Matching European dietary demands to the production of a self-reliant farm;

An evaluation and redesigning of the Droevendaal farm

Aug 2017

Farming Systems Ecology group (FSE)

Department of Plant Sciences

Department of Plant Sciences

Wageningen University

Matching European dietary demands to the production of a self-reliant farm;

An evaluation and redesigning of the Droevendaal farm

Aug 2017

Name student(s): Le Ma

Registration number: 931112536120

Course code: FSE-80436

Period: Period 6

Supervisor(s): Dirk van Apeldoorn

Professor/Examiner: Jeroen Groot

Abstract

A balanced diet not only presents the quantity of food intake but also the diversity of a diet. To produce a healthy diet locally and environment friendly, the mixed farming system with multiple crop products and animal products is regarded as a sustainable solution. The multi production system also reflects the system a more efficient use of nutrients and other resources. Oomen et al, (1998) did a research on the crop area distribution in farm land regarding produce balanced consumption diet in European condition. Following its theory, from 2014, Droevendaal experimental farm designed a six-year crop rotation, to produce multiple food products, furthermore, to improve the theory. This study is a midterm evaluation upon the accordance of experimental farm production and EU consumption pattern research.

Two treatments: monoculture and polyculture both with six replicates were analyzed and compared on its productivity and feeding capacity[1]. The animal production was simulated by Farm DESIGN based on feed production on farm. And human feeding capacity set as an indicator to evaluate which farm can better fulfill EU consumption pattern. The redesign mainly targeting on balancing the N on farm, to increase the yield potential of each food crop and possibly to shift nutrients from animal feed to food crop.

The results show that, in total, the polyculture farming system can produce more food/feed than monocultural system. But statistically, only grass clover production in strip5 shows significant higher yields in polyculture system. By contrast, wheat and grass clover (strip3) yields are significantly higher in monocultural farming system. Based on the food/feed production on both farms, the results show that mixed farming system can produce more animal products to feed more people. But food crop does not show any significant difference between two treatments.

On both treatment farms, the produced diet is unbalanced: animal products are over produced almost two times than non-animal products; in food crop, oil, potato and cereal production are limiting the average feeding capacity.

Redesign of the production based on the simulation of N balance on farm, and yield potential from empirical research. It is suggested that using around 8.85t/ha of grass clover as green manure to food crop can better balance the consumption diet, and resulted in feeding more people.

Key words: Diet, mixed farming system, feeding capacity, nitrogen balance, Farm DESIGN, NDICEA, yield potential.

[1] Feeding capacity in this study means the number of people can be feed within a limited area.

Acknowledgement

The end of this thesis is the two years' anniversary for me to arrive the Netherlands. I really appreciate the study in Wageningen University and the education altitude regarding on daily courses and academic research. Especially the latter one, which promoted me a lot to enhance my knowledge learned previously, and courage me to discover fresh knowledge. Though it is a hard time for me to really get into deep of academic ocean, but till here, I am already satisfied with the spirit I learned from here, which certainly will help me for the upcoming challenge. I would like to spread my appreciation to those who helped me and encouraged me to keep on going through this tough process.

First of all, I would like to appreciate my supervisor Dirk van Apeldoorn to offer me patience and teach me practical knowledge within this thesis period. We both know how hard it is when communicating in two academic level and inter-culture circumstance. I really gained a lot through this, and I wish this long-term experiment can reach a successful result, and hopefully, prove the positive effect of the organic farming system.

Secondly, I very much appreciate Carl and Jeroen inspire me how to use Farm Design properly, and for Maikel and Sausan from Bio Metrix group who teach me R and patiently solved "layman" & boring question for me for several times. I thanks to tutors and assistants from Unifarm for offering me care and help at the beginning of my first topic. And unforgettable, my dear study advisor Cor Langeveld, who work almost 20 hours each day (fairly to say), can still have time to play a psychologist role in my academic life. Finally, I would be very much appreciate to brother Ali in CSA group who give me sound and detailed feedback on my work, that makes me become much more confident for the results I got.

And never forget to thanks to my wife, Aminah Wei, who company me and taking care of my life for these special times.

Finally, I would like to thanks to my sponsor, Chinese Scholarship Council, to support my master in Wageningen University.

Remark for the students who have intercultural communication problem, I suggest recording the discussion with your supervisor, listen several times could be helpful for better understanding each other.

Table of content

List of tables

List of figures

1 Introduction

1.1 Background

With world population growing, in next forty years, not only the food security problem needs to be addressed, but also the unbalance of diet rephrase (Godfray, Beddington, et al., 2010; Tilman, Cassman, et al 2002). To maintain higher yields and in the meantime produce balanced diet in a certain area, mixed farming system due to its higher resource aggregation ability, is regarded as a potential solution (Hauggaard-Nielsen, Ambus, et al, 2001; Lantinga & Rabbinge, 1997).

What is mixed farming system?

Mixed farming system so called mixed crop-livestock farming system, based on soil-crop-animal-manure cycle, can be more efficiently using the resources produced on farm compare with current intensive farming system (Herrero, Thornton, et al, 2010; Lantinga & Rabbinge, 1997).

Current intensive or specialized farming systems have negative effects on both ecological aspects and economical aspects (Cassman, Dobermann, et al 2003; Lantinga & Rabbinge, 1997). In ecological aspect, it attributed biodiversity reduction, nutrients enrichment and other environmental issues, because of its high dependency on external inputs such as artificial fertilizer and chemical products (Isbell et al., 2013; Tilman et al., 2002). Whereas mixed farming system based on crop-crop interaction, crop-livestock and soil-crop interaction are less relying on external input, and more self-reliant on its internal resources. The key insights behind it are closing the resource and nutrients cycle, increase nutrients use efficiency (Aulakh & Doran, 2000).

Research found that, the mixed cropping system can potentially have higher yields/biomass than monolithic production system (Hauggaard-Nielsen, Ambus, et al, 2001; Badgley & Perfecto, 2007). The intercropping with legume species can enhance the nitrogen accumulation and crop nitrogen uptake (Aulakh & Doran, 2000). Besides, plant associated N fixation in mixed farming has shown a positive effect on biodiversity richness, livestock productivity, rhizosphere bioactivity, and reduction of greenhouse gas emission etc. (Fraser, Moorby, et al 2014; Shen et al., 2013).

Why balanced diet?

Essential dietary requires different food composition to fulfil health demand. According to Thiele, et al (2004), an unbalanced diet can be the reason of certain chronic diseases such as obesity, cancer, diabetes. Different research has shown current society is still facing challenges on balancing diet. According to Murray (2014) & IHME (2015), milk, fruit and oil products are still deficient in human consumption survey in the global scale. While red meat is over produced 6 times than average demand for a healthy diet. Dutch National Institute for Public Health and the Environment (RIVM) conducted a survey on consumption pattern from 2007 to 2010, reveals that food consumption in the Netherlands on vegetables and fibre-rich foods is insufficient, whereas saturated fatty acid has been over consumed and led the trend of overweight among adult and children. (van Rossum, Fransen, et al, 2011).

European consumption-production research

In 1998, regarding "producing sufficient & complete food diet in EU", Oomen, Lantinga, et al (1998) did research on "area-wise" mixed farming system, formulated the proportion of areas for growing certain essential food crops.

Following EU diet-area model (Oomen et al., 1998), Droevendaal experimental farm is conducting a six-year's crop rotation, dedicated to evaluate if the dietary production in real farming system could fulfil the EU consumption demand. And **this master research** serves as a **midterm evaluation** focus upon how the experiment is performing during previous year on its production. And the **objective** is how to balance the diet production and feed more people with more complete diet in limited area.

1.2 Research Questions

1. Can polyculture cropping-system feed more people than monoculture system?
2. Can dietary products on experimental farm providing balanced diet? Which crops are limiting the balance?
3. If the diet distribution on farm is not balanced, how to reallocation farm resource to better achieve EU dietary demand?

1.3 Outline of the thesis

The logic for the whole report is to address previous three questions. The methodology is divided into two parts, first part is introducing how Droevendaal six-year's crop rotation is designed, and the data collection process. Second part is the method for core process in this study, explaining how three models (consumption pattern model, Farm DESIGN model, NDICEA) works together to simulate the feeding capacity on farm.

In the results, a comparison on production between monoculture and polyculture, feeding capacity on both farms, and scenarios of redesign are explained. The discussion and recommendation is merged, summarized experiment insights and the limitation on this study. Several debatable points during this experiment are discussed and the potential solution are provided. The conclusion will summarize the main outcome address the research questions.

2 Material and Methodology

2.1 Materials

This study is based on the data collected in previous research, used software are: R Studio version 1.0.143 (R x64 3.4.0) (R Core Team, 2017); Farm Design version 4.18.6.0 (Groot, et al, 2012); NDICEA version 6.2.1 (van der Burgt, 2005)

2.2 Three-meter experiment setup in Droevendaal farm

2.2.1 Description of Droevendaal experimental farm

Droevendaal Experimental farm is an organic farm dedicated on organic farming related research. The experimental farm located at Kielekampsteeg (51°59'30" N 5°39'5" E) in Wageningen University, the Netherlands. The climate on the experimental site is temperate oceanic with an annual mean temperature of 11°C and annual cumulative precipitations of 829 mm. The soil type is classified as silty-sand (83% sand, 11% silt, and 3% of clay respectively)

2.2.2 Relate to EU consumption research--experiment setup in Droevendaal farm

In 2014, the Farming Systems Ecology group started a long-term experiment on the relation of diversity and agro-ecosystem dynamics. The selected crops in the experiment reflect the EU consumption pattern. Figure 2-1 shows an aerial view on 2016- crop pattern, highlighted different crop strips, two treatments, and buffer zone.

The Droevendaal experiment is designed to fit the area proportional of the European diet. The four-main crop group are forages, cereals, pulses & oil, and root & vegetables. Table 2-1 shows how much food (kg) is required for one person within one year, and the proportion of area needed to produce certain crops. The last row shows area percentage used in the experiment designed on farm.

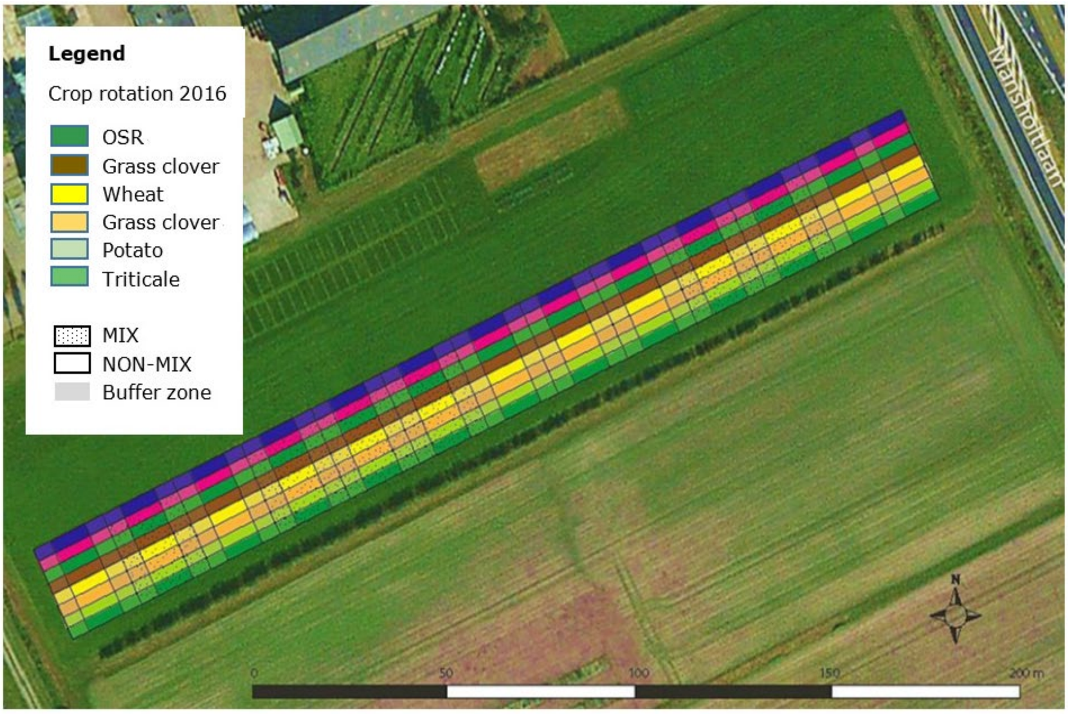


Figure 2-1 Overview of the complex strip intercropping experiment at the Droevendaal farm. The different crops are indicated in different colors. Buffer zones and the different treatments are marked separately (from Kirstin Surmann, 2015)

Table 2-1 Consumption pattern in EU and calculated percentage of land area to grow the related main crops in case of self-reliant agriculture. And area proportion/size* on experiment farm. Adapted from (Oomen et al., 1998)

Diet ingredient	yearly consumption (kg per person)	Area percentage of **crop group**				Total
		forage crops	cereals	pulses and oilseed crops	root crops and vegetables	
Cereal	80		9%			9%
Potato	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%
Area% on farm*		33%	33%	17%	17%	

The experimental design of the strip cropping system had in total 6 crop strips and of 250 meters long. Each crop strip had two different diversity treatments, non-mix and mixed. No-mix treatment, with one single crop or limited mixing, identified in this research as strip scale crop diversification. And mixed treatment, with two or more different crops or different varieties, identified in this research as both strip scale and plot scale crop diversification. The mixed treatment is highlighted by black dots in Figure 2-2. Each treatment had 6 replicates (plots), with a total of 12 plots per strip. Each block has four plots. In each block, are two replicates of each treatment were randomly allocated. Each plot was 3 meters wide and 20 meters long, including a buffer zone of 5 meters at the start and end of each plot highlighted with dark streaks in Figure 2-2. Leaving a total experimental area of 3 meters x 10 meters.

