinidia arguta*	Autumn Olive *Eleagnus umbellata*	Apple *Malus domestica*	Hazelnuts/ Filbert *Corylus spp.*	Red Currant *Ribes sylvestre*
Ramson / Wild Garlic *Allium Ursinum*	Strawberry *Fragaria spp.*	Chokeberry *Aronia spp.*	English Walnut *Juglans Regia*	Elderberrry *Sambucus canadensis*
Chestnuts *Castanea spp.*	Sea Buckthorns *Hippophae rhamnoides*	European Plum *Prunus domestica*	Rhubarb *Rheum spp.*	

Table 7 - Selected species

5. Design

5.1. Materials and methods

Three main principles have been used for the design: niche complementarity, easiness of management and hedging with services trees. Below is developed why those principles were interesting and how they were implemented in the case of this design. Then is presented a software used in making the design.

5.1.1. Niche complementarity

Space complementarity is important for:

- Optimal light resource use
  - The global shape of the design was sought to form a solar panel inclined toward the South, in order to catch the maximum amount of Sun energy (see Fig. 5 below). Therefore, the highest plants were placed North and the lowest South.
  - The species thriving in moderate or fairly deep shade were put under the canopy of the trees/bushes, e.g. Hazel and Ramson, the only ones that tolerate deep shadow, were put as North as possible, under the shade of large bushes and trees.
- Optimal root space use. The species known for their shallow root system were sought to be planted in complementarity with plants with tap roots, e.g. apples trees with shallow root and rhubarb with tap roots.
- Optimal volume use. The final maximum volume occupied by those plants at maturity was considered and a space of 0.5 m was left between plants so that plants branches don't mix with each other. The hardy kiwi was placed alternatively on the canopy trees and the apple

trees. The canopy trees were chosen because of their larger trunk space for the vine to climb. It should maximize the production but eventually needs some pruning to limit it to a harvestable height. The apple trees were chosen for similar reasons, but its lower mature height should “force” the kiwi fruits to stay quite easily reachable.

Time is the other fundamental dimension where complementarity was sought. Similarly, it allows optimal root space, light and volume use. It can be considered:

- At the season horizon. The best example in our design is the use of ramson that grows when the trees above still don’t have any leaves.
- At the plants lifespan horizon. Most of the species selected are pretty slow to reach their mature size, which makes space for fast-growing and fast-yielding species in early stage. For time limitation reasons it was not possible to model it precisely, but the design was adjusted for the 5 first years with more European plum trees, elderberries bushes, ramsons and strawberries. The details of the differences can be found in the Excel document “Model Calculations” sheets “y 5” and “y 10” (see Appendix 7).

5.1.2. Easiness of management

Pathways were set up 2m wide in order for car trucks or pallets transporters to be able to pass for harvest especially and eventually for some other management practices.

The 0.5 m minimum distance between mature plants was mainly decided so that people can pass to harvest or manage the plants. It is expected that most plants actually won’t reach their maximum width as the upper range of it was used and because it can take a very very long time before they actually reach this potential. Few plants are expected to go beyond this maximum and would then cost a little pruning work. It is then expected that the real space stays around 1 to 1.5m between plants that would allow the use of motorized or non-motorized tools and ways of transportation for the harvest.

It was decided to plant the plants in straight rows West-East with 1 species per row in order to facilitate the management and especially the harvest. The field was assumed to be completely flat. It also gives other entry points in the system to collect the harvest with motorized or non-motorized tools under the canopy of the trees, when they will be big enough and producing in large quantity.

Ramson and rhubarb were placed underneath trees producing fruits or nuts harvested on the ground. The reason is that they are being harvested before July, leaving the space free for walnuts, chestnuts and apples that are harvested the earliest in August. This is also another example of the use of time complementarity, but regarding the management side of the system.

The pathways were set as is in order to give easy and quick access to any plants. Moreover, the paths were designed so as to be clear of food forest plants on the ground and as canopy. This was done in order to use them as entries of light, facilitate their management and the passage of any kind of vehicles. That led to splitting the field according to the maximum cover of the canopy trees (about 14m) in order to get the most of them. The optimal solution found was to get 7 of them on the row. Regarding spatial arrangement, it means: 3 of them, a pathway North-South and 4 of them (7*14+2=100m). Then the 3D-design of the “solar panel” structure using all the 13 species was made. It ended up being 32m wide. It allowed us to repeat 3 times the same design North-South with 2 pathways between them (32*3+2*2=100m). The pathways subdivided the system in 6 units. The only differences between the different units were the canopy trees species. Walnut and chestnut trees each got half of the units in a way that their total numbers in the system were close.

5.1.3. Hedging

The last element in the design was the addition of a hedge of service trees or bushes around the 1ha plot. “Service trees or bushes” are defined here as trees which are not aimed to produce food but to support the production of food by the other plants of the system. 2 types of service trees were chosen:

- First, Nitrogen-fixing trees or bushes for the South and West hedges, the main wind directions in East Netherlands. The nutrient rich leaves of those trees or bushes are expected to be blown into the system by the main winds and fertilize it naturally. The species chosen is the Sea Buckthorns (*Hippophae rhamnoides*) for several reasons besides its great Nitrogen-fixing ability. It grows fast, then it is expected to quickly form a protective hedge for the young plants against the strong winds. The fruits can be harvested and are considered as “superfruit”. They are especially appreciated when processed as jam, fruit leather or juice for instance. More information regarding this species can be found in the Appendix 3, section « Species only for hedges ».
- Second, wildlife supporting trees or bushes. It is trees or bushes that provide habitat and food for wildlife and especially for birds and pollinators all around the season. The aim is to support the pest control and the pollination services within the field. The list of the species chosen for the hedges North and East can be found in Appendix 4, with their flowering period indicating the period they provide food resources to pollinators.

5.1.4. Software used for 3D design

In order to get a better view of what the system would look like and to help in its realisation, a 3D design was made for the mature system. The software *Realtime Landscape Architect 2016* was used to do so. The right species was not always available. In that case, a similar species was chosen and its size personalized through the « customize plant » tool and the « plant age » choice. The ground was chosen as bare soil so as to see the system with more ease.

No 3D design was made for the first 5 years. The number of plants added was calculated based on the 3D mature design and an estimation of the plant growth for the first 5 years.

