Planty Organic 5 year: evaluation of soil fertility, nitrogen dynamics and production

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Preface

Planty Organic is an ambitious project. We want to show that organic arable farming, which provides for 100% its own nitrogen supply, without ploughing is performing with very good results (or performing very well) regarding People – Planet – Profit. We also want to demonstrate that the used agroecological techniques can inspire other farms on their way to sustainability. It would have been no surprise if production would have gone down after some years without manure supply. We have now completed seven years. This 5-year evaluation, 2012-2016, shows that our doubts about the system can be set aside. Our ambitions are rewarded when facing the results of this living and robust agroecological system. Still, some important questions are not answered. So it's highly interesting to continue the Planty Organic project, integrated with other research projects. By publishing this report we want to inspire both conventional and organic arable farming to make further steps on the path of sustainability and CO_2 neutral management. Besides this we want to invite other stakeholders to participate in Planty Organic. With a partially new research agenda, coordinated with other research locations, Planty Organic can continue producing surprising and inspiring research results.

We want to thank the Farmers Association of the Wadden area, BioWad, for initializing Planty Organic. Of course we are grateful to the organisations which funded the Planty organic project: Friesland and Groningen Provinces, RaboBank and the Ministry of Economic Affairs. We also say 'thank you!' to SPNA, Louis Bolk Institute and Avestua for field maintenance, scientific coordination and project coordination respectively. Especialy grateful we are to the two Provinces for enabling the 2017 continuation of Planty Organic, which also meant enabling the production of this evaluation.

On behalf of BioWerk Foundation, Wridzer Bakker, Chairman

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Summary

In the Planty Organic experimental field, located at the SPNA location ‘Kollumerwaard’, an organic arable farming system is developed based on three principles:

- Nitrogen input fully based on leguminous crops
- Use of farm-produced cut-and-carry fertilizers
- Reduced tillage; no ploughing.

The results of this research will be available for improvements in both organic and conventional arable farming. The experimental site consists of six plots, 0,8 hectare each. There is a six-year rotation, which means that each crop is present each year in a different plot.. The project started in 2011. Since 2012 year-reports have been published. For this evaluation of the system results the start-up year has been left out and the data of 2012 – 2016 are used for analysis.
It has been shown that it is possible to fulfil the three principles. Nitrogen deliverance to the crops has been realized by means of cut-and-carry fertilizers, green manures and crop residues. Yield level was at an acceptable level and the weed pressure was controllable. Five years without adding minerals did not result in a decrease in mineral content of soil and crops.

The organic matter content of the soil has been measured each year. The measurements’ error is too big to enable reliable statements on changes. Five years of data show a trend towards a small increase of 0.03 % per year. This is remarkable for a system without external organic matter input. Data from the six plots have been used in the Ndicea nitrogen and organic matter model. The differences between measured and simulated levels of soil mineral N are relatively small. The model seems to give a reliable description of the systems’ nitrogen dynamics.

The simulated organic matter dynamics of the six plots indicate a stable situation. As is the case with the measurements, there is uncertainty in the modelling. Nitrogen leaching as simulated in Ndicea is very limited. This can be explained by the, in average, very low levels of soil mineral nitrogen, and by the relatively high rate of crop cover during the years by cut-and-carry fertilizers grass/clover and alfalfa/clover and by green manures.
The modelling enables a detailed view into the internal nutrient dynamics. This shows that, related to the output in products, a large amount of nitrogen and phosphorus (and other nutrients) is circulating by means of root- and crop residues, green manures and cut-and-carry fertilizers. This high rate of circulation might be an essential factor in system stability and productivity.
Nitrogen mineralisation coming from different sources of organic matter is more and more involved when nitrogen fertilization recommendations are made. In case of phosphorus this has never been explored up to now. The Planty Organic experiment offers an opportunity to study the importance of the internal phosphorus circulation related to phosphorus availability for crop growth.
Due to absence of input (except for nitrogen: leguminous crops) there is a negative mineral balance for all nutrients, which in the end is not sustainable. Mining of phosphorus (and other nutrients) is not sustainable either. As compensation for the loss of nutrients by selling produce, a limited input of compost could be considered, with phosphorus equilibrium as target. On the other hand, for an interesting contrast with other systems and the study of internal phosphorus dynamics, a zero input strategy might be continued for some years.

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Besides the produce, the Planty Organic system delivers services without being paid for: very low nitrogen leaching, no ammonium emission, very low methane and nitrous oxide emissions, preservation or increase of soil fertility, no emissions of crop protection residues to water or air, a high above-ground biodiversity, probably a high soil biodiversity, probably limited carbon dioxide storage, no manure transport, no animal welfare violence.

There are items for further research:

- Nitrogen dynamic: minor changes in crops, green manures, timing and quality of cut-and-carry fertilizers in order to increase the nitrogen availability for the main crops (yield potential) without fundamentally changing the system.
- Organic matter: the amount of carbon dioxide fixed in the soil, and the related profits for society and farm.
- System stability: the role of root depth and root intensity, the role of internal organic matter and nutrient dynamics on system stability and system productivity.
- The role of soil life related to stability and system productivity.
- Phosphorus dynamics: which part of crop uptake is related to phosphorus mineralisation out of soil organic matter, and can this knowledge be operationalized in the phosphorus recommendation approach in the Netherlands? The role of cut-and-carry fertilizers and green manures in mobilizing soil phosphorus supply.
- Carbon dioxide food print of this arable farming system without input of manure and with reduced tillage, compared to other arable systems, both conventional and organic.

1 Introduction and background

Agriculture is confronted with big challenges. Increased regulations in the Netherlands due to limits on input of Phosphorus and Nitrogen reduce the input of manure and fertilizer to arable and horticultural farming. Since input of manure is restricted, organic matter supply of the soil is in?? question. Besides this, the Dutch organic agricultural sector has another challenge: to substantially reduce the input of conventionally produced manure. Combining this results in:

- every farm of garden has a profit related to prevention of nitrogen losses
- every farm or garden has the task to reduce phosphorus input, meanwhile maintaining the production level
- the organic agricultural sector will increasingly be dependent on nitrogen fixation on the farm itself.

The Planty Organic project offers an opportunity to tackle these three challenges. On the experimental farm 'Kollumerwaard', run by SPNA (www.spna.nl), a 6-year organic rotation is realized on 6 fields, 0,8 hectare each. The crop sequence and fertilizer scheme is based on the following requirements (Van der Burgt, 2012):

- 100% nitrogen supply by means of nitrogen fixation by Grass-Clover or Alfalfa-Clover and green manures; use of cut-and-carry fertilizer system to redistribute the nitrogen.
- No input of manures or composts.
- Sufficient nitrogen for an acceptable yield level and product quality.
- A crop rotation that contributes to soil quality and nitrogen fixation.
- Maintenance or increase of soil organic matter content.
- Crops representative for the region.
- During winter time soil cover as much as possible.
- Alteration of above-ground products and uprooted products.
- Non-ploughing, and otherwise reduced soil tillage.

The Planty Organic farming system started in 2011 and has the designed crop rotation since 2012. This report evaluates the 2012-2016 period. Year-reports have already been published (van der Burgt 2012; Hospers et al., 2014a, 2014b, 2015, 2017).
It is remarkable that no compensation of mineral depletion by selling crops is taken place. This choice is based on two thoughts. First, why explore Phosphorus mining when the soil itself contains a lot of Phosphorus. Let's first mobilize these supplies. Second, by creating an extreme situation (no Phosphorus added) conditions are created to investigate Phosphorus dynamics and availability under a negative supply balance. This opens the opportunity to answer questions such as: 'What is the role of deep rooting systems?' , 'What is the importance of a high Phosphorus turnover related to supply and crop uptake?', 'Can the Phosphorus supply in the soil become mobile for crop uptake?'. This reasoning is also valuable for many other nutrients.