Within these twelve plots, the 2, 4, 5, 6, 10, 11 are the polyculture treatment and plot 1, 3, 7, 8, 9, 12 are monoculture treatment. We assume that one replicate with 6 strips can be considered as a **farm**.

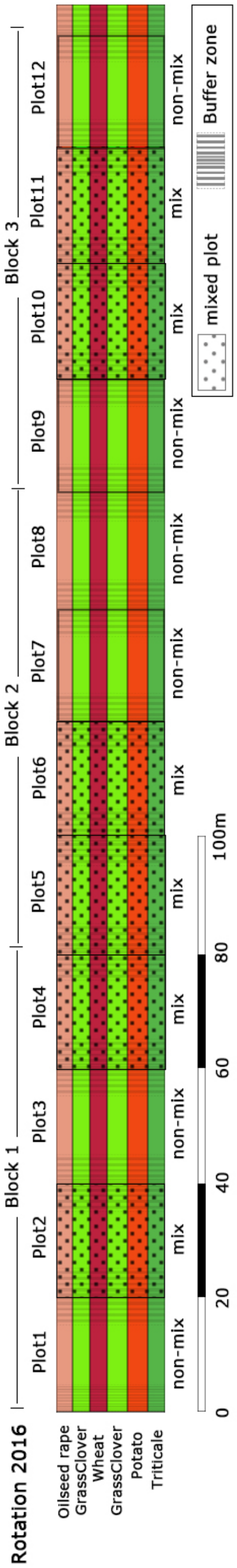


Figure 2-2 Experiment area settlement, crop rotation in 2016. Different colour shows different crop species; the plots with dots are mixture/intercropping plots. Between each plot, 5m wide buffer zone are highlighted in dark streak.

2.2.3 Data collection

The crop data has been collected through last three years, in this report, the evaluation only focused on the data in 2016 and part from 2015. See Table 7-3 for data sources, and time of harvest.

Crops were harvested at different time by different method. Triticale (× *Triticosecale*) in strip 1 was harvested as whole plant silage, fresh yield from each plot was weighed and recorded in kg. Two composite subsamples from each 1.5m row are randomly taken to dried in oven for 48h under 70 ℃ to determine dry weight. Triticale mixture treatment intercropped with pea (*P. sativum*), which also been harvested together as silage. Potato (*S. tuberosum*) in strip2 was harvested by four rows in each plot, fresh yield was weighed on farm, dry/wet ratio calculated after dry two days in lab. The mixture contains three different potato varieties (*S. tuberosum 'Agria, S. tuberosum 'Aloutte', S. tuberosum 'Carolus'*) which are included together in the fresh yield data, without separation. Grass clover (*T. repens*, *T. pratense 'Lucrum'*) in strip3 (2015) and in strip 5 (2016), both were harvested by 1.5m wide harvester and cut for four times within one year. Fresh samples were dried two days in lab for measuring dry/wet ratio. Clover mixture plot contains different grass species (*T. incarnatum*, *T. alexandrinum*, *Lolium*) were not separated. Wheat (*Triticum aestivum*) in strip4 was harvested by two rows within each plot. For the mixture, faba bean (*Vicia faba*) was harvested, measured separately. For strip6 the oilseed rape (*Brassica napus 'Avatar'*) subsamples were taken in four areas per plot. Seed yield and numbers were measured and counted, rape straw also was collected and weighted. In the OSR polyculture plots, clover was left on site as green manure, not measured.

The dry matter content for crops is calculated in following formula.

$$DM = \text{Fresh Yields} \times \frac{\text{Subsample Dry Weight}}{\text{Subsample Fresh Weight}}$$

2.3 Farm feeding capacity calculation

2.3.1 Yield comparison between two treatments

The average yield of six crops on two treatments is compared by using independent two sample t-test. Beforehand, F-test is used to check if the variance different between treatments. Land Equivalent Ratio (LER, Mead & Willey, 1980) is the way supposed to assess the production differences upon monoculture and polyculture, but due to the lack of information on "intercrop yield (ha^{-1})" on farm, the comparison will be discussed based on sowing ratio of intercrop in polyculture treatment.

2.3.2 Consumption Pattern "model"

In order to balance the animal products properly and precisely, farm scale has been enlarged to 60ha in total. Therefore, the results regarding feeding capacity calculation are based on 60ha scale. And will be further explained in the Results. Transformed yield data see Appendix A.

There are three modules functioning in consumption pattern model (Figure 2-3).

Module one based on the area distribution in Table 2-1. The production of each diet pattern is calculated by following formula[2] and distributed as production of each diet pattern.

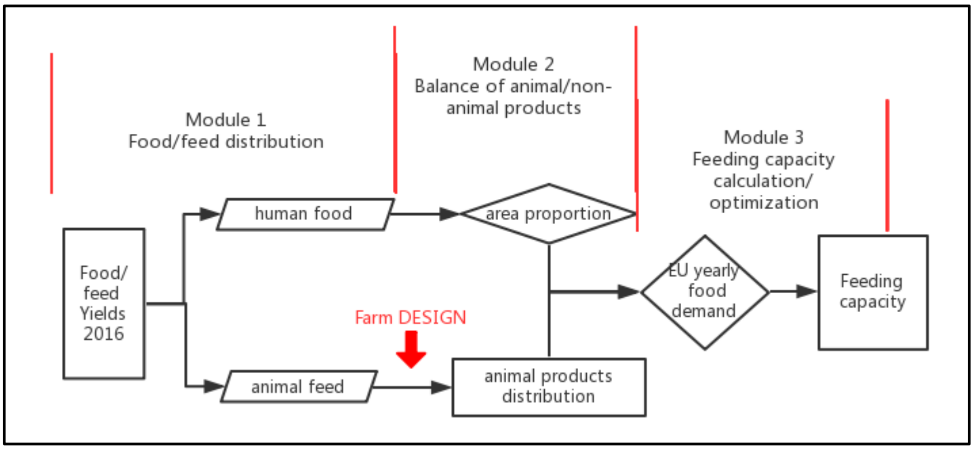


Figure 2-3 Consumption pattern model process diagram

$$Production\ (\mathrm{DP}) = \mathrm{Production\ (CG)} \times \frac{\mathrm{Percentage\ \ (DP)}}{\mathrm{Percentage\ \ (CG)}}$$

DP: Diet Pattern; CG: Crop Group.

Module two is for simulating the balance respectively on non-animal products and animal products. And the animal production is relying on the result from Farm DESIGN. Module 3, based on the yearly consumption demand per person, to calculate feeding capacity respectively on two treatment farms. Both module two and module three will be used in later redesign process, associated with the results from Farm DESIGN and NDICEA.

2.3.3 Analysis in Farm Design

The Farm DESIGN model is a aggregation of a large array of interrelated farm components and complicate algorithm, in order to help farmer/researcher on management for the farming system (Groot, et al 2012).

[2] For instance, forage crop has 41% area in total, dairy production requires 20% area, therefore, the forage for dairy production is calculated as:

$$Dairy\ produce\ required\ forage = \mathrm{Forage\ production} \times \frac{20\%}{41\%}$$

Farm DESIGN in this thesis research only used to simulate animal components (animal number, animal products and manure production) on farm, because only food/feed crops are produced on farm, the other elements are virtual or produce from model. For other variables such as operating profit, labor management are not considered in this research.

The feed evaluation system used in Farm DESIGN is Dutch VEM/DVE system, data resources see Table 2-2. The value used in Farm DESIGN can be found in Appendix C. In this study, the usage of Farm DESIGN can be illustrated as: first, import crop data, include yield, nutrients, feed value. Secondly, input animal requirement; except chicken and laying hen (Yard Manure), all animals were set in stable in order to separate farm yard manure, slurry and chicken pellets. Thirdly, feed balance as a constraint to determine the numbers of animals should keep on farm, which resulted a certain quantity of animal products, and manure.

Table 2-2 The data sources used in Farm Design.

Data	Source
Crop yield, dry matter content, area	Droevendaal farm data
Feed value	Tabellenboek Veevoeding 2012/2016 & Eurofins[3]
Animal requirements	FD repository & Tabellenboek
Other animal information (weight, production, age)	Tabellenboek Veevoeding 2012/2016 & wiki & FD repository
Manure: composition degradation	FD repository

2.3.4 Analysis in NDICEA

To build a healthy long-term farming system, organic cropping system mainly targeting on enhance soil nutrients resilience (Smith et al., 2015). While it is not easy to evaluate nutrients level in organic system compare with fertilizer feed system, due to its large application of organic matter. Nitrogen Dynamics in Crop Rotation in Ecological Agriculture (NDICEA) is a software designed for estimating available nutrients, especially NPK in farming system.

In this research, the manure production calculated from Farm DESIGN will be used to simulate nitrogen availability in NDICEA for next year crop rotation. In case of shortage on nutrients, grass clover will be transferred to food crop as cut-and-carry green manure, and, as a nutrients management solution for next growing season. Assumption has made on "the six-year manure production on farm is similar as year 2016", to fit the temporal nutrients allocation function in NDICEA.

Gelderse Vallei is set as experiment site in the software, which is the closest site in the system to Wageningen. And precipitation data is local annual average value. A six-year crop rotation "spring wheat- potato- grass clover- grass clover- winter oilseed rape- triticale" has set in NDICEA, default yield and crop dry-wet ratio has replaced by current crop data.

2.4 Method for redesign

The whole process of redesign is combining three models to simulate the feeding capacity in balance level on farm (Figure 2-4). The first step, conduct module 2 from consumption pattern model, to balance diet pattern and animal products respectively. The second step is N availability simulation in NDICEA, associated with application of manure produced from Farm DESIGN. In the third step, alternative scenarios are provided to compare and get an optimized result on feeding capacity. Regarding potential increase of food crop yield, the calculated amount of green manure has to shift from animal feed to food crop. After scenario selection, finally, a relative balanced and optimized

[3] http://eurofins-agro.com/ru-ru/en/wiki/vem

feeding capacity would generate, and based on the scenarios, redesign direction is suggested, to help further research on next year experiment.

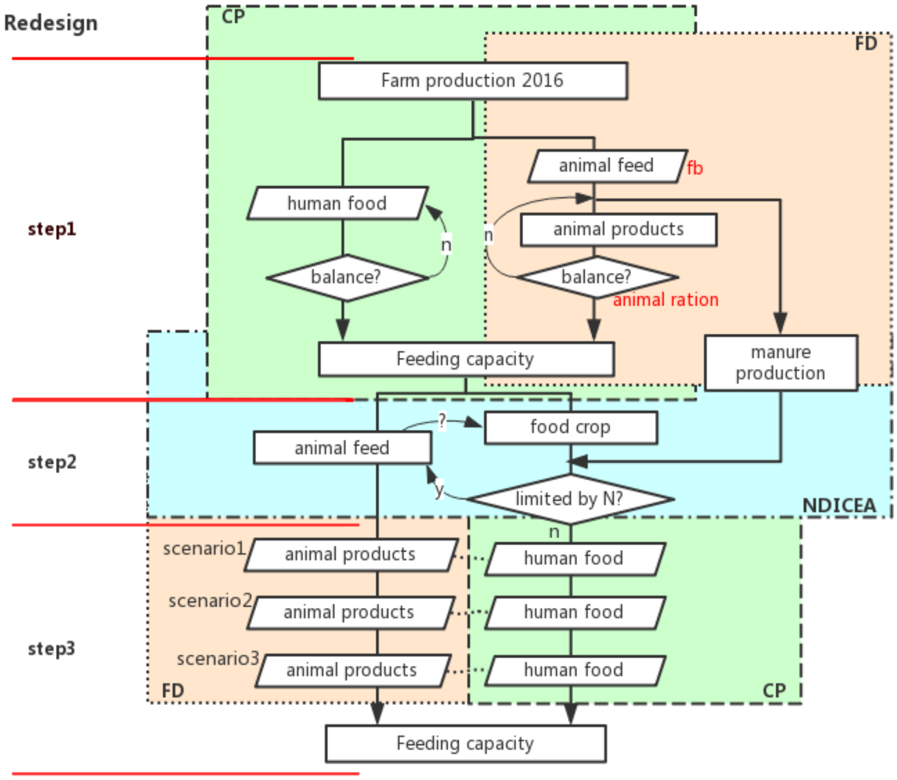


Figure 2-4 Redesign system diagram and modeling utilization. CP: consumption pattern; FD: Farm DESIGN; fb: feed balance

3 Results

The results are divided into three sections. First section will summarize the production performance during rotation 2016, in a form of comparison between monoculture and polyculture. Second part based on the average production in non-mix treatment and mixed treatment, using consumption pattern model, and Farm DESIGN to simulate the feeding capacity on both farm types. Regarding the unbalance level of feeding capacity from section two, third section will conduct a series of redesign using Farm DESIGN, NDICEA and excel-made consumption pattern model to rebalance the food/feed ratio to achieve the goal of feeding more people.