5.2. Results

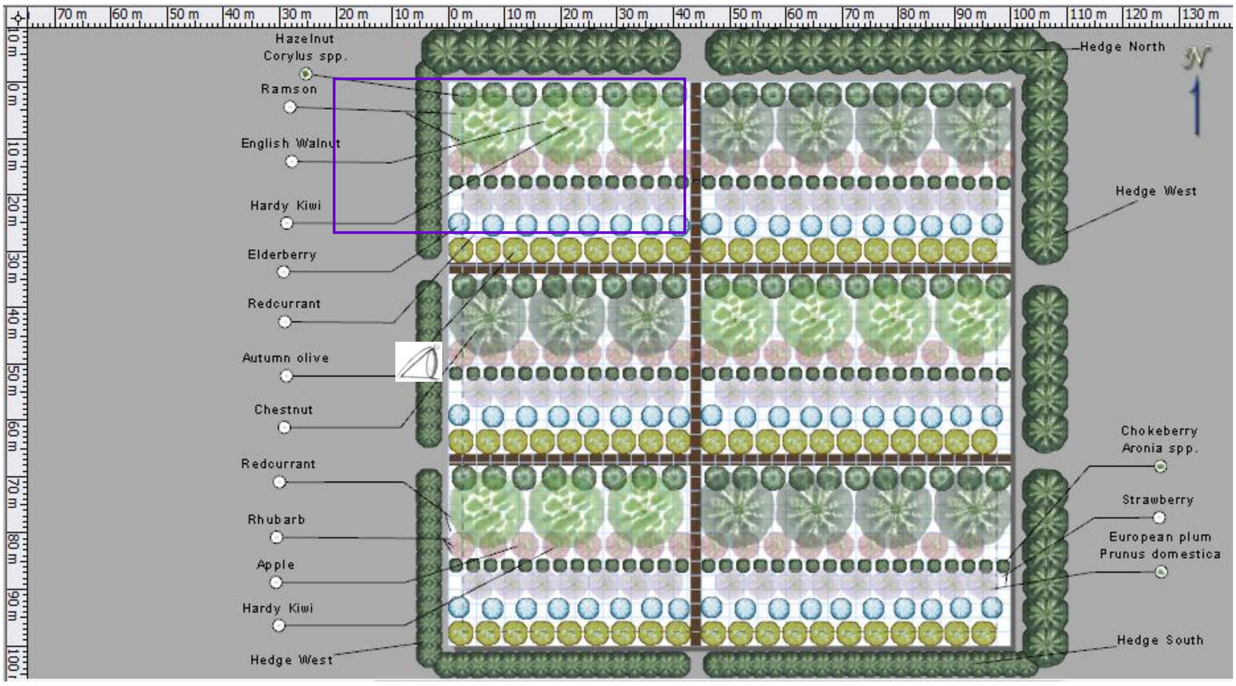

Figure 8- Design of the mature forest (50 years old)

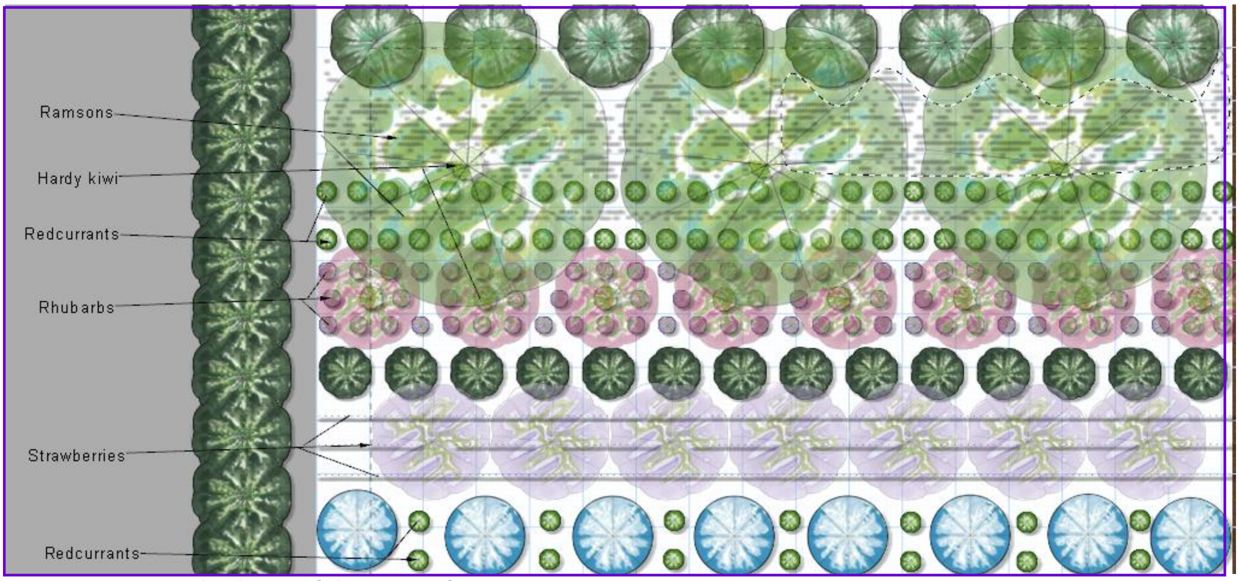

Figure 9 - Zoom on the design of the mature forest

More pictures giving an idea of the 3-dimensions representation of the system are presented in Appendix 4. A short movie attached with this report shows what walking in this theoretical food forest would look like (see Appendix 4).

6. Theoretical yield, economical result and nutritional carrying capacity

6.1. Materials and methods

6.1.1. Yield

The yield, economical result and nutritional carrying capacity of the design were evaluated over 50 years. The 50 year time span was chosen because the slower growing and most productive plants will still be highly productive at that age. Moreover, it is about the time span limit a Northern Europe human-being can project himself on. The end of usefulness of the species was taken as being the middle of the corresponding interval that can be found in the database (see Table 5). It was assumed that when the plants were reaching that age, they were removed and new plants of the same species were planted again.

The calculations were made for 8 ages of the system in order to get an idea of the evolution:

- Year 1 since it is the start and year 50 since it is the end and also an age where all the plants reach their mature yield
- Year 2 since it is when most of the fast yielding species start cropping
- Year 5 since it is expected to be the year when the harvest from the food forest starts to get significant
- Year 10 since all the plants but the slow growing species (chestnut, walnut and hardy kiwi) have reached their maximum yield
- Year 14 since the shortest living species have to be replanted
- Year 21 and 40 since new species have to be replanted

The intervals were not regularly chosen (e.g. every 10 years) in order to make a trade-off between having all the significant points of where the evolution of the food forest outcomes is significant and the time spent doing the calculations.

The yield of each plant species were calculated assuming a linear evolution between the starting yield and the mature yield. The age plants were starting to crop and the age when they were getting their maximum yield were both chosen to be the middle of the corresponding intervals in the database (see Table 5). The starting yield was determined from expert estimates. The maximum yield was chosen to be the lower limit of the interval found in literature or 75% of this yield when it was coming from the expert Wouter Van Eck (for Autumn Olive and Chokeberry) (see Table 4). It is expected that some plants won't perform well, will die sooner or won't crop evenly every year. Those conservative values were chosen in order to compensate for all those kind of realities and get a representative estimation of the yield, economic and nutritional outcomes of the system. All those data can be found in the Excel document "Model harvest yield depending of the age" page "Data species" (see Appendix 6).

The total yield per species and for the whole system were calculated for each of the 8 ages (see above) by simply multiplying the number of individual plants of each species and the yield of this species for that year. All calculations can be found in the Excel document “Model Calculations” (see Appendix 7).

6.1.2. Economical value

Due to a lack of time and data readily available, only the total sales could be calculated as an economical indicator.

Prices chosen can be found in the Excel document “Model Calculations” (see Appendix 7). It was assumed that this system would use a direct selling strategy. In order to approximate this price, it was then decided to use the common high quality supermarket price of this product or a similar product in Netherlands. By “common”, it has to be understood “most often found” and “conventional” (per opposition with “organic”). Most of those prices were retrieved from Albert Heijn website as a “high quality supermarket in Netherlands” (see references). For the nuts (hazelnuts, walnuts, chestnuts), shelled nuts prices have been used. No food processing was considered.

In order to get the total sales, the forecasted yield was simply multiplied by the corresponding prices which were giving the total sales per species. Those sales were added up in order to get the total sales for the whole system each year. All calculations can be found in the Excel document “Model Calculations” (see Appendix 7).

6.1.3. Nutritional carrying capacity

Due to a lack of time, data not readily available and simplicity, here “Nutritional carrying capacity” is reduced to being the number of average humans whose yearly intake requirement are fulfilled in energy and in the 3 macro-nutrients <u>carbohydrate, protein and fat</u> by the 1ha food forest system presented part 5 of this report. Other nutrients were not considered, the composition of each of those nutrient families was not considered and the assimilability of those nutrients was not considered. The 3 main macronutrients were considered in order to have a result closer from the real carrying capacity of the system comparing to using only the energy value.