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2 Questions within this evaluation

This evaluation has the target to answer some questions and to generate new research questions. The next questions are answered in a quantitative or qualitative way:

- Is this system feasible? (section 4.1)
- What is the production level of this, as expected nitrogen-limited, system? (section 4.2)
- What are the consequences for soil fertility, measured as soil organic matter and soil nutrient status? (section 4.3)
- Has this system consequences for nutrient content of the crops? (section 4.4)
- How does the system perform with regard to the environmental parameters nitrogen leaching, ammonium emission and emission of crop protection chemicals? (section 4.5)
- What are the climate-related performances of the system, measured as CO_2 sequestration and general CO_2 footprint including methane and nitrous oxide emissions? (section 4.6)

The project, the experimental field and the registrations are not such that all these questions can be tackled in a quantitative way. If possible, calculations are presented, if not, a reasoned outcome is given. For each question the used method will be described. In this, the modelling by means of the Ndicea nitrogen and organic matter model (Van der Burgt et al., 2006) plays sometimes an important role. To account for that, the model and the model approach are introduced and evaluated in chapter 3. In this chapter a renewed system design is introduced, based on the original design (Van der Burgt, 2012) and adapted with the results of 6 year experience. This system design plays an important role in section 4.5, 4.6 and 4.7.

3 The Ndicea model and its use

3.1 Short model description

Ndicea is an acronym for Nitrogen Dynamics In Crop rotations in Ecological Agriculture. The basic aim of the model is to offer farmers and farm advisors an easy insight in nitrogen availability during the crop season. In case of use of manure When manure is used instead of artificial fertilizer, matching crop nitrogen demand by nitrogen availability becomes more complex. Last decade the interest of conventional farming in soil processes has substantially increased. Since no other tool has been developed so far, the Ndicea model is the most attractive way to gain insight in nitrogen dynamics at field level, both in conventional and organic farming. The model has been described and scientifically validated (Van der Burgt et al., 2006). The model consists of three units: a soil/water model, a soil/organic matter model and a crop model. These sub models are explained in the next sections.

Soil/water

The soil is divided in two layers: top soil and second layer. The depth of the layers can be set by the user. For depth of the top soil, ploughing depth is usually used. The depth of the second soil layer depends on maximum rooting depth. Normally the organic matter dynamics are restricted to the top soil but can be extended to the second layer. Water input, as rain or irrigation, takes place in the top soil. Soil water characteristics are available for different soil types, mainly texture-driven. Based on these soil water characteristics, water stays in the topsoil or leaches to the second layer, or from the second layer to the subsoil, leaving the model system. Water evapotranspiration takes place from the topsoil in case of a growing crop but also when the soil is bare. For each day a moisture balance is calculated and the surplus is leaching. In case of shortage, capillary rise can occur, depending on the groundwater level.
With the percolating water, nitrogen is leached from topsoil to second layer or from second layer to the subsoil. If the last mentioned process is in charge, nitrogen is lost for the farm and causes environmental pollution.

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Soil/organic matter

A scenario calculation starts with the amount of organic matter in the soil, which is defined by the % organic matter as inserted by the user. For each crop (harvest day) or manure applied (day of application) organic matter is added to the soil. For crops this is always the root mass, mostly the crop residues and sometimes the product itself (in case of a failed and ploughed-in crop). For all regular crops default data are available which the user is free to adjust. The model contains a list of regularly used manures and compost with default values for mineral and organic matter content. All soil organic matter types and quantities are in process of decay following the same decay algorithm, mainly driven by the parameter virtual age. A higher virtual age results in a slower decay process. During the process the virtual age increases, so the speed of decay of a given type of organic matter is reduced in time. The initial virtual age (and so the speed of decay at start) is different for every type of organic matter (green leaves; compost). Daily decay is dependent on temperature and soil moisture conditions (which can vary from day to day) and on soil pH and texture (which are fixed parameters for a certain time). Non-ploughing and minimal tillage reduces the overall speed of decay.

The mineralisation of nitrogen depends on the C/N ratio of the decomposed material and on the characteristics of the soil life. For this soil life, default parameters are used since the properties of the soil life in a specific field are mostly unknown.

Crop

Crop growth and nitrogen uptake are mainly driven by day of sowing, day of full growth and harvest day. Default values are available which the user might adjust. Growth itself is mainly temperature-dependent, but shortage in soil moisture at a certain day will reduce crop growth that day. The crop model is target-oriented. This means that the user inserts expected values for both yield and nitrogen content (in case of exploring a future-oriented scenario) or realised values (in case of an evaluative scenario). The model distributes this 'fixed' nitrogen uptake over the days of crop growth.

Minimum requirements

The model simulates processes at field level. For an accurate calculation of the mineralisation, scenarios of more than one year are necessary. Use of the Ndicea model in a one-year scenario does not result in more accuracy as a regular calculation of nitrogen availability. It is strongly advised to insert at least two year of history, in other words a minimum of 3 year in a scenario. Requested are data on the soil, the crops and the fertilizer applications on that specific field during that time span. For the soil, the minimum requirements are soil type, depth of the topsoil and % organic matter in the topsoil. For the crops, the minimum requirements are sowing date, harvest date and yield. The other crop parameters can be obtained from the crop database. In case of manure, the minimum dataset is type, date of application and applied quantity. In most cases the mineral content of the manure will be known and can be used. If not, default parameters can be used.

Output

The model output consists of graphs on nitrogen, water and organic matter dynamics. First requested output for farmers and farm advisors is the relation between nitrogen availability and crop nitrogen uptake. In short: if in a future-oriented scenario (with *expected* yield) nitrogen availability is lower than crop uptake, the expectation is not realistic or the model calculation is not correct. In case of an evaluation (with *realised* yield as input) an availability lower than crop demand indicates a not-correct modelling. The cause of that can be incorrect crop parameters (such as default nitrogen content instead of real nitrogen content) but also failing overall process understanding.
A check is possible on the model outcome. Measurements of soil mineral N in topsoil or second soil layer can be inserted in the model and can be compared with the calculated level at those moments. A small difference between measured and simulated values indicates a reliable model outcome.

3.2 Example: field modelling Planty Organic

To illustrate the previous sections, the Ndicea output of Planty Organic field A is given below.
In Figure 1 the consecutive crops and the applied fertilizers are shown.

Figure 2 shows the nitrogen availability (green) and the demand (red). For a proper modelling the green line should always stay above the red one.
In Figure 3 the simulated level of soil mineral N in 0-30 cm (green line) and 30-60 cm (blue line) are given and can be compared with the measured values (green bullet, blue triangle). The model result is supposed to be ‘better’ when the lines are close to the measurements. See for further details section 3.3.
In Figure 4 the nitrogen leaching is shown. This is the nitrogen leaching with percolating surplus water from the second soil layer (30-60 cm), which is lost for the system. For each new crop the line is reset at zero.
In Figure 5 the modelled level of soil organic matter is compared with the measurements. The 2014 measurement seems to be exceptional, which was the case in all fields. This is more likely due to deviations in soil sample taking or analysis than to the agronomic reality.