3.1 Section 1 General report on production in 2016

The total production in rotation 2016 see Figure 3-1. The top three yield (plot4, 5, 6) all belongs to polyculture treatment. Lowest three plots contain one polyculture plot, and two monocultures. The average total yield of mixed system exceeding 1.4t higher than non-mix, with standard error 0.64 and 0.79 respectively.

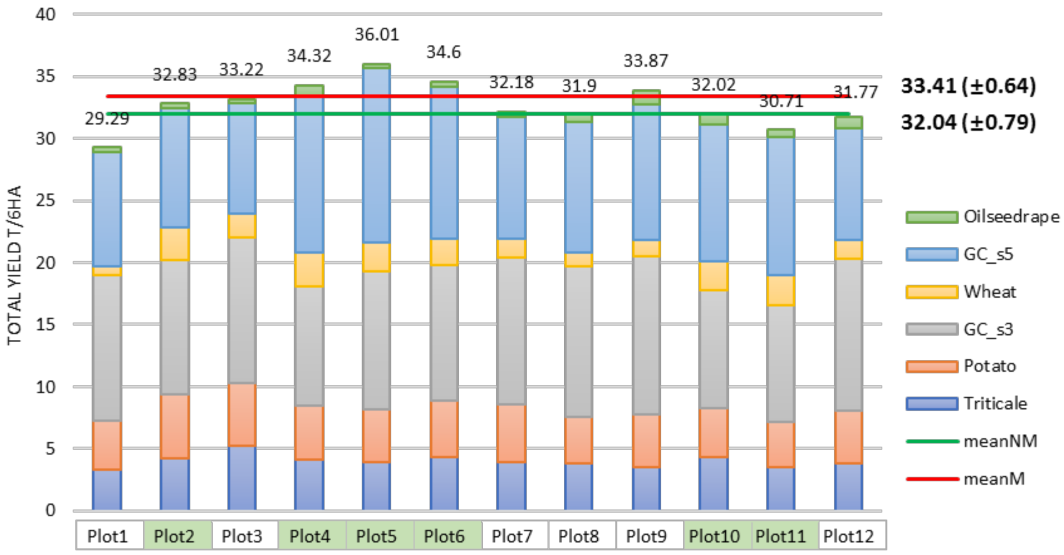


Figure 3-1 Total production (DM) of twelve plots in 2016. GC_s3: grass clover strip3

3.1.1 Strip by strip yield comparison between monoculture and polyculture.

The yield comparison between two types of farm was conducted after a F test, which shows under 95% significance level, there is no significant differences on variance between non-mixed farm and mixed farm in six strips. Based on that, a Welch two sample t test with equal variance assumption formulated that there are no significant differences between two farms on triticale, potato, and oilseed rape yield in 2016 (Figure 3-2). While grass clover in strip3 ($P = 0.000$), and wheat yield ($P = 0.019$) shows significant higher yield in monoculture treatment than polyculture. By contrast, grass clover in strip5 ($P = 0.009$) has significant higher yield in polyculture treatment than monoculture. Among the comparisons, yield of intercrop in in polyculture plot was not counted. And will be considered in following modeling calculation.

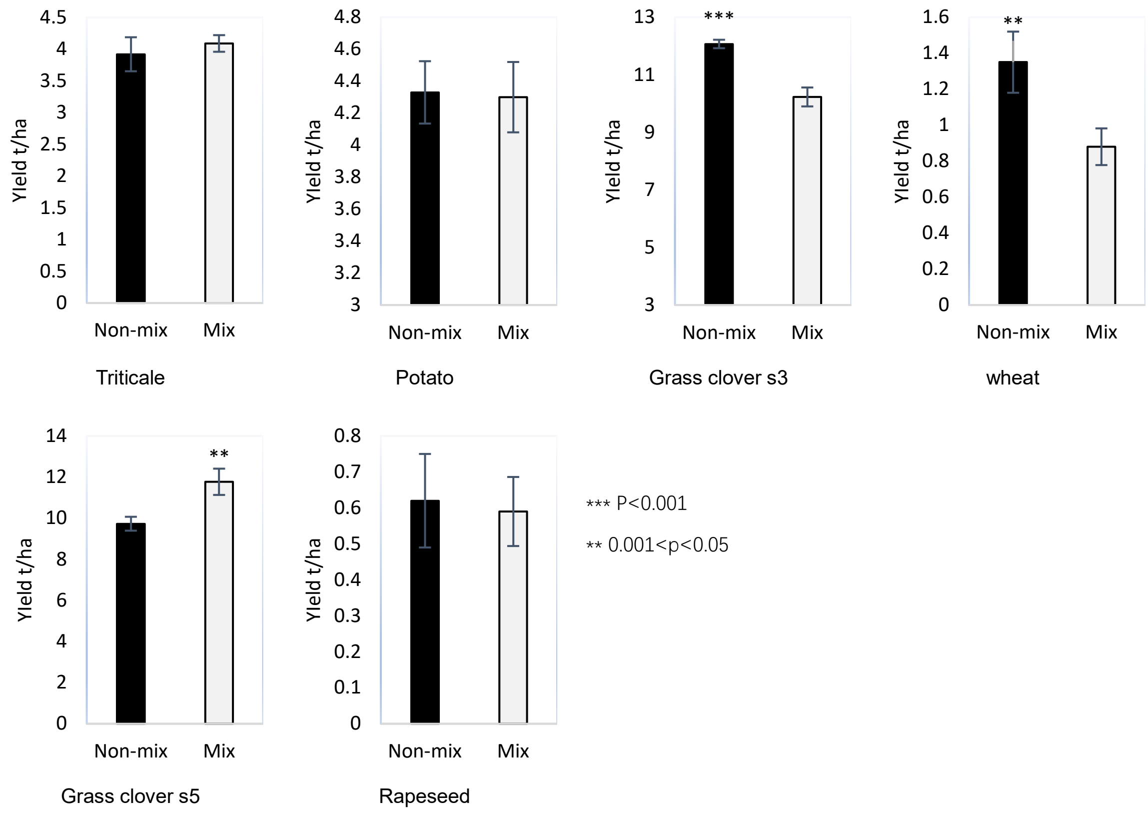


Figure 3-2 Yield (DM+standard error of mean) comparison between monoculture and polyculture treatment

3.2 Section 2 Calculated feeding capacity

3.2.1 Data imported into Farm DESIGN

The average production in each food/feed group was calculated in consumption pattern model, food, feed and straw for bedding material were separated (Table 3-1).

Table 3-1 Calculated total yield of four food group on both farm (t/60ha).

	Forage	**Cereal**				**Pulses & Oilseed**				**Root& Vegetable**
	GC	wheat grain	wheat straw	triticale grain	triticale straw	rapeseed oil	rapeseed cake	oilseed straw	faba	potato
Non-mix	218.07	13.50	40.963	19.63	19.63	1.87	4.36	50.63	0.00	43.33
Mixed	220	8.77	83.709	20.47	20.47	1.76	4.11	48.13	15.62	42.97

Group cereal include triticale and wheat: all triticale is as feed to animals, and simply assumed, half of triticale yield is grain to feed chicken, laying hen and pig; half of it is straw for cattle to enhance ruminant digestibility (McAnally, 1942). All wheat grain is for human consumption, and the wheat straw for bedding material in stable. In pulses & oilseed group, which include oilseeds and faba bean. 30 percent of oilseeds yield contributed to oil production[4], while 70 percent are the oilseed residue which is going to make high-protein feed: oil cake to animals. Rape straw also been collected for bedding. Additionally, all faba production is feed to animals. In root & vegetables

[4] According to BDC Systems Limited, Approximately 30 to 35% of the rapeseed will be extracted as oil giving around 300 to 350 liters per ton. Thus, oilseed cake here are calculated by oilseeds production multiply 0.7.

group, only potato is presented. Which is distributed into "potato", "sugar", and "vegetable" pattern based on the area ratio in Table 2-1.

3.2.2 Animal production calculated from Farm DESIGN

Feed balance

Based on the available feed produced on farm, Farm DESIGN calculated the number of animals can be fed on farm (Table 3-2). The saturation factor, structure and energy value of both animal and crop used in Farm DESIGN see Appendix C.

Table 3-2 Default scenario: number of animals raise on farm, (60ha)

Animal number.	cow	goat	pig	chicken	Laying hen
non-mix	22	50	39	99	100
mixed	22	69	39	270	260

The resulted feed balance on farm see Table 3-3. The deviation indicates percentage of unbalance between feed availability and animal requirement. When feed dry matter is completely been consumed, the energy and protein and structure value all have surplus.

Table 3-3 Feed balance table on farm. based animal number from Table 3-2.

	DM intake (kg)		Energy VEM		Protein DVE		Structure Value		Digestibility %
	Non-mix	mix	non-mix	mix	non-mix	mix	non-mix	mix	
Faba bean	0	13277	0	18400.4	0	2093.1	0	2343	0.888
Triticale grain	16685.5	17399.5	23222.3	24216	2296.7	2395	2944.5	3070.5	0.891
Triticale straw	32585.8	33980.2	16096.6	16785.4	628.2	655	84409	88021	0.402
Grass clover	218070	220000	207166.5	209000	54299.4	54780	654210	660000	0.646
Oilseed cake	1220.8	1150.8	4796	4521	1552.2	1463.2	1308	1233	0.733
TOTAL AVAILABLE (kg)	268562.1	285807.5	251281.4	272922.8	58776.5	61386.3	742871.5	754667.5	
Chicken	2202.4	6006.6	2584.8	7049.4	263	717.2	2202.4	6006.6	
Laying hen	2224.7	5784.2	2406.4	6814.9	245.2	693.3	2224.7	5784.2	
Dutch Dairy Cows	127677	127677	154458.4	154458.4	19097.2	19097.2	102141.6	102141.6	
Meat goat/sheep	25550	35259	17445.5	24074.8	1116	1540.1	17885	24681.3	
Pig	111033	111033	49926.8	49926.8	3731.8	3731.8	111033	111033	
TOTAL REQUIRED (kg)	268687.1	285759.8	226821.8	242324.2	24453.2	25779.5	235486.7	249646.7	
DEVIATION (%)	0	0	10.8	12.6	140.4	138.1	215.5	202.3	

3.2.3 Crop and animal product destination

Table 3-4 Crop and animal products destination for both farm (60ha)

Name		DM yield (kg)		animal feed (kg)		Bedding (kg)		Balance	
		NM	Mix	NM	Mix	NM	Mix	NM	Mix
crop	Faba bean	0	15620	0	15620	0	0	0	0
	Wheat grain	13500	8770	0	0	0	0	-13500	-8770
	Wheat straw	40960	83709	0	0	40960	83709	0	0
	Triticale grain	19630	20470	19630	20470	0	0	0	0
	Triticale straw	19630	20470	19630	20470	0	0	0	0
	Potato product	43333.3	42970	0	0	0	0	-43333.3	-42970
	Grass clover	218070	220000	218070	220000	0	0	0	0
	Oilseed for oil	6238.3	5866.7	4360	4110	0	0	-1878.3	-1756.7
	Oilseed straw	50630	48130	0	0	50630	48130	0	0
animal	Chicken meat	2168.1	5913	0	0	0	0	-2168.1	-5913
	Eggs	2299.5	5978.7	0	0	0	0	-2299.5	-5978.7
	Beef	8913.3	8913.3	0	0	0	0	-8913.3	-8913.3
	Milk	100375	100375	0	0	0	0	-100375	-100375
	Mutton	3467.5	4785.2	0	0	0	0	-3467.5	-4785.2
	Pork	15516.2	15516.2	0	0	0	0	-15516.2	-15516.2

The factor "balance" in Table 3-4 indicates food importation (+), exportation (-) and own farm used products (0). Assumption made on experimental farm is: all farm products for human consumption are exported to market. All animal feed (include bedding) are only for own farm use. Therefore, the negative values in balance bar indicates how many products (kg) for human consumption. And the zero in balance means the product is totally digested in this system.