The nutritional values have been retrieved from different books, food encyclopaedia and scientific articles (see references). The Recommended Daily Allowances for an average person of energy, protein, carbohydrate and fat were retrieved from European Regulation 1169/2011, Annexe XIII and multiplied by 365.25 in order to get « Recommended Annual Allowances ». All can be found in the page « nutritional value_kg » of the Excel document “Model Calculations” (see Appendix 7).

First the nutrient and energy production was calculated by multiplying per species the yield by the different corresponding nutrient and energy values. For the nuts, the nutritional data found were for 100g of edible product. Therefore the shell weight has been removed in the calculation of the nuts nutritional values. Same has been done for the core of the apple and the stone of the plum. For the other fruits, the share of not edible product has been considered as negligible. Then, the nutrient productions per species were summed, giving a total nutrient and energy production for the all system for each year. Those were then divided by the corresponding “Recommended Annual Allowances” for an average person, in order to get the nutritional carrying capacity of the system for each reference year. Those calculations can be found in the Excel document “Model Calculations” (see Appendix 7).

6.2. Results

6.2.1. Yield

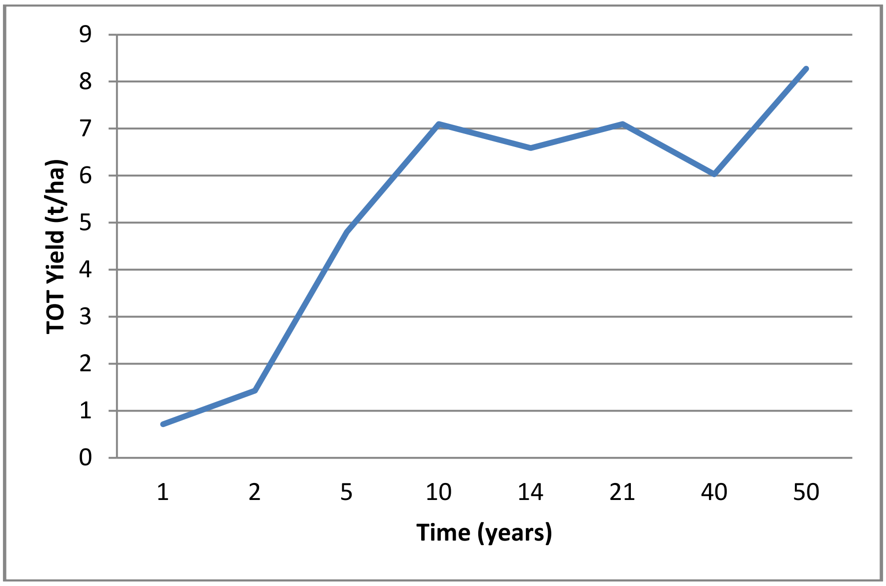

Figure 10 - Yield prevision of the 1ha Food Forest system on 50 years

The total yield of the system increases with the age, starting from around 0.8t and reaching more than 8t. Most of the increase happens during the first decade of the system, after which most of the plants are mature and yield their maximum. Then the total yield is steady and even decreases a bit between year 10 and year 40, when species need to be replanted. Finally, the total yield increases again to reach its maximum at year 50.

6.2.2. Economical value

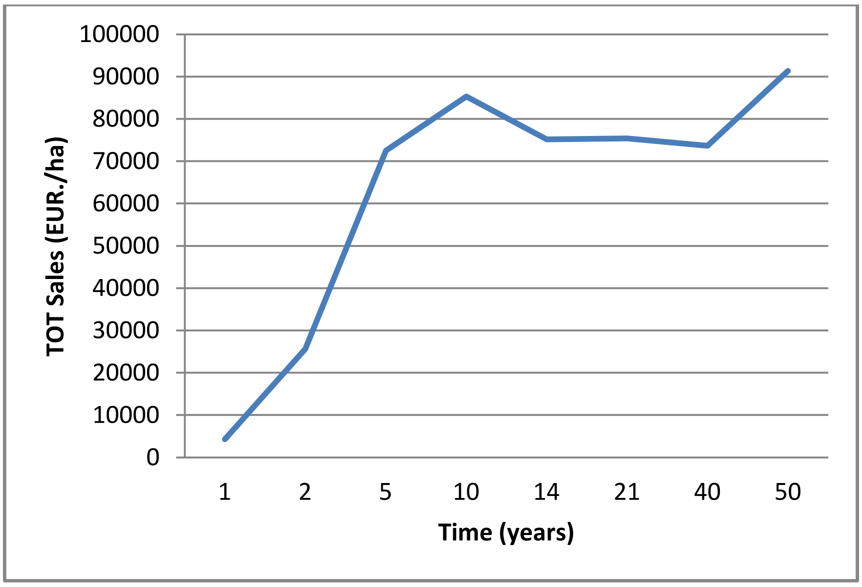

Figure 11 - Sales prevision of the 1ha Food Forest system on 50 years

The total sales of the system follows globally the same pattern over years as the total yield. However, it reaches nearly its maximum after 5 years and not 10 years for the yield. It goes from 4000 EUR at year 1, 25000 EUR at year 2, to 72000 EUR at year 5 and 91000 EUR at year 50.

6.2.3. Nutritional carrying capacity

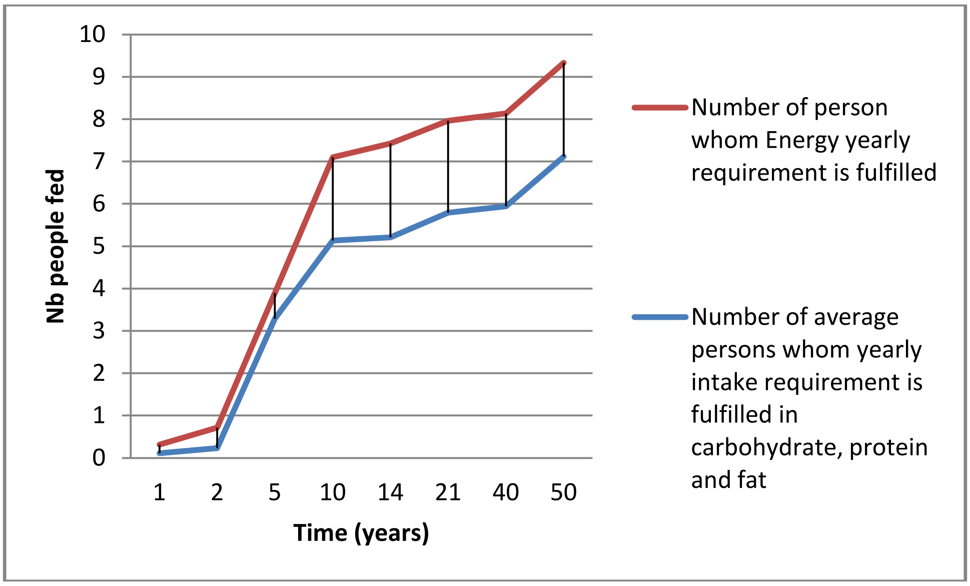

Figure 12- Nutritional carrying capacity prevision of the 1ha Food Forest system on 50 years

The nutritional carrying capacity of the system for both energy and macronutrients follows also globally the same pattern over years that the yield. Those are pretty similar until year 5. From year 10 onwards, 2 persons more could be fed if we were considering only energy compared to taking into account the 3 macro-nutrients. Conversely to the yield evolution, the nutritional carrying capacity for both energy and macro-nutrients increase slightly between year 10 and year 40, period when the slow-growing plants reach their maximum yield (hardy kiwi but especially chestnuts and walnuts). The number of average persons, whose yearly intake requirement are fulfilled in energy, carbohydrate, protein and fat, starts at 0 in year 1 and 2, 3 persons in year 5, 5 persons in year 10 (7 for only energy) and 7 persons in year 50 (9 for only energy).