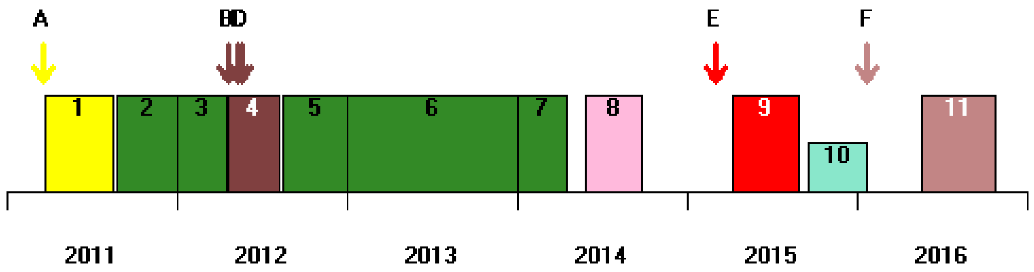

Figure 1: Crops and fertilizers of field A
1 = Oats; 2,3 = Grass-Clover; 4 = Potatoes; 5,6,7 = Grass-Clover; 8 = Squash; 9 = Field bean; 10 = Yellow mustard; 11 = Carrot; A = Dairy slurry; B,C,D,E,F = cut-and-carry fertilizer

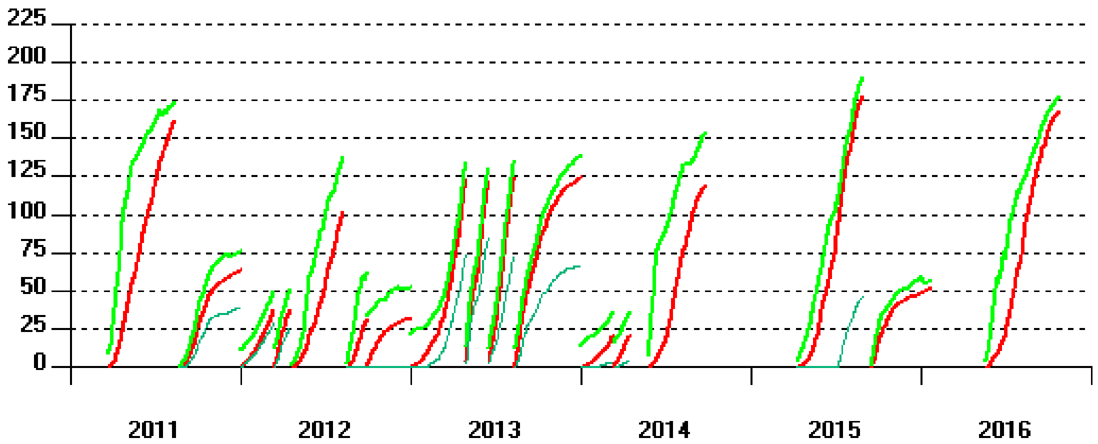

Figure 2: Available nitrogen and crop uptake
y-axis: kg N per hectare. Green: available nitrogen. Red: crop uptake. Blue-grey: N-fixation by leguminous crop

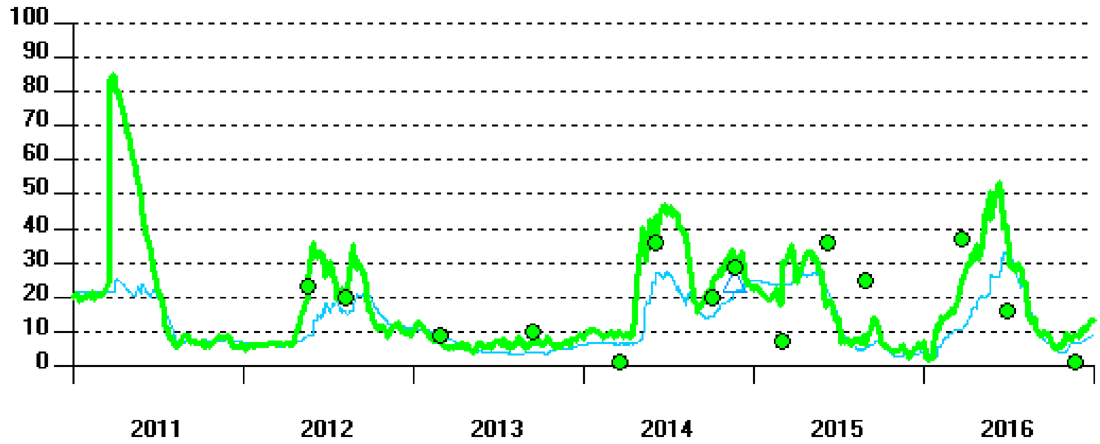

Figure 3: Simulated and measured levels of soil mineral nitrogen
y-axis: kg N per hectare. Modelling: green line = 0-30 cm ; blue line = 30-60 cm. Measurements: green dot = 0-30 cm; blue triangle = 30-60 cm.

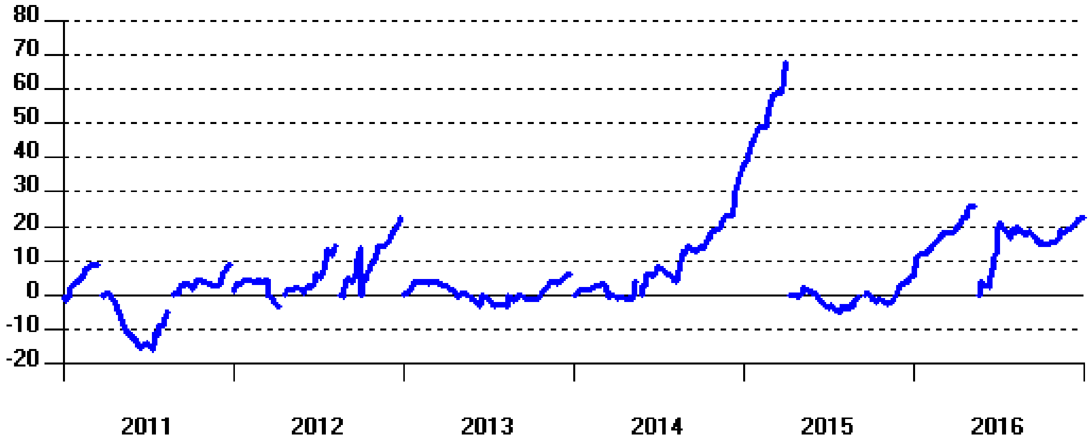

Figure 4: Nitrogen leaching, cumulative for each crop
y-axis: kg N per hectare.