3.2.4 Calculated feeding capacity.

Feeding capacity calculation

Based on the animal production simulated by Farm DESIGN, and the standard consumption demand from consumption pattern model, the human feeding capacity on two types of farm see Figure 3-3.

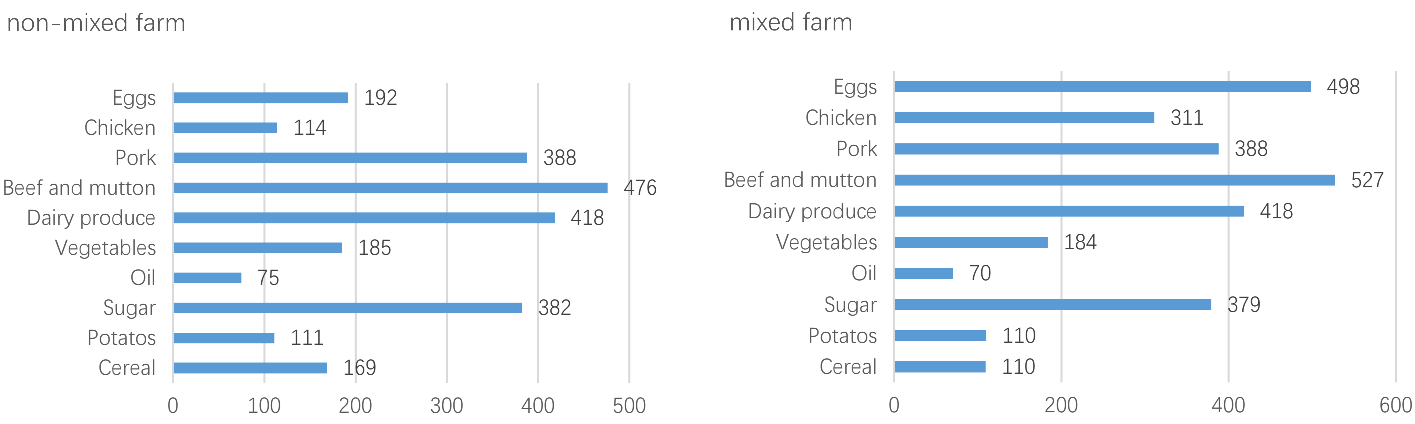


Figure 3-3 Feeding capacity based on crop yield produce on farm, and animal products simulated from Farm DESIGN. (number of people)

Overall, diet produce from both types of farm are unbalanced. The most limited products on non-mixed farm are oil, potato and chicken; in mixed farm, the most limited products are oil potato and cereal.

Beef & mutton are over produced on both farms, which can provide to around five hundred people. Mixed farm produces much more egg, chicken and pork than non-mixed. In crop products, sugar produced even two times higher than vegetable and potato production, which three were derived from same food group (root crop & vegetable).

3.3 Section 3 redesign of experimental farming system to reach balance of EU consumption demand

3.3.1 Redesign step1: balance food crop production and animal-food production respectively

The idea of the redesign is to rebalance all food pattern under same/similar feeding capacity. The area proportion in each food group is a constraint value which cannot be altered in this redesign.

Two aspects were taken into account to rebalance the dietary balance. One is non-animal product, to change proportion distribution under each food group. Another is animal products, constrained by animal products ratio proposed in consumption pattern research, using Farm DESIGN to simulate the adequate number of animals.

Redesigning on non-animal products

In four food groups, only root crop & vegetable group is purely produced for human consumption, others include animal feed portion. For the root & vegetable group, a new area portion of potato, sugar, and vegetables is designed as 3.4: 1.5: 5.1 instead of 2:3:5, which shows higher balance level of production distribution (Figure 3-5). The resulted consumption table see Appendix D

Redesigning on animal products

The ratio of required animal products derived from consumption pattern model see blue bar in Figure 3-4. In the previous scenario: egg, pork, chicken meat all showed under required proportion in monoculture farm (Figure 3-4: Left), in contrast, dairy beyond the requirement proportion. In mixed farm dairy products are relatively balanced; beef & mutton, and eggs were over distributed, whereas pork and chicken were under the requirement.

Rebalance on the number of animals showed that, when animal number set to value in Table 3-5, it is roughly reach to the balance ratio of the animal products demand (Figure 3-4: Right), in the meantime, resulted feed balance see Table 3-6.

Table 3-5 Redesigned animal number and the change compare with previous scenario.

Animal number	cow	goat	pig	chicken	laying hen
non-mix	21 (-1)	34 (-16)	41 (+2)	350 (+251)	220 (+120)
mixed	23 (+1)	32 (-37)	43 (+4)	390 (+120)	220 (-40)

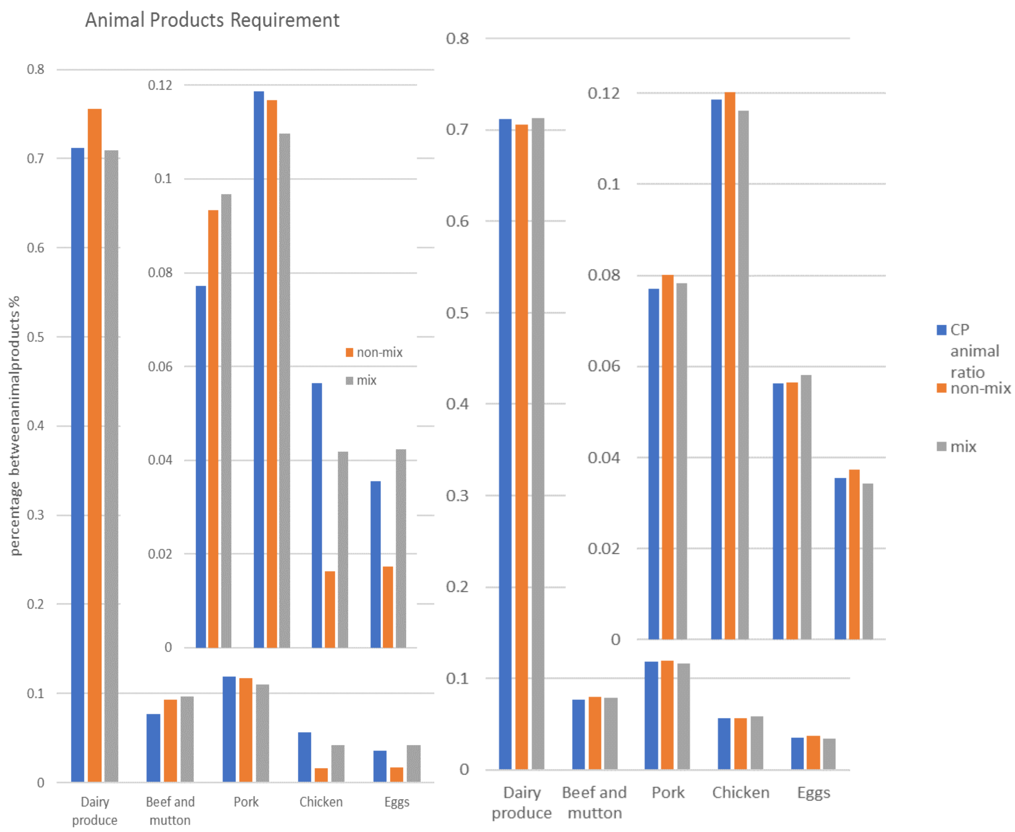


Figure 3-4 Percentage of required animal products (blue), production on non-mixed farm(orange), and mixed farm(grey). Left: animal products ration based on default animal numbers; right: redesigned animal numbers resulted balance. Mixed plot with an enlarged bar plot.

Redesigned feed balance

Compare with the default animal number set, in the redesign, the number of cow, goat and chicken has decreased, pig and laying hen (consider only for egg use, no meat) number has increased. The deviation in Table 3-6 indicates, for DM intake, it is just fulfilling for the animal numbers set in Table 3-5. The positive deviation of 11.1 % and 12% on two farms indicate that the energy produced on farm exceeding the total requirements, which can supply to more animals if not constrained by DM availability. There is over 100% surplus on protein supply and structure feed material, which can be a positive indicator if the farm requires more milk products.

Table 3-6 Redesigned farm resulted feed balance

	DM intake (kg)		Energy VEM		Protein DVE		Structure Value		Digestibility %
	Non-mix	mix	non-mix	mix	non-mix	mix	non-mix	mix	
Faba bean	0	13277	0	18400.4	0	2093.1	0	2343	0.888
Triticale grain	16685.5	17399.5	23222.3	24216	2296.7	2395	2944.5	3070.5	0.891
Triticale straw	32585.8	33980.2	16096.6	16785.4	628.2	655	84409	88021	0.402
Grass clover	218070	220000	207166.5	209000	54299.4	54780	654210	660000	0.646
Oilseed cake	1220.8	1150.8	4796	4521	1552.2	1463.2	1308	1233	0.733
TOTAL AVAILABLE (kg)	268562.1	285807.5	251281.4	272922.8	58776.5	61386.3	742871.5	754667.5	
Chicken	7786.4	8676.2	9138.1	10182.4	929.6	1035.9	7786.4	8676.2	
Laying hen	4894.3	4894.3	5294	5766.4	539.4	586.6	4894.3	4894.3	
Dutch Dairy Cows	121873.5	133480.5	147437.6	161479.3	18229.2	19965.3	97498.8	106784.4	
Meat goat/sheep	17374	16352	11862.9	11165.1	758.9	714.2	12161.8	11446.4	
Pig	116727	122421	52487.1	55047.5	3923.2	4114.6	116727	122421	
TOTAL REQUIRED (kg)	268655.1	285824	226219.7	243640.7	24380.3	26416.6	239068.2	254222.3	
DEVIATION (%)	0	0	11.1	12	141.1	132.4	210.7	196.9	

1st Redesigned *feeding capacity*

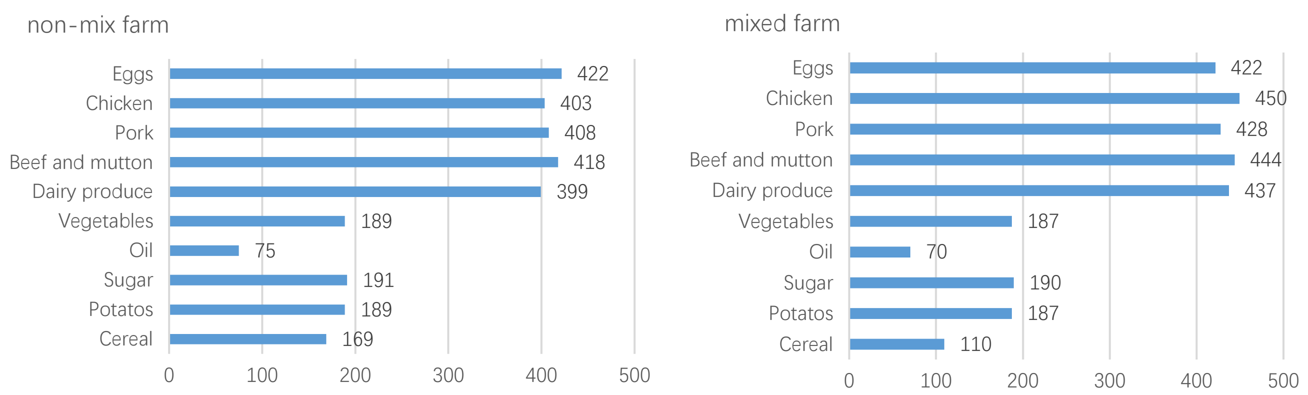


Figure 3-7 Redistribution of animal and crop products resulted feeding capacity. (number of people)

The redesigned feeding capacity shows that, overall, animal products are overproduced around two times higher than non-animal products. Within animal production, types of products are relatively even distributed after balance the number of animal feed on farm. Within non-animal products, potato, sugar, and vegetables are roughly balanced, whereas oil, and cereal are still the most limited crop in both farms, which will be discussed on nutrients shifting in next step redesign.

Compare two farms, mixed farm produced more animal products than non-mixed farm. The vegetable, potato, and sugar production are roughly same. And cereal production is higher in non-mix than mixed farm.