7. Discussion

7.1. A better system economically and nutritionally wise than conventional annual cropping?

7.1.1. Higher sales in Food Forest system

Giving the economic potential of a Food Forest system which is not actually implemented in a real market is a difficult exercise as well as putting it in perspective with other farming systems outcomes. The reason behind it is that it really depends on the price chosen. More work could have been done to choose averaged price or price corresponding to the willingness to pay to the target consumer group of those food forest products. In the other hand, the sales of alternative systems in place highly depend on the type of system, the commodity and the place chosen. For commonly produced and sold potatoes in Netherlands, the farmer could get maximum 10000 EUR/ha (Source:

Scholberg, 2016) which is far lower than what the potential of the Food Forest is. If now, following the same hypothesis than for the Food Forest products, this farmer could sell directly his 50t/ha potatoes to the consumer with the Albert Heijn price of 1.3 EUR/kg, he would get 65000 EUR sales. It is less than the food forest potential from the year 5 onwards (see Fig. 14). On the 50 year period, it represents about 443000 EUR sales more in the food forest compare to the potatoes direct selling system, meaning almost 9000 EUR/month.

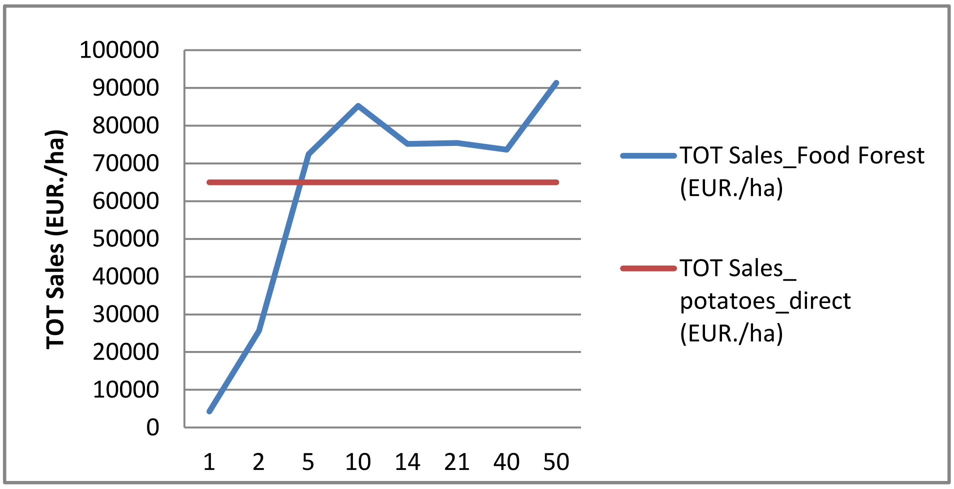

Figure 13 - Comparison of total sales of food forest with potatoes system

However the production costs can also be high, especially the labour costs. For instance, it is known for the small fruits, representing more than 60% of the sales, that labour costs for harvest are very high. Eventually, this is the balance between sales and total costs which will determine if the food forest system is economically interesting compared to other systems (see Fig. 15). Unfortunately, very little data about labour costs are available so far.

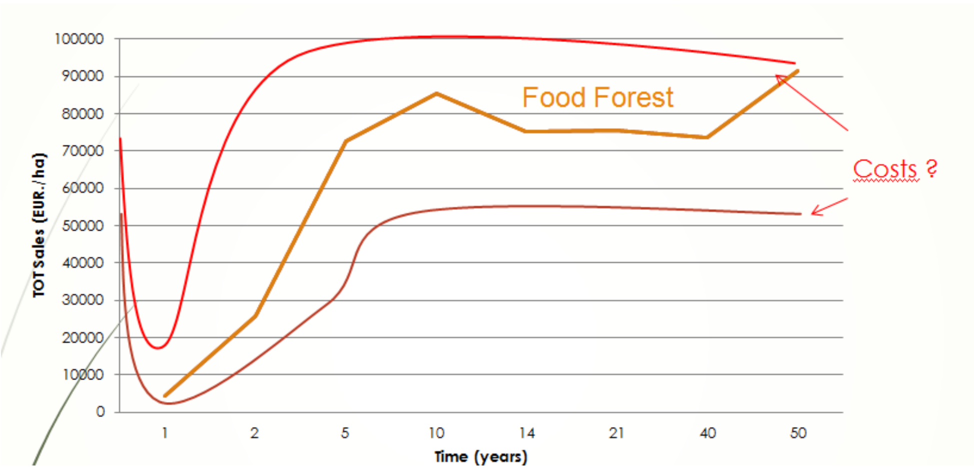

Figure 14- Comparisons Food Forest total sales and hypothetic cost curves

7.1.2. Nutritional carrying capacity

Nutritionally speaking, 1 average hectare of conventional potatoes (in Netherlands) or wheat (in France) would produce respectively 7 and 3 times more energy than the 50 years old Food Forest. However, the food forest is satisfying more people's carbohydrates, fat and proteins requirement from the year 10 onwards than wheat and potatoes cultivations (see Fig. 16). This comparison is however limited because annual cropping also includes legume cultivation, oilseed cultivation and horticulture. It would then be interesting to compare this system to a mix of those crops economically and nutritionally. Moreover, we also need minerals, vitamins and other organic acids. Those are likely to be much more balanced in our diverse Food Forest system than in a large scale annual cropping field.

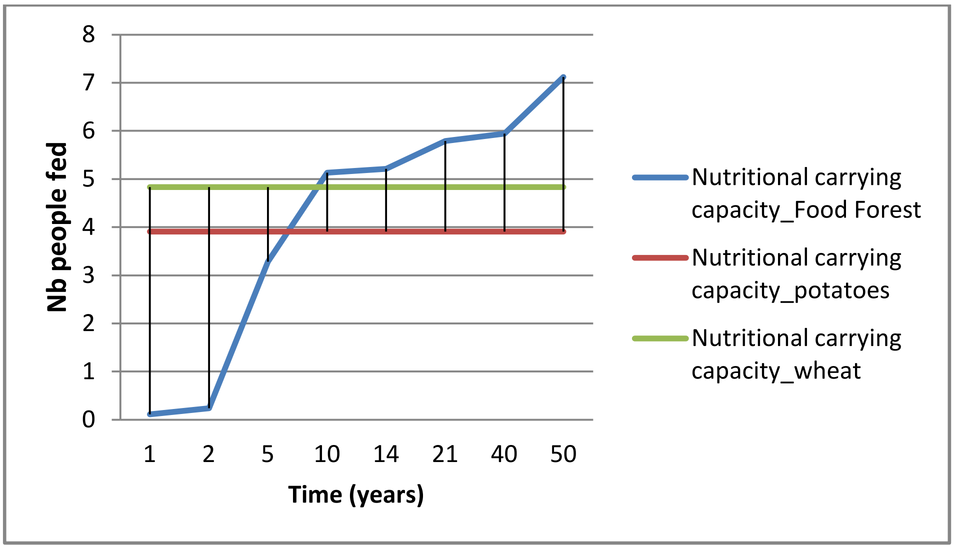

Figure 15 - Comparison of nutritional carrying capacity of Food Forest with potatoes and wheat systems

Finally, we can reflect on the nutritional carrying capacity of our 1ha Food Forest regarding the space we would need to feed all the people in the Netherlands and the European Union. According to the World Bank, in 2013, we got 0.21 ha/pers for European Union and 0.06 in Netherlands of arable feed to grow our food. We see then that comparable systems to the one designed, producing at the maximum enough food of for 0.14 pers/ha can't bring total food sovereignty to Netherlands. This is true if it is only planted on arable field. In the other hand, it could provide enough carbohydrates, fat and proteins for the all European Union if it would be planted on all arable fields, between year 5 and year 10 onwards. Moreover, this system, being based on perennial plants, could be suitable for much more land than the arable land. Permanent grassland and even forest lands could be farmed in this way. Of course, this should not be taken as an advice to plant this system everywhere in Europe but it gives an idea of the potential of such a system.