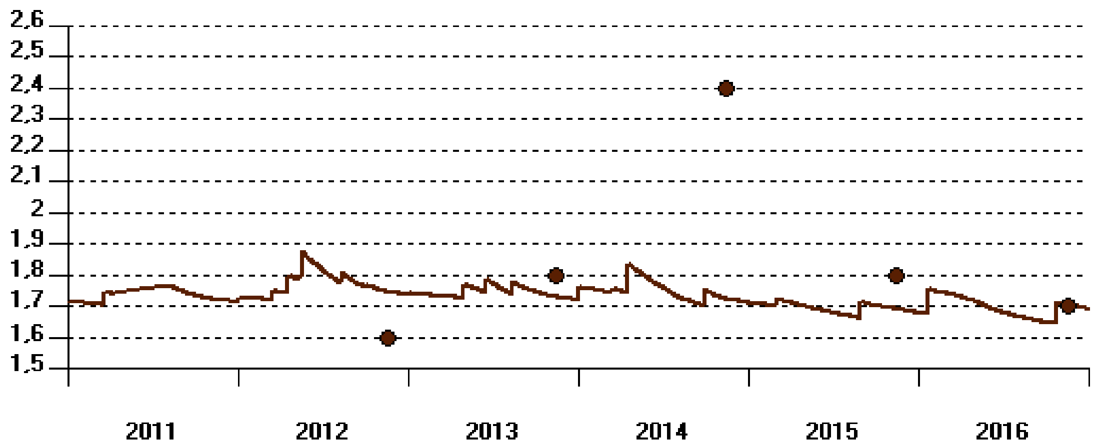

Figure 5: Organic matter in topsoil (0-30 cm)
y-axis: % organic matter in 0-30 cm

3.3 Model performance of Planty Organic scenarios

Model performance in general

Performance criteria are set for rating the model. Within the Ndicea model there are options for a check on three measurements: pF of the topsoil, topsoil organic matter and soil mineral N in topsoil and second soil layer.
Mostly pF is not measured. The soil water dynamics in Ndicea is not validated separately.
Soil organic matter content is more often measured. Measured values can be inserted in Ndicea and compared with the simulated level at the same moment. Unfortunately the used method for soil organic matter content has an uncertainty of plus or minus 15%, according to the Eurofins Laboratory, Wageningen. Changes in soil organic matter or often much smaller than this uncertainty, so rating of the Planty Organic model scenarios on soil organic matter is not possible. Nevertheless there are methods with a much more accurate outcome, so with renewed analysis a rating by means of soil organic matter might be possible.
The soil mineral N level in topsoil and second soil layer can be measured on several moments and compared with the simulated level. These measurements have an uncertainty of only a few percent and differences from one to another measurement can be substantial. This makes soil mineral N to a suitable parameter for scientific validation of the model (Van der Burgt et al., 2006) and judgement of scenario performance.
For the rating of a series of simulation-measurement duos of soil mineral N the RMSE Root Mean Squared Error is used:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(sim - obs)^2}{n}}$$

n = number of soil mineral N measurements
sim = simulated value at the time of measurement i
obs = value of measurement i

In the scientific validation of the model a RMSE of 20 kg N per hectare is proposed as critical value for a good model performance (RMSE <= 20) or an insufficient performance (RMSE > 20). A perfect simulation has an RMSE of 0 kg N per hectare, which means that measured and simulated values are exactly the same in all measurements.
Besides the RMSE it is of importance to look at the direction of the shown differences between simulation and observation: does the model at average overestimate or underestimate the soil mineral N level? This aspect can be used for improvement of this specific scenario performance.

Rating of the Planty Organic scenarios

There are six fields in the experiment, each with their own model scenario. If measured values of mineral content and dry matter content were available, these values (here mostly product and fertilizer characteristic) are used. If not, the default data within the model are used. For the soil the default parameters for this soil type are used, with one exception: the parameter for nitrogen fixation. This parameter is a threshold parameter: if soil mineral N decreases below this level, leguminous crop maximize their N fixation. In other words: if this parameter is set at a low level, leguminous crops will with preference take up soil mineral N until the level has gone down to this threshold value. The default value in Ndicea is 15 kg soil mineral N per hectare in the topsoil. Most

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measurements in the grass-clover and the alfalfa-clover swards are below ten kg, many times around five and sometimes almost zero. This might indicate that the default value is too high. For this modelling work it has been set at 5 kg N per hectare

The scenarios' rating according the RMSE and the direction of the deviation are listed in Table 1. Four out of six scenarios have an RMSE lower than 20; the fields C and F have a higher RMSE. There is no systematic direction of the deviation between observed and simulated values.
Nor from modelling or agronomy there is a simple explication why fields C and F seem less well described by the model: starting conditions and treatment or are very similar for the six fields. It is remarkable that almost all measurements on all fields have a value less than 40 kg N per hectare; at field C and F four measurements each are much higher. This might be caused by unknown processes and thus a wrong modelling or it can be attributed to unexpected deviations in the measurements. This cannot be decided upon. The complete set of simulated and observed values is given in appendix 1.

Table 1: RMSE and direction of deviation of soil mineral N

Perceel	n	RMSE	# Obs<Sim	# Obs>Sim
A	15	12	7	8
B	19	15	6	13
C	20	34	8	12
D	20	17	11	9
E	16	19	7	9
F	20	36	13	7

n = number of measurements in 5 years; RMSE = Root Mean Squared Error of soil mineral N observed versus simulated; # Obs<Sim = number of measurements lower than the simulated outcome; # Obs>Sim = number of measurements higher than the simulated outcome

3.4 Farm design 2

As can be seen in section 3.3 the field scenarios are good enough to formulate conclusions on soil nitrogen dynamics. To increase the insight in the nitrogen and organic matter dynamics a next step has been taken. In the beginning of the project a farm design has been published (Van der Burgt, 2012) which has been elaborated into a schematic Ndicea scenario. Now a new farm design 2 has been formulated, based on the experiences of the last five years and the six Ndicea field scenarios. This design is transformed in one future-oriented Ndicea scenario. This has been done based on the following assumptions:

- The main set-up is unchanged; the crops are corresponding with the crops grown in 2015 and 2016.
- The yields in farm design 2 are the average yields of the crops of 2014 – 2016
- Crop nutrient content is, as far as measured, average values from 2014 – 2016; otherwise the default Ndicea data are used
- Dry matter yield and nutrient status of the alfalfa-clover crop is a weighted average of results in 2014 – 2016, with each year three cuts with different yield and nutrient content.
- The yield of the full-year alfalfa-clover crop is equal to the amount of cut-and-carry fertilizer applied.

- The cut-and-carry fertilizer applications are chosen in such a way that the nitrogen dynamics over the complete cycle is optimized. This is iteratively explored and does *not* correspond with fertilizer application practice of the last years .

The adapted farm design 2 is given below (Figure 6)