3.3.2 Redesign step2 nutrients balance simulation

As it is shown in Figure 3-5, animal products are over produced compare with non-animal products. The rest of redesign will focus on 1) simulate the N balance in NDICEA to check if crop were limited by nitrogen, 2) shifting nutrients from animal feed- using grass clover as green manure to food crop.

The total nutrient resource applied on farm (per ha) for last year is 3t chicken pellets (40kg N/ton from Product package), 20t farm yard manure (6.5kg N/ton from NDICEA) and 20t slurry (4.2kg N/ton from NDICEA). During rotation 2016, the manure produced[5] (60ha) on non-mixed farm is 107 t Farm Yard Manure (FYM), 46t Slurry, 3t Chicken pellets; in mixed farm, it is 137t FYM, 59t Slurry, and 3t Chicken pellets. Divided into per ha level, which is quite a small amount of manure.

Oil production

An comparative study on oilseed rape cultivars shown that the lowest average cultivar seed-yield is 1.616t/ha (cultivar Defender) (Sana, Ali, et al, 2003). In this experimental farm, the poor production might determine by technical reason, such as precipitation, pest destruction, sowing density, etc. At the time when this chapter is written, the oilseeds of year 2017 has been harvested and the yield see Table 3-7. It is considered that this yield data can be more reliable as normal production compare with previous data.

Table 3-7 Oilseeds yield in rotation 2017 (t/ha)

plots	1	2	3	4	5	6	7	8	9	10	11	12
rapeseeds	1.409	1.491	2.275	1.91	1.461	1.476	1.884	1.759	1.767	1.807	1.837	1.99

Nitrogen balance of food crop

This step of redesign is checking N availability on food crop: if the available N is below crop intake, the expected yield cannot be realized.

In 2016, the available N produced from manure is 17kgN ha^{-1} and 21.23kgN ha^{-1} respectively in non-mixed farm and mixed farm.

Simulation in NDICEA is in temporal level, in order to fit spatial manure distribution on farm, assumption has made on "the farm gain similar amount of manure in different year crop rotation". Figure 3-6 shows nitrogen availability and N uptake by crop/forage in 2016 in both types of farm. On both farms, potato is limited by N. While in non-mixed farm, 1st year grass clover (represent grass clover_strip3 in 2016 rotation) also need more N to maintain current yield level. Mixed farm shows higher N availability especially in two years' grass clover, but the N uptake in wheat, oilseed rape are lower than non-mixed farm which reflected its lower yield.

[5] Manure production calculation in Farm DESIGN (Groot & Oomen, 2016), here the FYM and Slurry production from stable already included bedding material produce on farm.

$$\mathrm{DM\ ToManure} = \mathrm{FeedToAnimals} \times \left(1 - \frac{FeedLoss}{100}\right) \times (1 - \mathrm{DMD}/1000)$$

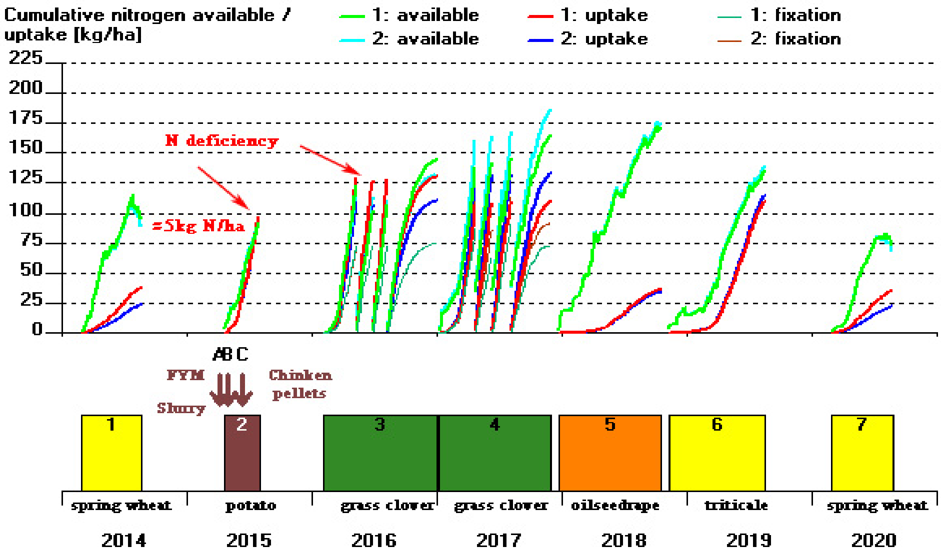


Figure 3-10 Nitrogen availability on both farms in 2016. Series 1 represent non-mixed farm; series 2 present mixed farm.

Figure 4-11 Suggested improvement for feed balance module_2. Modified by photoshopFigure 3-12 Nitrogen availability on both farms in 2016. Series 1 represent non-mixed farm; series 2 present mixed farm.

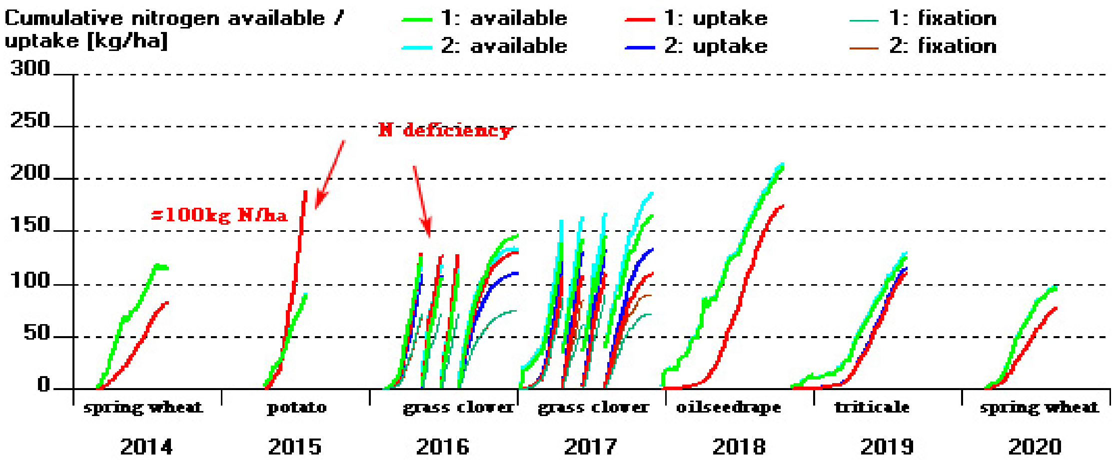
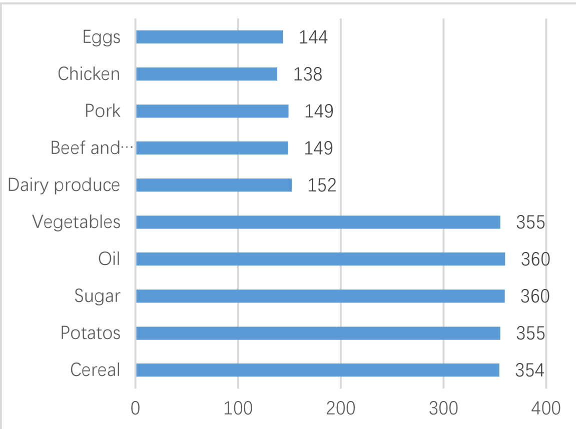
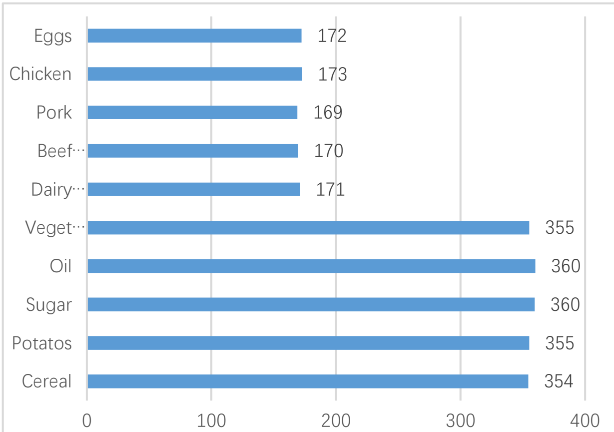
3.3.3 Redesign step3 Scenario analysis

The third step of redesign based on the empirical yield of food crops to use NDICEA simulate N dynamics. From NDICEA, the amount of N deficiency in food crop is estimated, which will determine how much N need to rebalance the nutrients availability. Then, based on the N equivalent of green manure (Aulakh & Doran, 2000), decide how much N (from grass clover) need to shift from animal feed as green manure to crop. Base on Aulakh 's study, we assume "20t of green manure (legume) correspondent to 113kg N ha^{-1} crop N uptake" also applicable in this experiment.

According the ADAS annual report (AHDB, 2016), the average spring wheat production in UK ranging around 6.6t-6.8t ha^{-1}; winter oilseed rape average yield 3.6t ha^{-1}, range from 1.0t-5.0t ha^{-1}. Potato production in the Netherlands can reach to 40t ha^{-1} with a dry matter content of 25% and to 50t ha^{-1} with dry matter content of 20% (Corné, 2014; Zaag, 1992). In following scenarios, the only objective is to optimize food crop yield, feed yield will not be altered but as a constraint value for balancing feeding capacity.

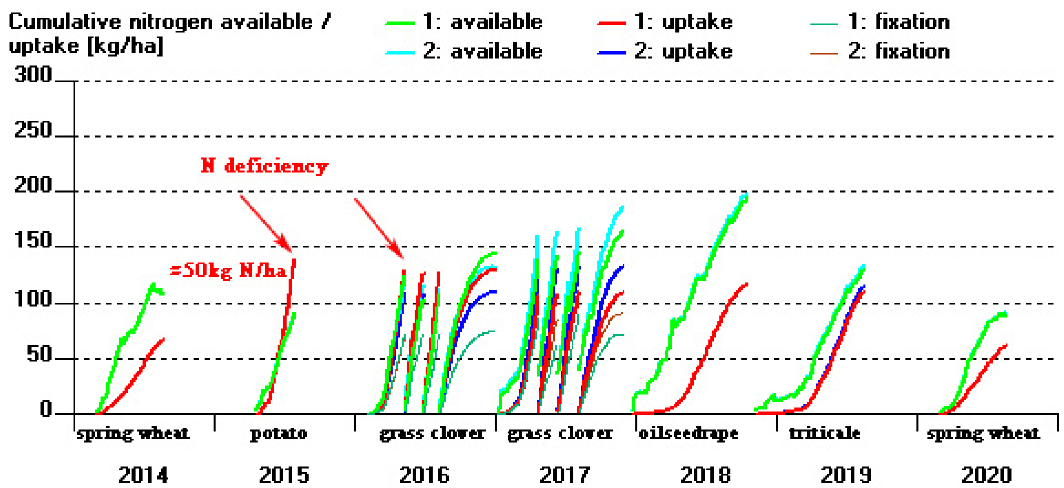
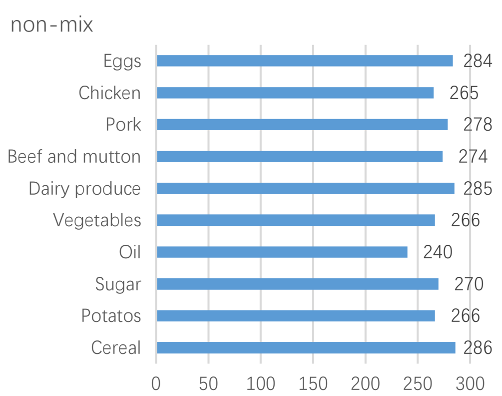
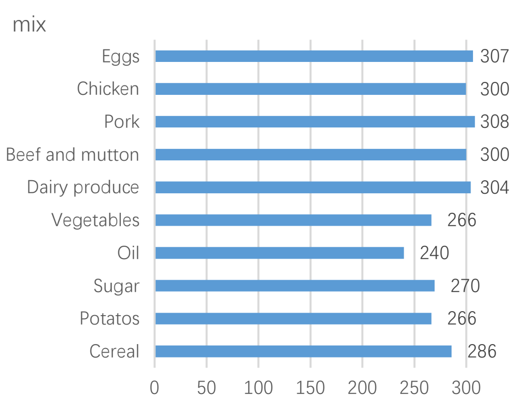
Scenario 1 maximizing the crop yield

<table>
<tr><td>Production assumption</td><td colspan="2">When the crop yield set as: wheat 3100kg/ha (fresh), potato 40000kg/ha (fresh), and oilseeds 3000kg/ha (without straw). The food crop production in consumption pattern model is balanced. (Consumption Pattern Module 2)</td></tr>
<tr><td>Result NDICEA</td><td colspan="2">Cereal and oilseed crop have enough N supply, only potato require additional 100kg N per ha (both farms).