7.2. A rough design needing fine-tuning?

7.2.1. Natural elements considerations

It has not been possible to study precisely the light pattern within the system across the season and the year. However it is a major factor determining if the design is concretely realizable. The plants might be too close from each other to produce as expected. For instance, it can be anticipated now that the 3D design is done, that when the canopy trees will grow big, there won't be enough light anymore for the autumn olives to thrive.

Wind dynamics couldn't be explored properly neither. There are real interrogations whether if the 5m high South and West hedges will be too tight to let good airflow in the system, inducing higher disease pressure, and/or too short to protect efficiently 1ha of plants.

The root pattern could also be more closely studied. However, in that field, very little data is available. This would guide us more for understanding the complementarities between the species and their vulnerability to the Dutch high water tables.

7.2.2. Fine-tuning species complementarities in functions, space and time

In Nature, you can observe gradual successions from annual to perennial species and from opportunistic to climax species. This provides a constant "maximum" productivity on the field. This gradual succession is lacking in the design presented. Only a rough succession has been designed for the aim of giving a more realistic idea of the potential of the system. Compared to the mature system, more plants are in the system from year 1 to year 5. Then, all of those "additional plants" are considered to be removed between year 5 and year 10. A fine-tuned gradual succession would very likely show the highest total yield, economic benefit and nutritional carrying capacity. For instance, there are still niches available in year 10 to be filled by more plants. Also the system could be started with other perennial or even with annual plants before moving toward the final design.

Also, the positive interactions between the different species and the services they give to the ecosystem bringing synergistic effects could be better explored. This would provide a more efficient and productive farming system design. The choice of the species and their spatial arrangement could be deepened. For instance, it would be interesting to take into account information available in the *Edible Forest Garden* book about functions for wildlife other than pollinators (e.g. food production, shelter) that are important for pest management.

7.3. Rough calculations needing elaboration

7.3.1. Temporal and spatial aspects of the calculations could be fine-tuned

Temporally, the calculations haven't been done at regular interval, which give an incomplete and maybe biased representation of the yield, sales and nutritional carrying capacity evolution. Indeed, there are also species being replanted between year 21 and year 40. Moreover, giving the results of the calculations for the years just following plants replanting might give artificially lower outcome for the period between year 10 and year 50. Therefore calculating the outcome every year would give a more precise outcome.

Spatially, there is the question of considering the hedges as part of the system or outside the system. What is meant is that we could divide the outcome of the system per the surface that includes the hedges or only per 1ha as it has been done so far. In this design, the hedges are considered as important to the good functioning and productivity, which is a reason to include them. However, in mainstream agriculture, numerous hedges can also be found around the field, but they are never included in the yield calculations. Therefore for comparative purpose, it is relevant to not include them in the calculations. Finally, the theoretical design made on 1ha could potentially be made on 0.5ha, 2ha or 10 ha and we could consider that there would only be one big hedge around those surfaces. That means then that the yield per hectare would artificially get higher with an increasing system area. This is another good reason to not include the hedges in the surface on which the outcomes of the system are calculated.

7.3.2. Yield calculations could get more precise

The linear approximation of yield evolution is arbitrary, not based on literature and may not represent reality. However, it fits the aim of this work to get a rough estimation of the food forest outcomes.

Another issue which would need to be explored is whether the age of the plants and the associated yield found in literature are referring to the age from seed or the age from plant commonly sold in nurseries. Indeed, in practice, plants are bought from nurseries and can be of various ages when planted in the system. This would change the yield dynamic by increasing the overall outcomes of the system.

7.3.3. Economical evaluation is partial

7.3.3.1. Costs inclusion

Sales are not sufficient to know if the farming system is economically viable. Even if costs couldn't be calculated, they were considered in choices that have been done for the design, especially regarding the spatial arrangement. Indeed, the choice of the plants spatial arrangements have been done regarding specific management techniques: no pruning method and hand or small machines harvesting (see Fig. 17 and 18). Big machineries could be used, e.g. blueberries harvester to harvest hazelnuts (see Fig. 19). However, they need much more spacing and labour in order to adapt the whole system to the machine and tend to be very expensive to buy and to use. Those management choices should be kept in mind for continuation of this work regarding cost-benefit evaluation.

Figure 16 - Nut wizards

Source: http://tcpermaculture.blogspot.fr/2013/02/nut-wizard.html

Figure 17 - Net harvesting

Source: http://www.diatex.com/-COLLECTION-NETS-.html

Figure 18 - Blueberries harvester

Source:http://www.farmersequip.com/ag-showroom/oxbo/

7.3.3.2. Food Forest products prices

The prices were chosen from the typical high quality Dutch supermarket price for conventional products at the moment this report was written. A mean throughout the season of Dutch production on several years and several supermarkets could be done in order to have a more precise price. Also, this is a conservative choice. A review of direct selling prices for products of comparable quality, sustainable produced, could be done. If not available, prices from organic supermarket could be chosen.

Moreover, so far, raw products prices have been considered. However, it is of high interest for the farmer selling directly to consumers to propose simple processed produce requiring a low investment: jam, juices, fruit leather, dried fruits. This could also increase the sales and net benefit of the production.

Finally, only the main yields were taken into account in this study. However, “byproducts” of high value could be considered. The most obvious one is the wood for biofuel or construction (e.g. highly valued walnut wood), but other ones could be considered: leaves as fodder (e.g. hazelnut leaves are very rich), flowers (highly valued elderflowers) and nut shells (walnuts and hazelnut shells can be used as biofuel or fertilization materials) could be sold as long as a market can be found. Mushrooms could be produced too, in order to make a profitable and edible use of the wood.

7.3.3.3. Products loss

In the reality of food production management, significant amount of products are lost between harvest and sales. However, conservative yield values were also chosen to take this into account and give a relevant evaluation of the Food Forest outcomes.

8. Prospective work

As highlighted at the very beginning of this report, this work is a first step. It is a study that people interested by food forestry could, I hope, use as a basis, an inspiration regarding the methodology and the design, a source of data, a block on which elaborate a larger study. More work needs to be done in order to get stronger data about this system and build a better future for farming. In this part are exposed the ways that I foresee for improvement of this study to build something even more interesting and relevant for the community. This will partly becomes more and more possible, year after year, when the research on complex Agroforestry systems, starting from the very little body available today, will make more and more knowledge available.