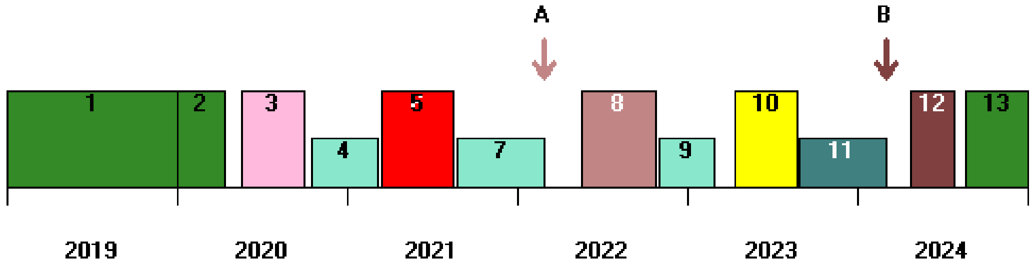

Figure 6: Crops and fertilizer applications in Plant Organic farm design 2

1 = alfalfa-clover, yield 9.500 kg d.m. with 3% nitrogen in the d.m. (for cut-and-carry fertilizer))
2 = alfalfa-clover, estimated 1.500 kg d.s. incorporated in the soil with 3% nitrogen in the d.m.
3 = squash, yield 18.000 kg fresh weight (18,3% d.m.) with 1,52% nitrogen in the d.m.
4 = rye green manure, 1.200 kg d.m. incorporated, with 2,60% nitrogen in the d.m. (default value, not measured)
5 = Field bean / spring wheat mixed culture, Field bean yield 2.500 kg (85% d.m.) with 4,71% nitrogen in the d.m.; spring wheat yield 1.000 kg (85% d.m.) with 2,00% nitrogen in the d.m.
7 = cereal green manure, 1.700 kg d.m. incorporated with 2,60% nitrogen in the d.m.
8 = carrots, yield 62.000 kg fresh (10,4% d.m.) with 1,10% nitrogen in the d.m.
9 = rye green manure, 1.200 kg d.m. incorporated with 2,60% nitrogen in tee d.m. (default value, not measured)
10 = oats, yield 4.500 kg (85% d.m.) with 1,76% nitrogen in the d.m.
11 = vetch green manure, 1.800 kg d.m. incorporated with 4,00% nitrogen in the d.m. (default value, not measured)
12 = potato, yield 30.000 kg (21% d.m.) with 1,28% nitrogen in the d.m.
13 = alfalfa-clover, estimated growth in the autumn 1.500 kg d.m. with 2,60% nitrogen in the d.m.
A = cut-and-carry fertilizer, 5.000 kg d.m. with 3,00% nitrogen in the d.m.
B = cut-and-carry fertilizer, 4.500 kg d.m. with 3,00% nitrogen in the d.m.

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4 Method and results

4.1 Feasibility

Many daily practices in the Planty Organic experimental field are comparable to those in conventional arable farming. Even the no-ploughing system is becoming more mainstream and less exceptional. New is the spreading and incorporation in the soil of the cut-and-carry fertilizer.

The cut-and-carry fertilizer is stored as sealed package. The package is opened and put in a solid manure spreader, distributed on the field and smoothly incorporated in the soil a couple of weeks before sowing or planting. It has shown important that the cut-and-carry fertilizer can immediately start its process of decay to prevent obstacles for ridge-building or sowing. At the start of the project it was a question how much dry matter of the cut-and-carry fertilizer could be processed in the soil superficially.
Five years of experience have learned that the soil can manage quite an amount. It has been shown profitable to store the alfalfa-clover cut-and-carry fertilizer at a higher moisture content than a dairy farmer would do, to enhance the decomposition in spring.

The initial farm design included cauliflower. After two years this crop has been replaced by squash. This system cannot deliver a high level of available mineral N in Spring, as requested for the cultivation of cauliflower. Squash, with a lower nitrogen demand spread over a longer period, has proven to be a more suitable crop.

The crop for harvesting the cut-and-carry fertilizer has been adapted during time. To harvest as much nitrogen as possible, the grass-clover mixture has been replaced by a pure leguminous mixture including alfalfa. Nevertheless, at sowing after potatoes some wheat is added to the leguminous seeds mixture. Because the wheat goes initially faster than the leguminous plants a substantial initial growth is realized, thus catching the remaining nitrogen after the potato harvest, both left-over (if any) and freshly mineralized. After the first cut an almost pure leguminous crop persists.

In the first years, part of the harvested cut-and-carry fertilizer was processed into pellets. This practice is not continued. The expected benefits (efficient and effective nitrogen supply) did not show that much and the price and energy demand for processing the green mass into pellets is high. Also in the first years it is tried to use the first cut of the cut-and-carry fertilizer directly and freshly-cut on another field. This practice is abandoned too; the timing rarely fits and the organisation is demanding.

A point of attention was the mixed Field bean Spring wheat culture. With regard to weed control, both crops must be placed in the same row, inducing the risk that the fast-developing bean suppresses the wheat. Sowing these two crops at the same time in one run will induce this risk and showed complicated because of separation of the different-sized seeds in the storage bin of the seeding machine. The solution for this dilemma was found in two consecutive activities, first sowing the beans, than sowing the wheat in the same row but less deep than the beans. This is possible due to the GPS technique with fixed driving lanes. An attractive alternative would be a double sowing system on one tractor, saving time and fuel.

The produce, a mixture of beans and wheat, could be used as fertilizer or as fodder, or it could be separated and sold for human consumption. So far, the second way has been followed. It would be interesting to develop a system for cultivation (beans fit for human consumption, compatible cultivars, optimized cultivation technique) and separation of the produce after harvest to realize the full profit of such a mixed culture.

4.2 Yield level

The yields as expected in farm design 2 (see section 3.4) are shown in Table 2.

Table 2: Expected yield

	Crop	Yield kg/ha	Corrected yield kg/ha
1	Squash	18000	15000
2A	Spring wheat	1000	833
2B	Field bean	2500	2083
3	Carrot	62000	51667
4	Oats	4500	3750
5	Potato	30000	25000

In the last column the yield is corrected for the fact that for this production on five hectares an additional hectare is needed for the production of the cut-and-carry fertilizer. The yield per hectare, including this hectare for soil fertility and nitrogen input, is 17% lower.
These corrected yield data are interesting if you want to know how much land surface is required for this production. For a comparison with other organic arable farm the uncorrected data can be used: the 'area needed for manure production' is normally not taken into account. Comparing the data with conventional arable farming the corrected yield data could be used, combined with the energy demand for artificial fertilizer production. A fair comparison of these two should take place by means of a life cycle analysis or total footprint calculation which is beyond the realm of this report.
The Planty Organic system is clearly nitrogen-limited (see Figure 7). A substantial increase of the yield level within the boundaries of the system cannot be expected. Higher yields are surely realized on other organic farms, but the nitrogen dynamics and the losses to the environment will also be different.

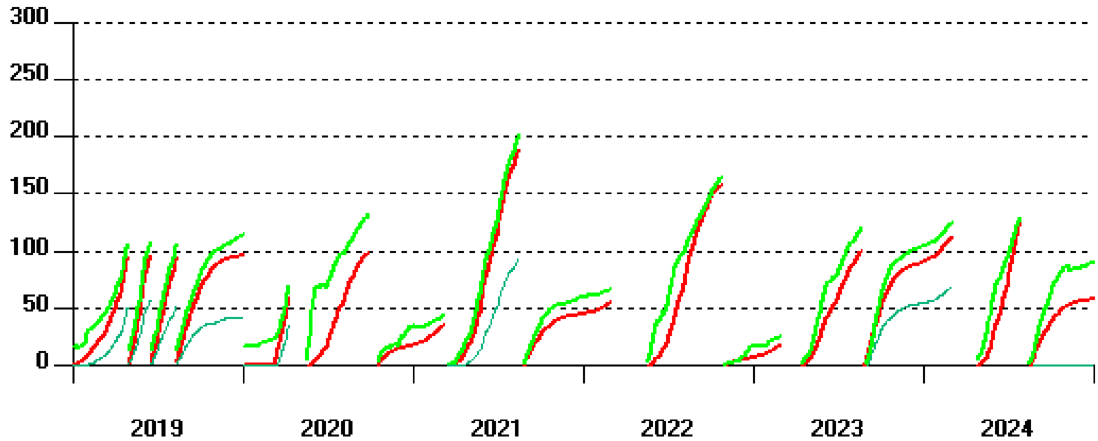

Figure 7: Available nitrogen and crop uptake in farm design 2.
Y-axis: kg N per hectare. Green: available nitrogen. Red: crop uptake. Blue-grey: N-fixation by leguminous crops

4.3 Soil fertility

Each year after harvesting the last crop, soil samples have been taken and analysed. The results are published in the year reports (van der Burgt 2012; Hospers et al., 2014a, 2014b, 2015, 2017). Since 2014 this is the same set of parameters each year; in 2012 and 2013 less parameters have been analysed. Due to this, the evaluation of the soil is sometimes based on data from 5 years but sometimes on data from 4 or three years. For the evaluation of crop parameters average data from 5 years and 6 fields are used.