</td></tr>
<tr><td>Assess FNE</td><td colspan="2">Equivalent to 17.7t/ha of grass clover as green manure to potato</td></tr>
<tr><td>To Farm DESIGN</td><td colspan="2">1. Animal feed reduce 177t grass clover
2. Oilseed cake yield increase to 21t.</td></tr>
<tr><td></td><td>Non-mix</td><td>Mix</td></tr>
<tr><td>Constraints</td><td>Animal dry matter intake deviation -1.9
Animal number: 8:9:15: 120:75</td><td>1.7
9:11:17: 150:90</td></tr>
<tr><td>Feeding capacity report</td><td>
</td><td>
</td></tr>
<tr><td>Results</td><td colspan="2">Food crop is roughly two times exceeding animal products in both farm.
In non-mixed farm, the most limited product is chicken, which can only supply to 138 person. In mixed farm, animal products produced more than non-mix, which can at least feed 169 person.
Overall, to much grass clover was shifted to green manure.</td></tr>
</table>

Scenario 2 shifting 8.85t ha^{-1} of grass clover as green manure to food crop

<table>
<tr><td>Production assumption</td><td colspan="2">When the crop yield set as: wheat 2500kg/ha (fresh grain yield default) potato 30000kg/ha (fresh yield default), and oilseeds 2000kg/ha (without straw). The food crop production in consumption pattern model is balanced.</td></tr>
<tr><td>Result NDICEA</td><td colspan="2">Cereal and oilseed crop have enough N supply, only potato require additional 50kg N per ha (both farms).


</td></tr>
<tr><td>Assess FNE</td><td colspan="2">Equivalent to 8.85t/ha of grass clover as green manure to potato</td></tr>
<tr><td>To Farm DESIGN</td><td colspan="2">1. Animal feed reduce 88.5t grass clover
2. Oil production increase to 6t, oil seed cake yield grows to 14t</td></tr>
<tr><td></td><td>Non-mix</td><td>Mix</td></tr>
<tr><td>Constraints</td><td>Animal dry matter intake deviation 0
Animal number: 15:15:28: 230:148</td><td>0
16:19:31: 260:160</td></tr>
<tr><td>Feeding capacity report</td><td>
</td><td>
</td></tr>
<tr><td>Results</td><td colspan="2">After redesign, animal products and food crop supply to same level of population. Oil is slightly limited the feeding capactity to 240 person.
Mixed farn is able to provide more animal products compare with non-mix.</td></tr>
</table>

4 Discussion and recommendation

4.1 Yield comparison between monoculture and mixture

It is more convincible to use land equivalent ratio for comparing two treatments on farm (Mead & Willey, 1980). Whereas there has no treatment for sole intercrop species in previous experiment set. It is recommended to have a monoculture plot design also for intercrop species in next growing season.

Regarding LER, relevant information can get from the crop sowing ratio in 2016 (Appendix A, Table 7-2), it is suggested that: triticale yield could be higher in polyculture treatment, because the sowing density in monoculture and polyculture were 200kg/ha and 134kg/ha respectively. It might because intercrop pea add more available N into soil, can potentially increase the biomass of cereal in polyculture treatment (Hauggaard-Nielsen, Ambus, et al, 2001), though some research found the opposite result that cereal biomass in polyculture treatment is lower (Tofinga, Paolini, et al 1993).

Wheat was sown under the same amount of seeds in two treatments, and there was 20 seed/m^2 faba intercropped in polyculture plot. Therefore, faba bean may have competition on nutrient, sunlight or water demand with wheat. But in another hand, the total biomass in polyculture wheat +faba (1.35$\pm$0.17 t ha^{-1}) is higher than monoculture (2.43$\pm$0.11 t ha^{-1}).

4.2 Limitation of the approach

The idea of this experiment is to use a farm scale crop rotation which has limited crop species to simulate the animal production, and to optimize its total feeding capacity. But there are limitations which can influence the result to deviate from a real farm configuration.

4.2.1 Experiment design

Limited crop diversity

Due to the limited crop diversity, which can be potentially "conflict" to the production proportion in EU consumption model. For example, potato is the only crop in root crop & vegetables group, which need to distribute into potato, sugar and vegetables. Due to the different property (DM) of different root & vegetable products, it might show higher/lower yield distribution to use the ratio from consumption pattern table rather than a redesigned proportion which only have one crop. This need to be testified by a more crop-diversified experiment.

Optimization of crop yield

The increase of production need to think in another way rather than shifting the nutrients in order to get an optimized simulation. Compare the yield production on farm and other literature & business report, the general production on experimental farm are lower than the average in other research (AHDB, 2016; Diepenbrock, 2000; Corné, 2014; Sana et al., 2003; Zaag, 1992).

In practice, adequately adjusting solar radiation, temperature, and plant density etc. to a certain crop variety can be solution to increase the yield potential[6]. Though crop yields and N uptake has positive correlation (Cassman, Dobermann, & Walters, 2016; Cassman et al., 2003; Sinclair & Horie, 1989), but over supply of nitrogen would attribute to human health and environment problem such as greenhouse gas emission, air and water pollution, biodiversity loses (Cassman et al., 2003; Dobermann, 2005; Pretty, Brett, et al 2000).

[6] Yield potential was defined as:" the yield of cultivar when grown in environments to which it is adapted, with nutrients and water non-limiting and with pests, diseases, weeds, lodging and other stresses effectively controlled." Quote from Evans, p292, (1996).

4.2.2 Farm DESIGN on animal production calculation

The experimental farm only produces food/feed on farm, but does not really raise animals. Farm DESIGN model was used to simulate how many animals can be feed on the farm. There are three limitations upon using of Farm DESIGN in this experiment.

Animal feed distribution

The animal feed was carefully separated regarding on different feed composition and target to different type of animals in Table 3-1. For instance, triticale straw will only feed for ruminants, grass clover will not feed to chicken.

But in Farm DESIGN, dry matter intake is calculated based on the saturation value of feed and animals, but not considering which types of feed should be distributed to which animal. That mains, feed is evenly/proportionally share to all animals. Furthermore, it can be concluded that Farm DESIGN is more suit for farm configuration where has lower animal diversity.

But, to some extent, it also made the redesign relatively easier. For example, reduce the grass clover yield in Farm DESIGN, would cause all animal numbers drop down, then it has possibility to rebalance again in this master case.

Manure production

In the redesign, different scenario would have different animal numbers to fit the diet balance. But, if the total feed not change, no matter how to alter the animal numbers, DM of manure will keep the same. The manure production is only affected by Feed to Animal, Feed Loss, and Dry Matter Digestibility which dependent on feed energy content (J. Groot & Oomen, 2016). Additionally, in case of using NDICEA, organic fertilizer from different animals are specified, but the Farm DESIGN does not have interactive command to link feed- animal -manure, which is important in reality for farm configuring.

$$\text{DM ToManure} = \text{FeedToAnimals} \times \left(1 - \frac{FeedLoss}{100}\right) \times (1 - \text{DMD}/1000)$$

Manure production in Stable

Manure production in Farm DESIGN is divided as Pasture manure, Yard manure, and Stable manure. In order to have the manure production "completely", except chicken and laying hen, other animal manure are all set to Stable. In concepts, Grazing system cost 20% more energy than set animals in Stable (J. Groot & Oomen, 2016), which may reduce the feeding capacity on farm in case of changing animal to grazing system. But it is more likely to have animal on pasture in organic farming system.

Potential improvement

It is not possible to give constructive feedback without development code behind the model. But based on my limited knowledge on programming, it is suggested that, set an interactive command in animal requirement interface, to restrict animal feed in certain types of feed (Figure 4-2). The command can link products Group as variable. In the meantime, crop destination→ used for feeding animals could be another constraint to provide feed to certain types of animals. Or it can even be more specific link to crop products Figure 4-2.

Same as feed distribution to certain animals, manure can also be separated in types of animals. Depends on which kind of manure management way more often used in farm configuration.

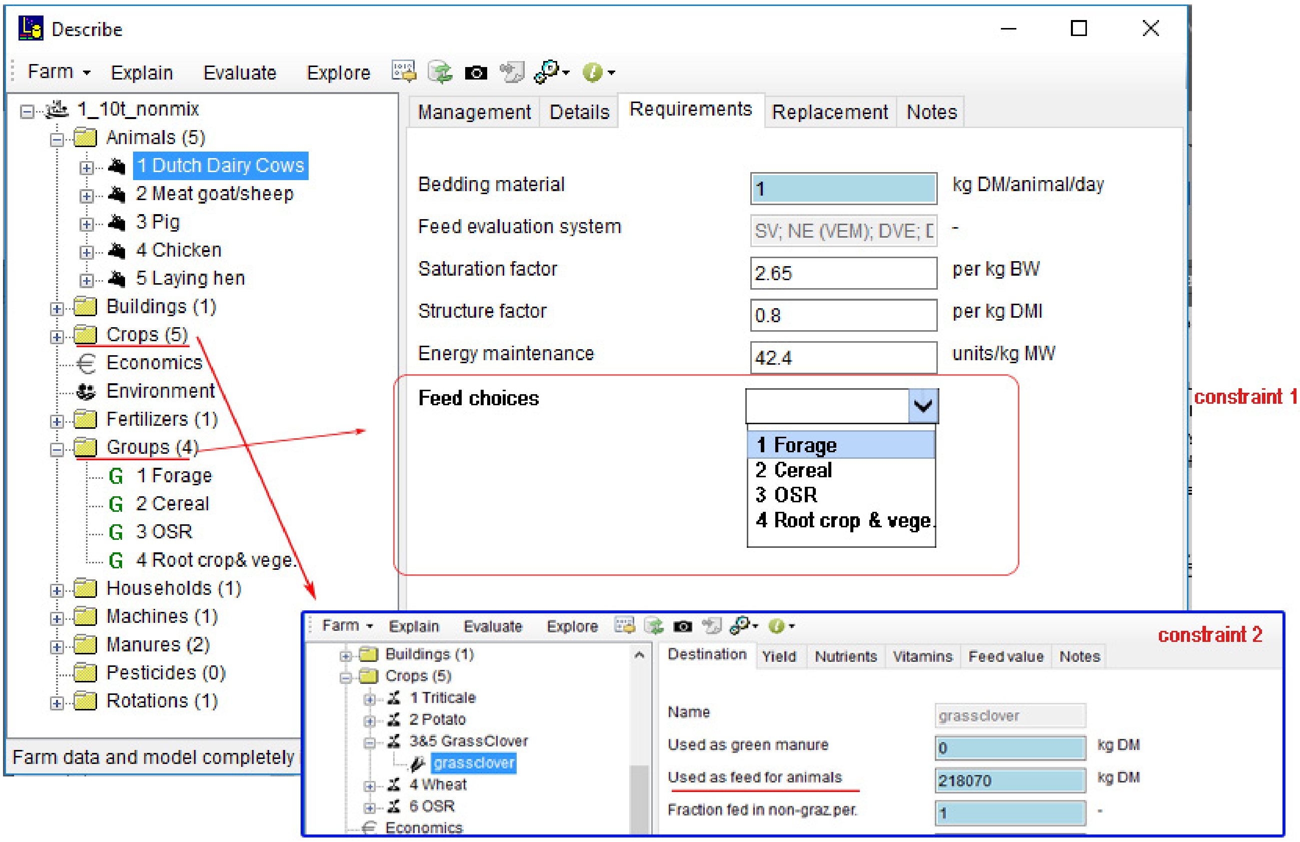


Figure 4-4 Suggested improvements for feed balance module. Suit to multi-animal species farms. Made by photoshop