8.1. Building an overall stronger scientific model

First and foremost, more peer-reviewed and scientifically produced literature would need to be explored and used to support this model. This applies to various elements:

- The hypotheses used in the model, e.g. the linearity of the plants yield evolution from the initial yield to the mature yield
- The parameters used, e.g. plants initial and mature yields, plants dimensions, species interactions
- The species choice, e.g. negative and positive interactions between species, especially regarding pest and diseases dynamics
- The spatial arrangement, e.g. precise analysis of light and shade patterns and wind flow
- The precision of the model.
    - For the nutrient carrying capacity calculation, having the proportion of macro and micro-nutrient contained in the food forest products and their requirement in average healthy human diet is essential to have a precise idea of the carrying capacity of the system designed. The work showed by Mark Shepard in his *Restoration agriculture* book, chapter 12 “Nutrition and perennial agriculture” can be used as inspiration for that. The assimilability for human body of the nutrients depending on the food sources would also need to be explored and take into account.
    - For economical evaluation, food product loss should be taken into account.
- The variables of interest of the model. For the economical evaluation: estimations of the costs, especially planting and labour costs, should be retrieved from scientific literature in order to get a good idea of the economic viability of this kind of system.

Then, a larger range of designs, using different species combinations, spatial arrangement and management hypotheses could be made to have a more robust estimation of the potential of such systems.

8.2. Improving the understanding of the management of such a system and the cost associated

The exploration of use of machinery in such small-scale complex Agroforestry system would provide new insight on what management techniques are possible. Different sources can be explored for that. The ones we are aware of are Mark Sheppard work at *New Forest Farm* and open source platforms such as *open source ecology*[2].

The evaluation of the impact of non-pruning techniques on the productivity depending on the varieties chosen and the nurseries method are to be evaluated.

The costs and benefits are best to be evaluated with a prototype of the design made in this study and other similar systems. Some promising data gathering are already on their way, done by the Sylva Institute in Bec Hellouin Farm (France) and the Savanna Institute in USA. The system presented in this report will normally be integrated in one of the project designed by Wouter Van Eck in Netherlands.

The cost-benefit evaluation has to be done for the food forest by-products valorization and simple food-processing operations (making and selling for instance juice, jam, fruit leather and dried fruit).

The different business models for this food forest design could also be explored in relation with the management and the costs involved. For instance, a Community Supported and Self Harvest System could be imagined. It would be a very different management and then costs than an on-farm shop and weekly market selling system.

8.3. Using a better reference in annual cropping systems to compare with

Instead of just a one-crop cultivation system, a complete direct-selling polyculture system could be used for comparisons. This would be more representative of what an alternative annual system can be. An example of resource which could be used for that is given by the Table 8.

	Yearly consumption (kg per person)	Forage crops	Cereals	Pulses and oilseed crops	Root crops and vegetables	Total
Cereals	80	–	9%	–	–	9%
Potatoes	78	–	–	–	2%	2%
Sugar	34	–	–	–	3%	3%
Oil	25	–	–	5%	–	5%
Vegetables	117	–	–	–	5%	5%
Dairy produce	240	20%	3%	–	–	23%
Beef and mutton	26	21%	–	–	–	21%
Pork	40	–	12%	5%	–	17%
Chicken	19	–	6%	5%	–	11%
Eggs	12	–	2%	2%	–	4%
Total		41%	32%	17%	10%	100%

Table 8- Consumption pattern in EU and calculated percentage of land to grow the related main crops
(Source: Oomen, 1998)

[2] http://opensourceecology.org/

8.4. Implementation of the design

The aim here is to provide with some points of attention to have in mind for implementing the design made in this study. This design can't be used as it is, but needs to be fine-tuned in order to be adapted to the local natural, social and market conditions and corresponding to the desires of the stakeholders involved.

The species chosen and the spatial arrangement should be adapted to your local conditions. If the main wind directions are different, you might want to adapt the design and especially the hedges. If the field is sloppy, you might want to follow the contours line for better water infiltration and low erosion. If the water table is high for a long period, as it is so often the case in Netherlands, you will need to invest in ecological constructions to give more root space to the canopy trees, as for instance making a pond somewhere and using the material dug out for soil elevation. Otherwise, you will need to change species.

You need to gather a good knowledge on the varieties and rootstock the most suitable for your conditions, build a similar database that is showed in the third part of this report and explore their complementarities (e.g. good spatial arrangement regarding the size, light and shadow pattern, harvest evenly spread throughout the season) or incompatibilities (e.g. peak of harvest too high, not enough resources for pollinator in March). It is a plus to know their behavior for your specific conditions. It might change depending on the climate and/or the soil type.

A rotation would be needed and can be done between short-living species like rhubarb, strawberry, ramson and red currant.

Finally, here is an idea of management not mentioned before. Each subplot of the food forest could have a different age, in order to stabilize the yield throughout the years and increase the niches diversity. If you are on 1ha, the 6 sub-plots could be planted at 8 years of interval and the rest of the field used for annual farming (cereal cropping or horticulture) in the meantime. That would also allow you to use the experiences of installing and managing the first subplots for the next ones

9. Conclusion

The scientific community acknowledges that worldwide, today, our way of farming is not sustainable. The soils are getting less and less fertile, the biodiversity is decreasing tremendously, the yields are stagnating when the human population is still growing and farmers still struggle to make a proper living out of their farming activity all around the world. There is an urge to develop new farming systems meeting those challenges. This work has presented to you one of these new systems, how it can be designed for a farming business and what economic and nutritional potential it has.

First, a limited amount of complementary species, adapted to the local context, have to be chosen. Then they have to be arranged spatially for an optimal ecological functioning, productivity and easiness of management. Compared to a conventional potato cropping system, this system offers higher sales. It offers a higher nutritional carrying capacity for the 3 human macro-nutrients than a potato and wheat field of the same size.

The complex Agroforestry systems under temperate climates such as this food forest are just beginning to get scientific interest. Much more work has to be done to assess their real potential. Two of the most important works are to get data about the investment and management cost of such systems and to set a proper reference model in conventional agriculture. Those will likely be explored in the coming years. Professionals are already working on it, e.g. in Netherlands Wouter Van Eck with its partners and in France the Bec Hellouin farm with the Sylva institute.

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Theoretical economical and nutritional carrying capacity of the design

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APPENDIX

Appendix 1: Criteria relevance of pre-selected plant species

Species	Identified as interestin g by Wouter Van Eck (personal communi cation 01 to 04/2016)	Present in other systems	Economi cally valuable	Potentially very economical -ly valuable (market opportunit y foreseen)	Occupying a free[3] ecological niche	Special nutritional/ health value
Hardi Kiwi *Actinidia arguta*	X	Savanna h Institute		Same as kiwi but smaller and skin edible. Very good taste. Unknown from consumer. Productive	Climber	
Ramson / Wild Garlic *Allium Ursinum*	X			Herbs with garlic taste. Tasty pesto can be made out	Harvested in Spring. Supporting heavy shade	

[3] For instance, a climber can be set on the trunk of a tree without taking space of another plant (but another climber)

				of it (see Melilotus farm, France)		
Chokeberry *Aronia spp.*	X	Savannah Institute		Very valuable in mix juice with apple. Niche market.		
Chestnuts *Castanea spp.*		Savannah Institute New Forest Farm	X			Very rich in carbohydrates
Hazelnuts/ Filbert *Corylus spp.*		Savannah Institute New Forest Farm				Very rich in oil and proteins
Autumn Olive *Eleagnus umbellata*	X					Lycopene anti-cancer and good for heart
Strawberry *Fragaria spp.*						
Day Lilies *Hemerocallis spp.*						