Soil organic matter

The change in soil organic matter is shown in Figure 8.

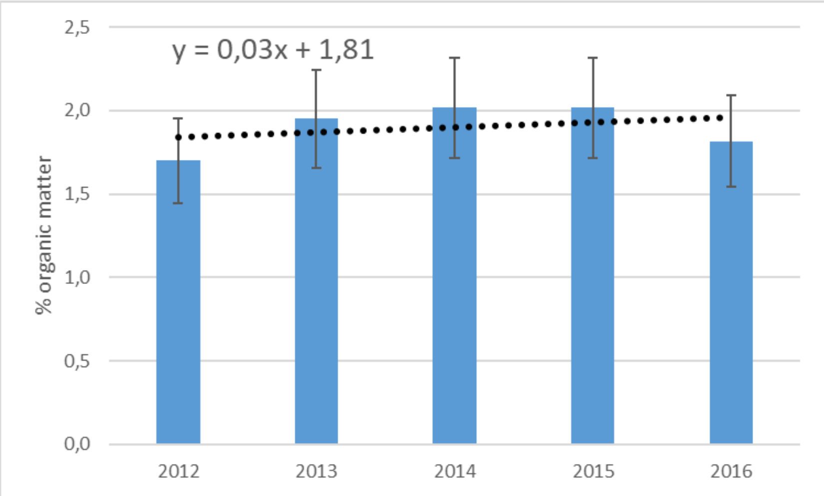

Figure 8: Measured soil organic matter content, 0-30 cm

The error bar is based on a statement from the Wageningen Eurofins laboratory, being 15% of the measured value. The trend line is slightly positive, but due to the measurement error nothing can be concluded about changes in soil organic matter.

The model outcome of the soil organic matter of six fields (Table 3) shows minor variations which can be caused by yearly differences in yield (and crop residue), by differences in the amount of applied cut-and-carry fertilizers and by small changes in the crop rotation. On average, the model result shows an almost stable soil organic matter.

Table 3: Simulated soil organic matter content

	January 2011	November 2016
	%	%
A	1,72	1,69
B	1,72	1,72
C	1,91	1,92
D	1,91	1,88
E	1,91	1,85
F	1,91	1,95
Average	1,84	1,83

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Soil nutrient status

In absence of any input it could be expected that the soil nutrient stock will decrease. A set of soil parameters has been analysed since 2014; 2012 and 2013 have a different set (Table 4). To gain insight in structural changes over time all parameters are indexed at 100 being the average over five year (in some cases three or four years). Since the error of the parameter value is unknown, a decent analysis of the data is not possible. Explored is the presence or absence of tendencies (increase of decrease over time) and coincidence of this for several parameters. It appears that a general tendency is absent. At a maximum of abstraction, all indexed parameters are put together except for C/N , C/S, and % clay, silt, sand. The thought behind this approach is: higher values indicate a higher soil fertility. The result is presented in Figure 9.

With these results in mind nothing can be definitely concluded about improvement of soil fertility. A question might rise about the accuracy of the laboratory measurements. It is very unlikely that the 2014 values are at average 6% higher than the 2013 and 2015 values. There is only one parameter with a clear and substantial increase - soil life - but this is only measured in 2014-2016.

A selection of the indexed parameters is given in appendix 2. Those are the graphs only with a smaller or clearer tendency. In accordance with Figure 9 some graphs shown an increase and others a decrease. In the future the development of the soil fertility might become clear.

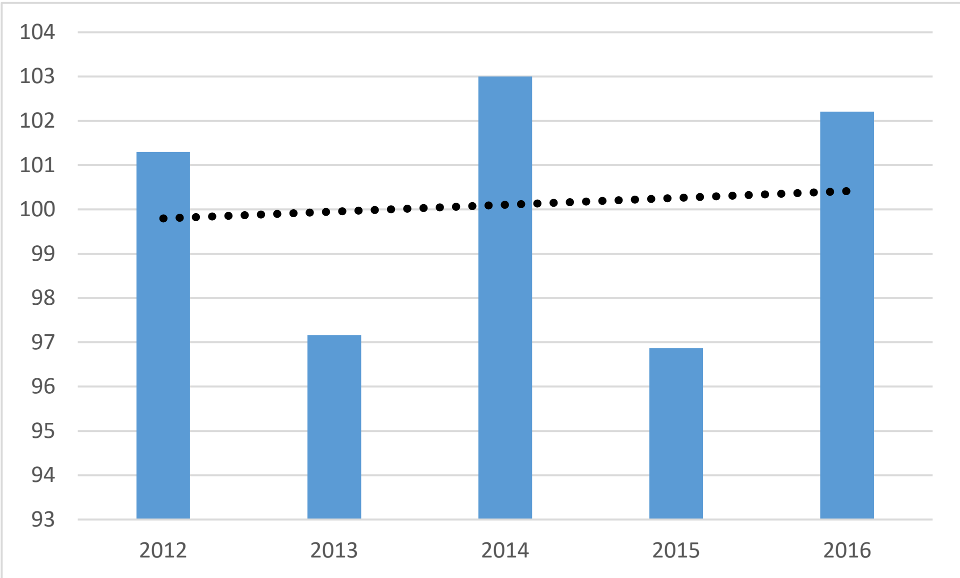

Figure 9: Indexed average of all soil parameters

Table 4: Analysed and calculated soil parameters, each indexed on average = 100

Parameter	unit	2012	2013	2014	2015	2016
N-total	mg N/kg	117	92	100	97	95
C/N-ratio		87	107	102	104	100
N-delivery capacity	kg N/jaar	118	90	100	97	95
S-total (1)	mg S/kg		97	93	108	101
C/S-ratio (1)			104	110	98	89
S-delivery capacity (1)	kg S/jaar		98	93	104	105
P-PAE	mg P/kg		102	94	90	114
P-AL	mgP_2O_5/100g	98	104	103	97	97
Pw	mgP_2O_5/l	83	118	114	90	94
K (1)	mg K/kg		118	116	92	73
K (1)	mmol+/kg		95	112	95	98
Ca (2)	kg Ca/ha					
Ca-soil supply (1)	kg Ca/ha		93	102	103	102
Mg	mg Mg/kg	100	109	115	101	76
Na (2)	mg Na/kg					
Si (1)	µ Si/kg		84	112	94	111
Fe (2)	µ Fe/kg					
Zn (2)	µ Zn/kg					
Mn (2)	µ Mn/kg					
Cu (2)	µ Cu/kg					
Co (2)	µ Co/kg					
B (1)	µ B/kg		102	124	89	85
Mo (1)	µ Mo/kg		77	86	79	157
Se (1)	µ Se/kg		77	93	92	138
pH		103	98	99	98	101
C-organic (1)	%		102	106	102	90
Organic matter	%	89	103	106	106	96
C-inorganic (1)	%		92	108	100	99
$CaCO_3$ (1)	%		92	109	100	99
Lutum (3)	%			104	102	94
Silt (3)	%			101	106	93
Sand (3)	%			98	97	105
CEC (3)	mmol+/kg			100	101	99
CEC-occupation (3)	%			99	101	99
Soil life(3)	mg N/kg			83	91	126

(1): not measured in 2012
(2): one or more years with values below detection level
(3): not measured in 2012, 2013

4.4 Nutrient content crops

Market crops

Most of the years the N-P-K status has been analysed. Since 2014 much more nutrients have been analysed and published in the year reports. In some cases a mistake has occurred, presenting P and K data but mentioning P_2O_5 and K_2O in the header of the tables. In appendix 3 the correct data are given for all years.
In absence of nutrient input a decrease in crop nutrient content might be expected. However, there is no sign of this decline. The result of all nutrients indexed on 100 being the average over the years, and all nutrients put together, is presented in Figure 10. Changes over the year are considerable, and the trend is an *increase*, not a *decrease*.