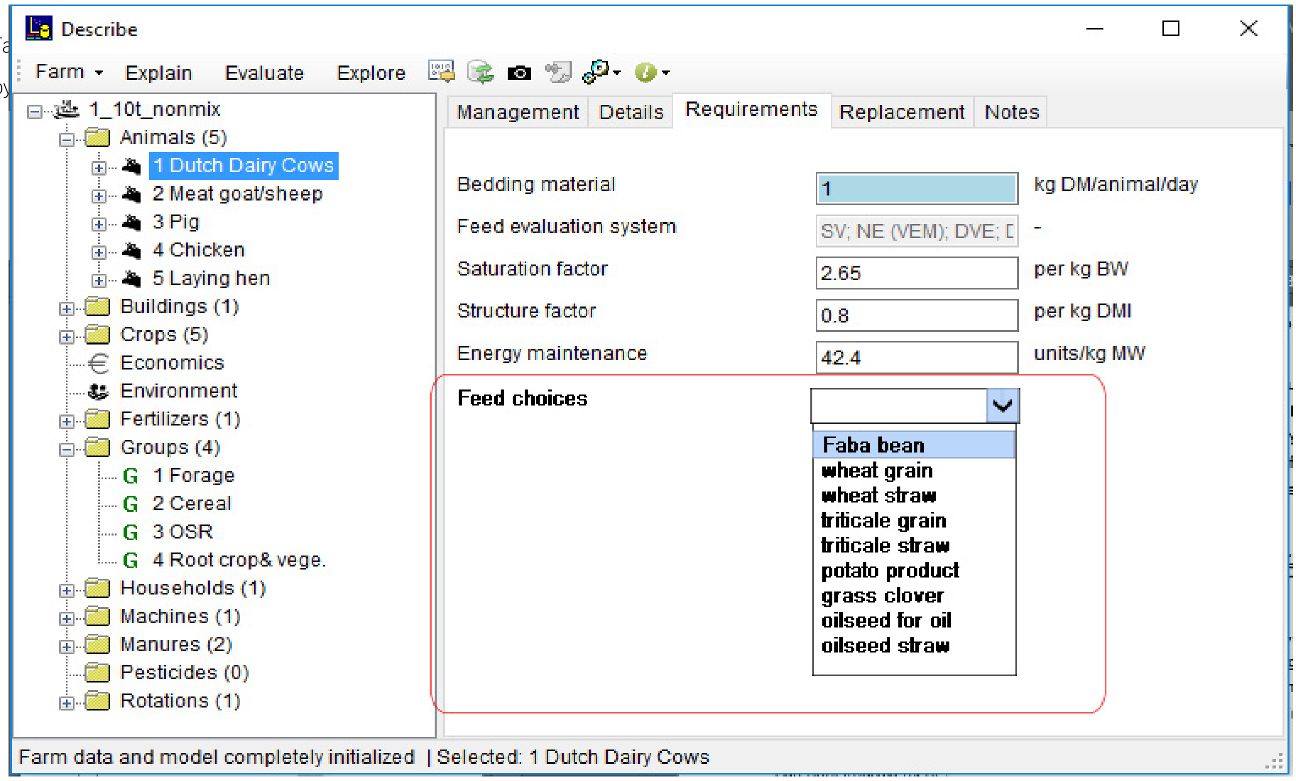


Figure 4-1 Suggested improvement for feed balance module_2. Modified by photoshop

4.2.3 Use of NDICEA

Temporal vs spatial distribution

The N accumulation in NDICEA is in temporal level (Van Der Burgt, Oomen, et al 2006), and the residue/straw left on field or not will determine the quantity of N availability for next crop. But the manure production in this experiment is produced in one year, spatial level. Though assumption made on yearly equal manure production, but there still has uncertainty for N distribution in this way.

Fertilizer nitrogen equivalent of green manure

Fertilizer nitrogen equivalent of green manure is defined as: under same environment condition (i.e. temperate), the amount of fertilizer nitrogen applied to a crop must obtain the same grain yield from green manure applied group. Here we simply assumed grass clover have the same N effect with experiment did by Aulakh & Doran, (2000). In order to tackle this limitation, relative cropping experiment on comparison of green manure and fertilizer N on different crops is suggested for future master study on Droevendaal farm. The decomposition process of green manure in different crop might be similar, but the N uptake by various crops could be different.

Hopkins, (2011) concluded that Lucerne and grass-clover as green manure have more positive effect to crop performance rather than chicken manure, But some research shows there is no significant effect on crop production and N uptake under application of green manure (grass clover), while soil N concentration shows slight reduction in subsequent years (Olesen, Askegaard, & Rasmussen, 2009, Baggs (2000)). Here in this experiment, we assume applied green manure can decomposed properly and relate the correspondent crop N uptake after application.

5 Conclusion

Production summarization 2016

The production analyzation on experimental farm in 2016 shows that, there is no significant differences between monocultural treatment and mixture on triticale, potato, and oilseed rape yield. While grass clover in 2015 (strip 3, P=0.000) and wheat production (P=0.019) in monoculture is significant higher than mixed treatment. It needs to taking consideration that, wheat production in mixed treatment does not include faba bean yield, if included, the total biomass would exceed monoculture. Grass clover in 2016 (strip5) is higher (P=0.009) in polyculture plots than monoculture. Overall, the average total production in mixed treatment (33.41±0.64t ha^{-1}) is higher than non-mix one (32.04±0.79t ha^{-1}), which included the intercrops in mixed treatment.

Feeding capacity on two farms

Based on crop dry matter yield and animal production simulated from Farm DESIGN, the feeding capacity result shows production on all diet in 2016 on are unbalanced. Notice the calculation is based on total farm land as 60ha; in default scenario numbers of animals are randomly assigned to farm, which only taking dry matter balance (fully consumed the feed produced on farm) into account, but not the balance of consumption pattern.

From the feeding capacity result (Figure 3-3): oil is the most limited products in all food diet. Which can only fulfill 70 to 75 persons' demand in 60ha farm production. Potato yield and cereal also limited the feeding capacity below 180 persons. While animal products can feed relatively more people than food crop but still unbalanced distributed in different types of products.

Rebalanced farm produced diet (Figure 3-5) shows that animal products can supply to two times more people than non-animal food. Within food crop, area for root & vegetable group set to potato 3.4: sugar1.5: vegetables 5.1 instead of 2:3:5, can lead the feeding capacity on these three food-patterns in same level around 190 persons on both farms. Animal products are relatively balanced when the number of animal set as cow 21-23 heads, goat 32-34 heads, pig 41- 43 heads, chicken 350-390, and laying hen 220. Mixed farm can produce more animal products than non-mixed farm, and also provided more diverse feed diet to animals (3 more species: faba, pea and more grass species).

Redesigning on balanced diet

The manure produced on farm is not sufficient to fulfill crop rotation in 2016. Potato yield was limited by nitrogen. The results from scenario analysis suggested that shifting 8.85t ha^{-1} grass clover as green manure to crop can potentially increase the food crop yield and still maintain a balanced animal production. In the main time, feeding capacity can be optimized to at least 240 people on a balanced diet.

6 References

AHDB, A. (2016). Cereals & Oilseeds Final Harvest Summary. Report.

Aulakh, M. S., & Doran, J. W. (2000). Yields and Nitrogen Dynamics in a Rice – Wheat System Using Green Manure and Inorganic Fertilizer, 1867–1876.

Badgley C, Moghtader J, Quintero E, et al. Organic agriculture and the global food supply[J]. Renewable agriculture and food systems, 2007, 22(2): 86-108.

Cassman, K. G., Dobermann, A., & Walters, D. T. (2016). Agroecosystems , Nitrogen-use Efficiency , and Nitrogen Management. *Ambio*, *31*(2), 132–140.

Cassman K G, Dobermann A, Walters D T, et al. Meeting cereal demand while protecting natural resources and improving environmental quality[J]. Annual Review of Environment and Resources, 2003, 28(1): 315-358.https://doi.org/10.1146/annurev.energy.28.040202.122858

Corné Kempenaar, P. (2014). Dutch Potato business, WUR report.

Diepenbrock, W. (2000). Yield analysis of winter oilseed rape (Brassica napus L.): A review. *Field Crops Research*, *67*(1), 35–49. https://doi.org/10.1016/S0378-4290(00)00082-4

Dobermann, A. R. (2005). Nitrogen Use Efficiency – State of the Art.

Fraser, M. D., Moorby, J. M., Vale, J. E., & Evans, D. M. (2014). Mixed grazing systems benefit both upland biodiversity and livestock production. *PLoS ONE*, *9*(2). https://doi.org/10.1371/journal.pone.0089054

Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., … Toulmin, C. (2010). Food Security: The Challenge of Feeding 9 Billion People. *Science*, *327*(5967), 812–818. Retrieved from http://www.jstor.org.ezproxy.library.wur.nl/stable/40509896

Groot, J. C. J., Oomen, G. J. M., & Rossing, W. A. H. (2012). Multi-objective optimization and design of farming systems. *Agricultural Systems*, *110*, 63–77. https://doi.org/10.1016/j.agsy.2012.03.012

Groot, J., & Oomen, G. (2016). *Farm DESIGN Manual*.

Hauggaard-Nielsen H, Ambus P, Jensen E S. Interspecific competition, N use and interference with weeds in pea–barley intercropping[J]. Field Crops Research, 2001, 70(2): 101-109.

Herrero M, Thornton P K, Notenbaert A M, et al. Smart investments in sustainable food production: revisiting mixed crop-livestock systems[J]. Science, 2010, 327(5967): 822-825.

Hopkins, A. (2011). in a Green Future, *18*(September).

Isbell, F., Reich, P. B., Tilman, D., Hobbie, S. E., Polasky, S., & Binder, S. (2013). Nutrient enrichment, biodiversity loss, and consequent declines in ecosystem productivity. *Proceedings of the National Academy of Sciences* , *110*(29), 11911–11916. https://doi.org/10.1073/pnas.1310880110

Institute for Health Metrics and Evaluation (IHME). GBD Compare. Seattle, WA: IHME, University of Washington, 2015. Available from http://vizhub.healthdata.org/gbd-compare.

Lantinga, E. A., & Rabbinge, R. (1997). The renaissance of mixed farming systems: a way towards sustainable agriculture.

McAnally, R. a. (1942). Digestion of straw by the ruminant. *The Biochemical Journal*, *36*(3–4), 392–9. Retrieved from http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1265707&tool=pmcentrez&rendertype=abstract

Mead R, Willey R W. The concept of a 'land equivalent ratio'and advantages in yields from intercropping[J]. Experimental Agriculture, 1980, 16(3): 217-228.

Murray, C. (2014). Presentation given to the first EAT Stockholm Food Forum

https://www.youtube.com/watch?v=hg4qBjUS_aM.

Olesen, J. E., Askegaard, M., & Rasmussen, I. A. (2009). Winter cereal yields as affected by animal manure and green manure in organic arable farming. *European Journal of Agronomy*, *30*(2), 119–128. https://doi.org/10.1016/j.eja.2008.08.002

Oomen, G. J. M., Lantinga, E. A., Goewie, E. A., & Van Der Hoek, K. W. (1998). Mixed farming systems as a way towards a more efficient use of nitrogen in European Union agriculture. *Environmental Pollution*, *102*(SUPPL. 1), 697–704. https://doi.org/10.1016/S0269-7491(98)80101-2

Pretty, J. N., Brett, C., Gee, D., Hine, R. E., & Mason, C. F. (2000). An assessment of the total external costs of UK agriculture, *65*.

Sana, M., Ali, A., Malik, M. A., Saleem, M. F., & Rafiq, M. (2003). Comparative yield potential and oil contents of different canola cultivars (Brassica napus L.). *Pakistan Journal of Agronomy*.

Shen, J., Li, C., Mi, G., Li, L., Yuan, L., Jiang, R., & Zhang, F. (2013). Maximizing root/rhizosphere efficiency to improve crop productivity and nutrient use efficiency in intensive agriculture of China. *Journal of Experimental Botany*, *64*(5), 1181–1192. https://doi.org/10.1093/jxb/ers342

Sinclair T R, Horie T. Leaf nitrogen, photosynthesis, and crop radiation use efficiency: a review[J]. Crop science, 1989, 29(1): 90-98.

Smith, L. G., Tarsitano, D., Topp, C. F. E., Jones, S. K., Gerrard, C. L., Pearce, B. D., … Watson, C. A. (2015). Predicting the effect of rotation design on N, P, K balances on organic farms using the NDICEA model. *Renewable Agriculture and Food Systems*, *31*(March 2016), 1–14. https://doi.org/10.1017/S1742170515000381

Thiele, S., Mensink, G. B., & Beitz, R. (2004). Determinants of diet quality. *Public Health Nutrition*, *7*(1), 29–37. https://doi.org/10.1079/PHN2003516

Tilman, D., Cassman, K. G., Matson, P. A., Naylor, R., & Polasky, S. (2002). Agricultural sustainability and intensive production practices. *Nature*, *418*(6898), 671–677. Retrieved from http://dx.doi.org/10.1038/nature01014

Tofinga M P, Paolini R, Snaydon R W. A study of root and shoot interactions between cereals and peas in mixtures[J]. The Journal of Agricultural Science, 1993, 120(1): 13-24.

Van Der Burgt, G. J. H. M., Oomen, G. J. M., Habets, A. S. J., & Rossing, W. A. H. (2006). The NDICEA model, a tool to improve nitrogen use efficiency in cropping systems. *Nutrient Cycling in Agroecosystems*, *74*(3), 275–294. https://doi.org/10.1007/s10705-006-9004-3

van Rossum, C. T. M., Fransen, H., Verkaik-Kloosterman, J., Buurma-Rethans, E., & Ocke, M. (2011). Micronutrients. *Dutch National Food Consumption Survey 2007-2010 : Diet of Children and Adults Aged 7 to 69 Years*, 61–76.