Sea Buckthorns *Hippophae rhamnoides*						
English Walnut *Juglans Regia*						Very rich in oil and proteins
Apple *Malus domestica*						
Apricot *Prunus armenica*						
Cherry Plum *Prunus cerasifera*						
European Plum *Prunus domestica*						
Almond *Prunus dulcis*						
Peach & Nectarines *Prunus Persica (nucipersica)*						
Japanese Plum *Prunus salicina*						
Poire Pyrus communis						
Rhubarb *Rheum spp.*						
Black currants *Ribes nigrum*						
Red Currant *Ribes sylvestre*						

Gooseberry *Ribes uva-crispa*						
Raspberry *Rubus spp.*						
Elderberrry *Sambucus canadensis*						
Grape *Vitis spp. (i.e. labrusca)*						

Appendix 2: Pre-selected plant species ecology database

Appendix 3: Pro and cons of each species selected or rejected

Species selected	Pro	Cons
Hardi Kiwi ***Actinidia arguta***	• Good harvest, do very good in food forest according to Martin Crawford • easy to eat and very good taste so good anticipated economic value • tolerate semi shade • Tolerate most soil • Flower late • harvesting until late Autumn • Vine (doesn't take space)	• Fruit not known from consumers • Die after 30 years • Diecious -> need female AND male • Need a little pruning to control size
Ramson / Wild Garlic ***Allium Ursinum***	• Doing excellent in food forest according to Martin Crawford rating • Harvest early in the season from beginning from beginning February to end of May • Prefer light shade and tolerate complete shade -> suitable for understorey of dense canopy cover (mature trees) • No maintenance (spread by itself) • Tolerate drought and acid soil	
Chokeberry ***Aronia spp.***	• Good marketable value with processing potential • Doing excellent in food forest according to Martin Crawford rating • High value juice with Apple • Semi-shade tolerant • Tolerate extreme soil moisture condition • Tolerate most soil texture • Summer harvest • Crop quickly	
Chestnuts ***Castanea spp.***	• Canopy tree producing known, easily marketable food product	• Need to pick up daily over a period of 10-12d • Fruit in shell with spines

	• Doing excellent in food forest according with Martin Crawford rating • Good yield, good economic value • various options of processing and very long storage possible • Quite Easy to harvest • No management needed • Flowering late • Do well on most soil	• Litter acidifying soil
Hazelnuts/Filbert ***Corylus spp.***	• Good yield with high value and easily marketable product • Very high potential of added value through transforming • Doing very good in food forest according to Martin Crawford rating and well adapted to Dutch climate • Litter enriching soil • Good hedging species • Support a wide range of soil • Stand full shade • Frost resistant	• Doesn't stand well high fertility and acid soil • Harvesting same time that other nuts • Stop cropping before 50y (from 30 to 50y)
Autumn Olive ***Eleagnus umbellata***	• Doing excellent in food forest according with MC rating • Good Yield • Very rich food in nutrients/vitamins (super food) → High market potential • Doing well on any soil • Good hedging plants (fast growing) + wind resistant • N fixing plant/enrich soil • Producing pollen • No noticeable pest and diseases	• Need splitting seeds too big therefore mainly attractive processed

	• Start producing early (After 1 to 2 years)	
Strawberry ***Fragaria spp.***	• Good yield (/m²), high marketable value with high processing potential • Doing excellent in food forest according to Martin Crawford rating • Harvest early in the season (June-mid-September) • No maintenance (spread by itself) • Tolerate semi shade • Tolerate most soil texture • Cropping rapidly (from first year onwards)	• As Rosaceae, sensitive to Juglone (Walnut)
English Walnut ***Juglans Regia***	• Canopy tree producing known, easily marketable food products • Possibility to process in an high value oil • Doing very good in food forest according with Martin Crawford rating • Very long storage possible • High yield, good economic value • Quite Easy to harvest • No management needed • Do well on most soil • Litter enriching soil • Producing very little Juglone	• Edible fragile part in hard shell • Highly frost sensitive • Max production late (after 30 y)
Apple ***Malus domestica***	• High yield and marketable value with processing potential • Doing excellent in food forest according to Martin Crawford rating and we'll adapted to Dutch climate • Easy to harvest • A considerable amount of varieties of climate rootstock allowing to choose those matching with the flowering/harvesting time, tree size, apple use, soil/climate/pest and disease conditions you have/want • Food niche complementarities with rhubarb	• Often need fruit thinning especially if for fresh apple • Doesn't stand well Juglone produced by walnuts

	• High value juice with Chokeberry • Wind resistant	
European Plum ***Prunus domestica***	• High yield and marketable value with processing potential • Doing excellent in food forest according to Martin Crawford rating and well adapted to Dutch climate • Quite easy to harvest • A considerable amount of varieties of tree and rootstock allowing to choose those matching with the flowering/harvesting time, tree size, plum use, soil/climate/pest and disease conditions you have/want • All harvest in 2 or 3 picking • Crop rather quickly	• Need fruit thinning
Rhubarb ***Rheum spp.***	• High yield and marketable value with processing potential • Doing excellent in food forest according to Martin Crawford rating and well adapted to Dutch climate • Cropping quickly (S y2 Max y4) • Early cropping (March-August) • Tolerate semi-shade • Mineral mining plant enriching surface layer of soil • Good niche complementarity with Apsensitive • No maintenance (spread by itself)	• None
Red Currant ***Ribes sylvestre***	• High yield and very high marketable value with processing opportunities • Doing excellent in food forest according to Martin Crawford rating • Tolerant to complete shade • Highly frost resistant • Harvest early in the season (from mid-June onward to mid-September)	• Short lifespan

	● Cropping quickly (from y2 onwards) ● Most soil suitable	
Elderberrry ***Sambucus canadensis***	● High yield and high marketable value with high processing potential. Product part of current trend (cf drinks) : flowers and berries ● Doing good in food forest according to Martin Crawford rating ● Late flowering ● Little pest, disease tolerant and shade tolerant ● Extreme moisture tolerant ● Cropping quickly	

Species only for hedges	**Pro**	**Cons**
Sea Buckthorns *Hippophae rhamnoides*	- Doing excellent in food forest according with MC rating - Very rich food in nutrients/vitamins (super food) → High market potential - Excellent hedging plants (fast growing) + wind resistant - N fixing plant/enrich soil - Food resource and habitat for biodiversity - Strive on almost any kind of soil - No noticeable pest and diseases	- Harvesting hard because of horns - Cannot eat fresh, need processing - Market not existing, people doesn't know this product - Not pollen producing
Cherry Plum *Prunus cerasifera*	● Doing excellent in food forest according with MC rating ● Yield ??? ● Wind resistant ● Fast growth rate (40cm/y)	● Difficult to harvest

	• Flower rather early in se season (from mid-February on) • Tolerate most soil • Considered as good hedging plant on the litterature	

Species rejected	**Pro**	**Cons**
Day Lilies *Hemerocallis spp.*	• Fine in most of soils • Drought resistant • “Crop” quickly (from y1 onwards	• Another cover plant • Do less good in food forest according to Martin Crawford grade • Not known from consumers, no established market
Apricot *Prunus armenica*	• Fruits with good economic value • Free shape is ok • Crop well quickly after planting • Drought resistant	• Another understorey tree/those selected • Do less good in food forest according to Martin Crawford grade • Doesn't tolerate shade AND need shelter • Doesn't live very long (stop cropping well after 12 to 30 years • Share diseases with plums • Need to be picked daily during harvesting period • May need pruning • Require neutral to alkaline soil (?) and strive better in deep soil
Almond *Prunus dulcis*	• Flowing very early in the season and pollen producing species > early resources for bees (nice in hedges if no frost risk spot • Tolerate poor and dry soil	• highly Frost sensitive (make it not suitable even got hedges) • Doing less good than other understorey trees in food forest according with MC rating • At the limit between tolerating and not suoporting Dutch climate condition (cf Hardiness zone)
Peach & Nectarines *Prunus Persica (nucipersica)*	• High marketable value as fresh product and consequent secondary yields • Tolerate wind (not really strong one though)	• Another understorey tree/those selected; • Yielding less/its size • Do less good in food forest according to Martin Crawford grade • Doesn't tolerate shade • Frost sensitive