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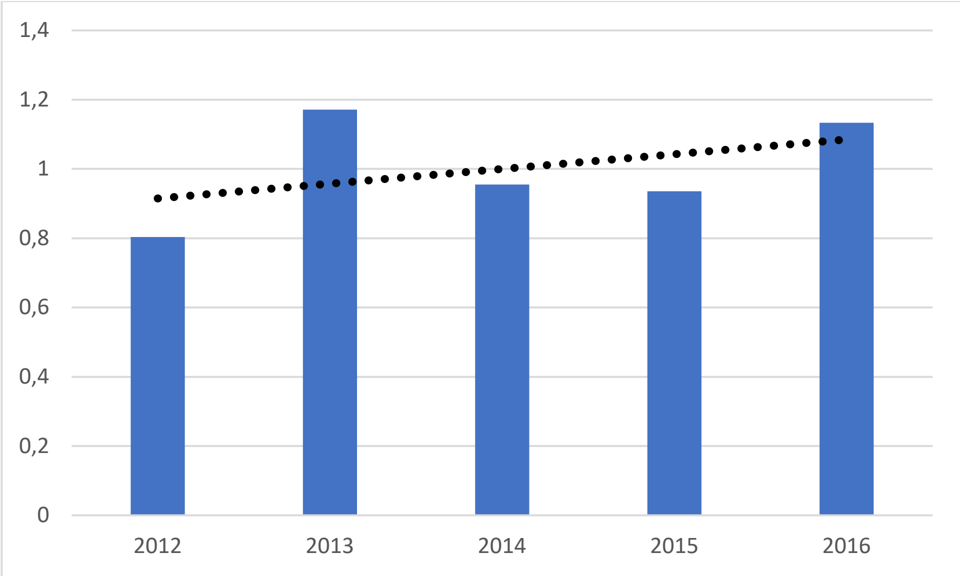

Figure 10: All nutrients, average value indexed as 100

More in detail (see appendix 2) only in the case of the micro-nutrients Fe and Mn (only measured in 2014 – 2016, and only in potatoes, carrots and squash being cultivated in those three years) there is a consequent *increase*. Most parameters don't show a consequent changes, and there are some with an overall decrease.
It is concluded that the crop nutrient content is not decreasing.

Cut-and-carry fertilizer crop

The crop management of the cut-and-carry fertilizer crop was as follows. A mixture of leguminous seeds and grasses or cereals is sown as soon as possible after the potato harvest. The following year three (or four) times the sward is cut and stored in sealed packages. In the first two years a part of the harvested green matter was processed into pellets. The advantages are much less mass to distribute in the field, a much higher nitrogen content per kg of fertilizer and the possibility to put the pellets in the plant row only. The degree of freedom of this nitrogen is high (Van der Burgt, 2008). Also during the first years the first cut was not harvested in packages but directly spread on another field. That saves the expenses of package-making and transport to the storage area. Both methods are not continued: the first because of too high expenses and too less positive effect, the latter because of a too complex organisation request.
In the year following the full-use year, the first and only cut is not removed but incorporated in the soil as fertilizer. In 2012 and 2013 this following crop was cauliflower, in the other three years it was squash. In total the cut-and-carry sward grows during almost one and three quarter year (September – April), but it displaces only one commercial crop.
Together with the leguminous green manure and one leguminous crop (Field bean) the cut-and-carry fertilizer sward is the nitrogen engine of the system. Both yield and nitrogen content are crucial. The search for the best fitting combination of species and varieties is ongoing.
Yield performance and nitrogen content are mentioned in the year reports. They show variation, with sometimes disappointing low nitrogen content (2.6% N in dry matter), but sometimes 3.2% N in an alfalfa-clover mixture. The first cut mostly has a lower nitrogen content than the second and third, which is a normal pattern. This part of the Planty Organic system is still in development, but we think 9.5 tons of dry matter with 3.2% Nitrogen in the dry matter must, at average, be achievable as harvest for cut-and-carry fertilizer production. In 2016 this is indeed realized.

4.5 Environmental parameters

Nitrogen leaching

In the five years of this evaluation no measurements on nitrogen leaching have been taken place. This section is based by means of the farm design 2 as it is modelled in Ndicea, see section 3.4.
In Figure 11 the simulated nitrogen leaching is shown. The average leaching from the second soil layer to the subsoil is 18 kg nitrogen per hectare and per year. Nitrogen deposition is supposed to be 28 kg nitrogen per hectare and per year. This means that the Planty Organic system is able to profit from the deposited nitrogen; the systems functions as a cleaning system for precipitation water.

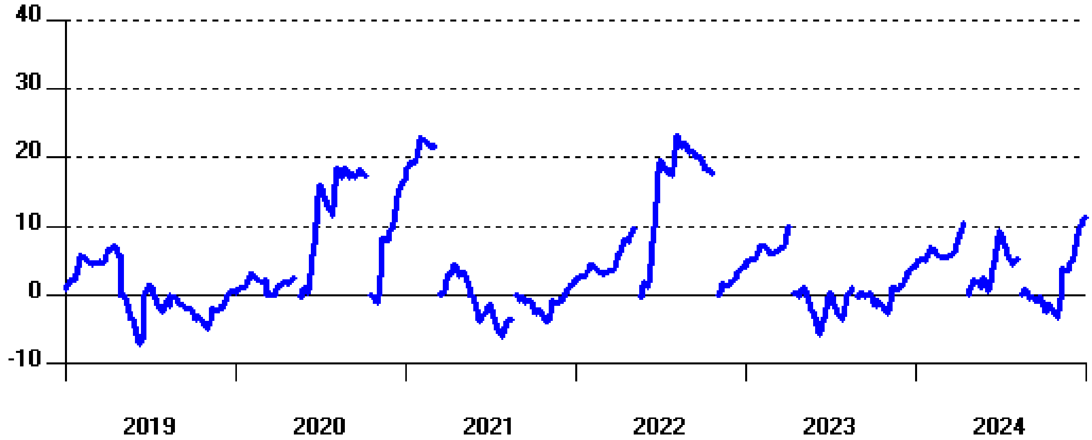

Figure 11: Cumulative nitrogen leaching
y-as: kg N per hectare. De blue line is reset at zero each time when a new crop starts growing.

With two assumptions a rough estimate can be made from the nitrogen content of the water that is added to the uppermost groundwater layer:

- If 18 kg are lost, four or more kg might disappear by the process of denitrification before ground water is reached (very rough estimate, based on Jahangir et al., 2012; Zwart, 2003)
- There is a yearly rainfall surplus of 450 mm

This results in a groundwater nitrogen content of a bit more than 3 mg nitrate-N per litre. That is far below the maximum EU-level, 11 mg nitrate-N per litre as mentioned in the European Nitrate Directive (Ann. 2010).
The conclusion is that the nitrogen leaching of this system is expected to be very low; the system nitrogen losses to the groundwater are lower than the nitrogen incoming by deposition.