Zaag, D. E. van der. (1992). Potatoes and Their Cultivation in the Netherlands. *The Ministry of Agricultural and Fisheries*, 47.

7 Appendix A

Table 7-1 Rotation scheme set on farm 2014-2020, green highlighted the target rotation for this study

Strips \ Rotation	Year						
	2014	2015	2016	2017	2018	2019	2020
6	maize	Grass clover	Oilseed rape	winter triticale	spring wheat	potato	GC
5	spring wheat	potato	Grass clover	Grass clover	Oilseed rape	winter triticale	spring wheat
4	Grass clover	Oilseed rape	spring wheat	potato	Grass clover	Grass clover	Oilseed rape
3	potato	Grass clover	Grass clover	Oilseed rape	winter triticale	wheat	potato
2	Oilseed rape	spring wheat	potato	Grass clover	Grass clover	Oilseed rape	winter triticale
1	Grass clover	Grass clover	winter triticale	spring wheat	potato	Grass clover	Grass clover

Table 7-2 Crop sowing ratio in 2016

sowing ratio	**mono**	**poly**				
triticale	200kg	67kg wheat	67kg triticale	50kgrye	75kgpea	
potato	200kg	200kg	90 per variaty			
gc_y1	35kg rye 5kg red clover	200kg triticale	17.5kg rye	10kg Alex.clover	15kg Incu.clover	5kg red.clover
wheat	170kg	170kg	20seed/m^2 faba			
gc_y2						
oilseed rape	6kgrapeseed 3.91kg zomerkoolzaad Helga	6kg koolzaad	2.5kg riesling			

Table 7-3 Three-meter intercropping strips data source (2015-2016).

Field	Time		Collected by
	Year	Date	
Strip1 Triticale	2016	Jul.	Dine Volker, Dirk van Apeldoorn
Strip2 Potato	2016	12_9	Jan, Dine Volker, Dirk van Apeldoorn
Strip3 Grass Clover	2015(S1)	19_5, 30_6,6_8, 21_9	Rianne Prinsen, Andries Kirstin Surmann, Dine Volker
Strip4 Wheat	2016	Dec.	Jan Jansen, Marston, Dine Volker
Strip5 Grass Clover	2016	12_5, 7_7, 18_8, 11_10	Jan Jansen, Dirk van Apeldoorn
Strip6 OSR	2015(S4)	21_8	Dine Volker, Sarah, Maren Weller, Kirstin Surmann

Table 7-4 Summarized yield data t/10ha within each plot

Without_mixture

	Plot1	**Plot2**	**Plot3**	**Plot4**	**Plot5**	**Plot6**	**Plot7**	**Plot8**	**Plot9**	**Plot10**	**Plot11**	**Plot12**	**total**
Triticale	33.2	42.4	51.9	41.5	39.2	43.5	39.1	38.2	35.2	43.7	35.3	37.9	481.1
Potato	38.9	51.7	50.8	43.1	42	45.7	46.4	37.9	42.9	39.1	36.2	43.1	517.8
GrassC3	117.5	107.5	117.6	95.8	111.9	109.2	119.1	121	127	95.4	94	122.2	1338.2
Wheat	7.2	9.5	19.5	9.8	5.6	6.1	15.1	10.9	13.5	9.3	12.3	14.8	133.6
GrassC5	92.3	95.4	88.9	126.8	140.4	122.6	97.6	105.6	108.9	110.2	110.8	90.7	1290.2
OilseedR	3.8	4.1	3.4	8.3	3.4	4.4	4.5	5.4	11.3	9.1	5.9	9	72.6
Total (t/60ha)	292.9	310.6	332.1	325.3	342.5	331.5	321.8	319	338.8	306.8	294.5	317.7	3833.5

Include_mixture

	Plot1	Plot2	Plot3	Plot4	Plot5	Plot6	Plot7	Plot8	Plot9	Plot10	Plot11	Plot12	total
Triticale(pea)	33.2	42.4	51.9	41.5	39.2	43.5	39.1	38.2	35.2	43.7	35.3	37.9	481.1
Potato	38.9	51.7	50.8	43.1	42	45.7	46.4	37.9	42.9	39.1	36.2	43.1	517.8
GrassC3	117.5	107.5	117.6	95.8	111.9	109.2	119.1	121	127	95.4	94	122.2	1338.2
Wheat(faba)	7.2	27.1	19.5	27.7	23.2	20.7	15.1	10.9	13.5	22.7	24.8	14.8	227.2
GrassC5	92.3	95.4	88.9	126.8	140.4	122.6	97.6	105.6	108.9	110.2	110.8	90.7	1290.2
OilseedR(clover)	3.8	4.1	3.4	8.3	3.4	4.4	4.5	5.4	11.3	9.1	5.9	9	72.6
total (t/60ha)	292.9	328.2	332.1	343.2	360.1	346.1	321.8	319	338.8	320.2	307	317.7	3927.1

7.1 Soil analysis

Two farms are compared on three soil nutrients indicators (Table 7-4): soil N concentration, soil organic matter and soil PH. Welch two sample t test shows that, except soil organic matter in potato field shows higher organic matter content in non-mixed treatment (P=0.025 < 0.05); soil pH in wheat strip (P= 0.008), and grass clover strip5 (P = 0.054) show significant higher pH value in non-mix treatment. The rest of comparison are statistically suggested no differentiation.

	triticale		**potato**		**gc s3**		**wheat**		**gc s5**		**osr**	
	non-mix	mix	non-mix	mix	non-mix	mix	non-mix	mix	non-mix	mix	non-mix	mix
Soil perc-N (%)	0.14	0.13	0.16	0.15	0.14	0.13	0.12	0.13	0.14	0.13	0.12	0.13
SE	0.008	0.005	0.017	0.013	0.004	0.005	0.008	0.005	0.008	0.005	0.008	0.005
P value	NS		NS		NS		NS		NS		NS	
Soil OM	4.03	3.97	4.18	3.94	4.04	3.98	4.21	4.04	4.02	3.96	3.77	3.82
SE	0.073	0.051	0.030	0.094	0.101	0.015	0.095	0.073	0.205	0.051	0.202	0.080
P value	NS		0.025		NS		NS		NS		NS	
Soil pH	5.22	5.17	5.40	5.37	5.28	5.27	5.48	5.35	5.52	5.42	5.47	5.38
SE	0.040	0.033	0.063	0.071	0.070	0.021	0.040	0.022	0.048	0.031	0.042	0.031
P value	NS		NS		NS		0.008		0.054		NS	

Table 7-5 Mono. vs Poly. comparison of soil analysis index among 6 strips. mean value, standard error and P value.

Soil samples were comparing under three factors: soil N concentration, organic matter and PH. N concentration in soil does not show significant differences between two treatments in six strips. but the average N% value in non-mix shows higher in monoculture than polyculture, except wheat and oil seed rape strip. Organic matter content in potato (P<0.05) strip show significant higher value in monoculture treatment. Though the rest of strip does not show significant differences, but the average value on organic matter are all higher in monoculture plots except oilseed rape. Soil pH value on wheat (0.001<P<0.05) and grass clover (strip5, 0.05<P<0.1) are higher in monoculture treatment. Rest of the strips does not show significant differences.

8 Appendix B

Table 8-1 Calculated consumption pattern table

Yield (ton/10ha) Exclude fababean data in wheat strip													
	Plot1	Plot2	Plot3	Plot4	Plot5	Plot6	Plot7	Plot8	Plot9	Plot10	Plot11	Plot12	Total
osr biomass	53	43.4	61	54.8	45.5	60	55.4	39.7	56.1	39.3	45.8	38.6	592.6
faba_t/ha	0	17.6	0	17.9	17.7	14.5	0	0	0	13.4	12.6	0	93.7

Forages	209.80	202.90	206.50	222.60	252.30	231.80	216.70	226.60	235.90	205.60	204.80	212.90
Cereals	40.40	51.90	71.40	51.30	44.80	49.60	54.20	49.10	48.70	53.00	47.60	52.70
pulses and oilseed crops	3.80	21.70	3.40	26.20	21.10	18.90	4.50	5.40	11.30	22.50	18.50	9.00
root crops and vegetables	38.90	51.70	50.80	43.10	42.00	45.70	46.40	37.90	42.90	39.10	36.20	43.10

HIGHLIGHT	MIXTURE

Farm_NonMIX average

	yearly consumption (kg per person)	yearly consumption (kg per person)	forage crops		cereals		pulses and oilseed crops		root crops and vegetables		total	total	perc.
Cereal	80	11.92%			9%	13.50					9%	13.50	4.21%
Potatos	78	11.62%							2%	8.67	2%	8.67	2.71%
Sugar	34	5.07%							3%	13.00	3%	13.00	4.06%
Oil	25	3.73%					5%	1.87			5%	1.87	0.58%
Vegetables	117	17.44%							5%	21.67	5%	21.67	6.76%
Dairy	240	35.77%	20%	106.37	3%	19.63					23%	126.00	39.33%
Beefmutton	26	3.87%	21%	111.69							21%	111.69	34.86%
Pork	40	5.96%			12%	11.78	5%	1.82			17%	13.59	4.24%
Chicken	19	2.83%			6%	5.89	5%	1.82			11%	7.71	2.41%
Eggs	12	1.79%			2%	1.96	2%	0.73			4%	2.69	0.84%
Total	671	100.00%	41%	218.06	32%	52.75	17%	6.23	10%	43.33	100%	320.38	100.00%
Total (t/ha)					13.50	39.25			320.38				

Farm_MIXED average

	yearly consumption (kg per person)	yearly consumption (kg per person)	forage crops		cereals		pulses and oilseed crops		root crops and vegetables		total	total	perc.
Cereal	80	11.92%			9%	8.77					9%	8.77	2.62%
Potatos	78	11.62%							2%	8.59	2%	8.59	2.57%
Sugar	34	5.07%							3%	12.89	3%	12.89	3.86%
Oil	25	3.73%					5%	1.76			5%	1.76	0.53%
Vegetables	117	17.44%							5%	21.48	5%	21.48	6.43%
Dairy	240	35.77%	20%	107.32	3%	20.47					23%	127.78	38.24%
Beef mutton	26	3.87%	21%	112.68							21%	112.68	33.72%
Pork	40	5.96%			12%	12.28	5%	8.22			17%	20.50	6.13%
Chicken	19	2.83%			6%	6.14	5%	8.22			11%	14.36	4.30%
Eggs	12	1.79%			2%	2.05	2%	3.29			4%	5.33	1.60%
Total	671	100.00%	41%	220	32%	49.70	17%	21.48	10%	42.97	100%	334.15	100.00%
Total (t/ha)					8.77	40.93	5.87	15.62			334.15		

9 Appendix C

Table 9-1 Animal requirements value & feed values used in Farm DESIGN

animal	satuaration factor	structure facor	energy maintenance	
cow	2.65	0.8	42.4	
goat	2	0.7	30	
pig	6	1	36.6	
chicken	2.56	1	35.3	
hen	2.56	1	35.3	
crop	satuaration value	structure value	energy content	protein content
tritical grain	0.85	0.15	1183	117
triticale straw	1.66	4.3	820	32
potato				
grassclover	1	3	950	249
faba	0.85	0.15	1178	134
wheatgrain	0.85			
wheatstraw	1.66			
oilseeds oil	0.28	0.3	1100	356
oilseeds straw	1.15			

10 Appendix D

Redesigned area proportion of root crop and vegetables- suit for Droevendaal experiment 2016 case.

	yearly consumption (kg per person)	yearly consumption (kg per person)	forage crops		cereals		pulses and oilseed crops		root crops and vegetables		total	total	perc.
Farm_NonMIX average													
Cereal	80	11.92%			9%	13.50					9%	13.50	4.21%
Potatos	78	11.62%							3.4%	14.73	2%	14.73	4.60%
Sugar	34	5.07%							1.5%	6.50	3%	6.50	2.03%
Oil	25	3.73%					5%	1.87			5%	1.87	0.58%
Vegetables	117	17.44%							5.1%	22.10	5%	22.10	6.90%
Farm_MIXED average													
Cereal	80	11.92%			9%	8.77					9%	8.77	2.62%
Potatos	78	11.62%							3.4%	14.61	2%	14.61	4.37%
Sugar	34	5.07%							1.5%	6.45	3%	6.45	1.93%
Oil	25	3.73%					5%	1.76			5%	1.76	0.53%
Vegetables	117	17.44%							5.1%	21.91	5%	21.91	6.56%