		• Rather soil specific • Short lifespan : 8-12 years
Japanese Plum *Prunus salicina*	• Easy and quick to harvest (3-4 picking over a period of 7-10 days) • More pest and diseases than other plums	• Another understorey tree/those selected • Do less good in food forest according to Martin Crawford grade • Need shelter • Very frost sensitive • Need thinning for good marketable fruit size
Poire Pyrus communis	• High yield with high marketable value and processing opportunities • Do well on ride range of soil texture • Tolerate water logging • Harvestable from August onward • Lifespan can be over 50 Y depending on the variety	• Another understorey tree/those selected • Do less good in food forest according to Martin Crawford grade • Need shelter and warm spot
Black currants *Ribes nigrum*	• High yield and very high marketable value with processing opportunities • Doing excellent in food forest according to Martin Crawford rating • Harvest early in the season (from mid-June onward to mid-September) • Cropping quickly (from y2 onwards) • Most soil suitable	• short lifetime => need to be replaced often with moving the zone because of soil diseases • Should not be placed near hazelnuts a if not big bud mite resistant
Gooseberry *Ribes uva-crispa*	• High yield and very high marketable value with processing opportunities • Doing excellent in food forest according to Martin Crawford rating • Tolerant to semi shade • Frost resistant • Harvest early in the season (from mid-June onward to end of July). Possibility to process green berries from May • Cropping quickly (from y2 onwards) • Most soil suitable	• short lifetime => need to be replaced often with moving the zone because of soil diseases
Raspberry	• Good yield high marketable value with high	• As a Rosaceae, sensitive to Juglone (Walnut)

Rubus spp.	processing potential ● Doing excellent in food forest according to Martin Crawford rating ● Harvest early in the season (mid-June-end November function of variety) ● No maintenance (spread by itself) ● Tolerate semi shade ● Tolerate most soil texture ● Cropping rapidly (from first year onwards) ● Frost resistant	● Short lifespan, need rotation otherwise deplete all soil fertility
Grape *Vitis spp. (i.e. labrusca)*	● High yield and marketable value with high processing potential ● Doing excellent in food forest according to Martin Crawford rating and well adapted to Dutch climate ● Easy to harvest ● Tolerant to extreme moisture condition ● Rather late flowering ● Vine (doesn't take space) ● Crop quickly (S y2 Max y4) ● Lifespan over 50y ● Suitable on most soil	● Need pruning to control size ● Another wine more shade tolerant already selected

Appendix 4: Trees/bushes for pollinator support

Hedge to the East

Shrubs with moderate vigor; flowering at different periods; most offering berries (mainly for wildlife); leaf litter decomposes easily

Botanische naam	English name	Flowering period
Acer campestre	Field maple	May
Crataegus monogyna	Hawthorn	April
Cornus mas	Cornelian cherry	February
Prunus insititia	Damson plum	April
Prunus spinosa	Blackthorn, sloe	March
Rosa rubiginosa	Sweetbriar rose	June-July

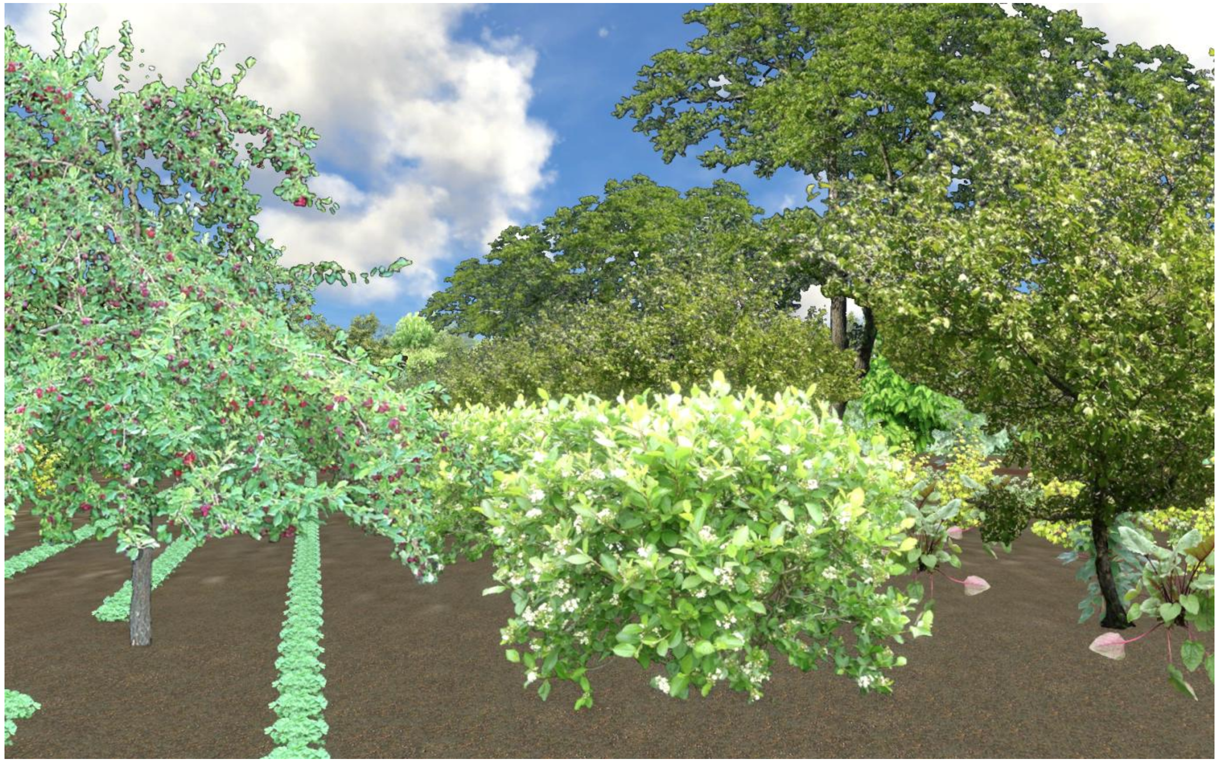
Hedge to the North

Fast growing trees/shrubs; good with pollen and nectar (and / or nitrogen fixing); leaf litter decomposes easily

Botanical name	English name	Flowering period
Alnus glutinosa4	Black alder (not dry tolerant)	February-March
Alnus incana5	Grey alder (dry tolerant)	February
Robinia pseudoacacia6	Black locust (dry loving, not wet tolerant)	May
Salix alba7	White willow (not dry tolerant)	March-April
Salix caprea	Goat willow (dry tolerant)	March
Sambucus nigra	Elder (tolerate every kind)	May-June
Populus trembla	Aspen (tolerate every kind)	March

4 Prefers wet conditions
5 Good for dry conditions
6 Prefers dry conditions
7 Prefers wet conditions

Appendix 5: Design mature food forest additional picture and video



Video: https://www.dropbox.com/s/jlsauqa8wzoym2j/Food%20forest%20mature_v3.wmv?dl=0

Appendix 6: Model harvesting yield depending on the age

Document : Model harvest yield depending of the age.xlsx

Appendix 7: Model yield, sales and nutritional carrying capacity calculations

Document : Model Calculations.xlsx