Ammonia emission

Fresh manure in stable, storage and spreading in the field are by far the most important sources of ammonia in agriculture. In the Planty Organic system no manure is used. On a very low level ammonia emission occurs during crop growth and during crop residue decomposition. This is not measured and is no part of the Ndicea model. The quantities are expected to be very low (van Bruggen et al., 2015).
The conclusion is that ammonia emission is expected to be nihil. This means that the contribution of this system to nitrogen deposition elsewhere is nihil too.

Crop protection product remnants

The Planty Organic farming system is an organically managed system. During the five years evaluation period no (in organic agriculture allowed) products have been used.
The conclusion is that the emission is zero.

4.6 Performance in climate related parameters

CO_2 sequestration

In the soil CO_2 can be stored as organic matter. This is a dynamic process of adding and decay in which (temporary) organic matter is added to the organic matter supply. In this way, CO_2 is withdrawn from the atmosphere. As shown in section 4.3 there might be an increase in soil organic matter in the Planty Organic farming system of about 0.03% per year. With a supposed bulk density of 1.4 kg/l (Zwart et al., 2013) and calculating with 30 cm topsoil, the organic matter supply is 76 tons per hectare. An increase of 0.03% means that 1260 kg organic matter is added each year to the soil. With the assumption that 58% of the soil organic matter is carbon, some 2700 kg CO_2 is sequestrated per hectare per year. This is temporary performance; the speed of sequestration will decrease until a new equilibrium has been reached. The actual organic matter content of 1.8 – 1.9% is already close to the expected (modelled) equilibrium level.
The conclusion is that, if the model outcomes are reliable, there is a limited potential CO_2 sequestration. A more accurate measurement of the historic and actual soil organic matter content could clarify this uncertainty.

Methane and nitrous oxide emission

No methane or nitrous oxide emissions have been measured or modelled in the Planty Organic plots. The emissions can be expected to be very low. Emissions of these gasses are increased in case of anaerobic soil conditions, as is the case with denitrification. The denitrification process is part of the Ndicea model. Figure 12 shows the denitrification, cumulative for each year. The average is 9 kg N per hectare per year. That is a low level, explained by the on average very low levels of soil mineral nitrogen in the topsoil (see Figure 3).

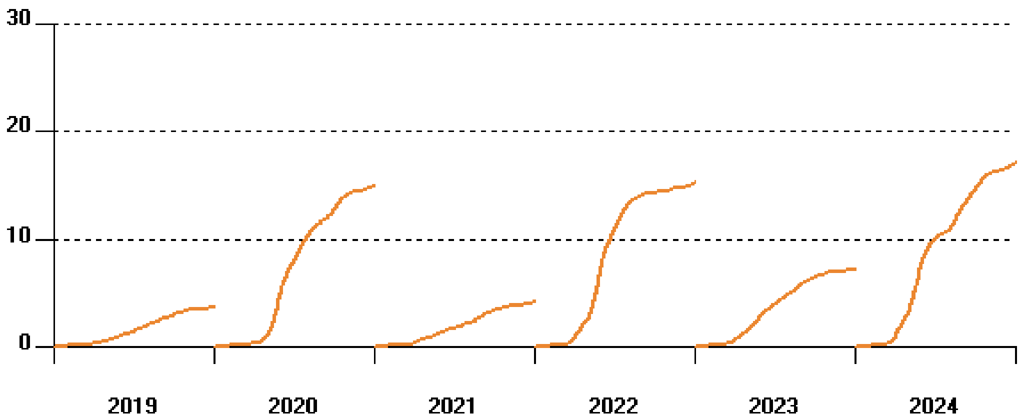

Figure 12: Denitrification in the top soil
y-axis: kg N per hectare, per year cumulative

Fuel usage

Ploughing requires a lot of fuel. However, in a non-ploughing system a lot of other tillage practices are needed. The construction of the total CO_2-balance of the system is beyond this evaluation but is very interesting:

- Is the fuel saved by non-ploughing counterbalanced by extra fuel use in other (extra) tillage practices?
- What is the impact of the non-use of manure? This comes to the question where the CO_2 impact of manure production is accounted: in the dairy sector or in the arable production system.
- The CO_2 impact of the production of artificial nitrogen fertilizer plays no role in this system, but in a comparison with conventional agriculture it does.

4.7 Internal processes

The computer simulations of farm design 2 enables a detailed view on the internal processes such as the course of nutrients and organic matter within the production system. This exercise becomes more profound if it could be compared with a conventional arable farming system. For this, a conventional farming system has been defined and simulated in Ndicea, based on the experiences of the Kollumerwaard experimental farm (personal communication Philip Kramer, farm manager). The Planty Organic farm design is presented in Figure 6; the conventional farming system in Figure 13.

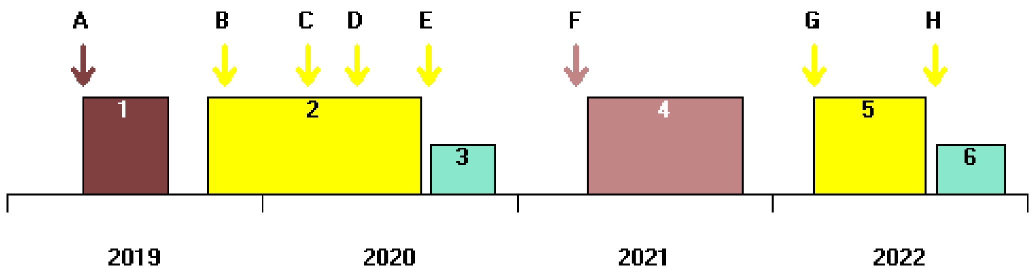

Figure 13: Crops and fertilizer, regular arable farming system in

1 = Seed potato, yield 35.000 kg (20% d.m.) with 1,57% nitrogen in de d.m.
2 = Winter wheat, yield 9.500 kg (85% d.m.) with 2,1% nitrogen in de d.m.
3 = Fodder radish, 2.200 kg d.m. incorporated in the soil with 2,3% nitrogen in de d.m.
4 = Sugar beet, yield 80.000 kg (21,8% d.m.) with 0,55% nitrogen in de d.m.
5 = Spring barley, yield 7.000 kg (85% d.m.) with 1,76% nitrogen in de d.m.
6 = Yellow mustard, 2.200 kg d.m. incorporated in the soil with 2,1% nitrogen in de d.m.
A = Artificial fertilizer N-P2O5-K2O 78-70-200
B = Artificial fertilizer N-P2O5-K2O 100-0-0
C = Dairy slurry N-P2O5-K2O 102-38-145
D = Artificial fertilizer N-P2O5-K2O 50-0-0
E = Artificial fertilizer N-P2O5-K2O 40-0-0
F = Artificial fertilizer N-P2O5-K2O 140-100-140
G = Artificial fertilizer N-P2O5-K2O 80-20-0
H = Artificial fertilizer N-P2O5-K2O 40-0-0

Mineral balance

The mineral balance of both systems is given in Table 5.

Table 5: Mineral balance of Planty Organic and conventional system

	Planty Organic			Conventional		
	N	P2O5	K2O	N	P2O5	K2O
Fertilizer supply	0	0	0	158	57	121
N-fixation	68			0		
Deposition	28	3	8	28	3	8
Total supply	96	3	8	186	60	129
Removal with products	64	32	94	120	60	145
Calculated surplus	32	-29	-86	66	0	-16
Volatilization	0			7		
Denitrification	10			14		
Leaching	18			45		
Soil stock	4			-2		

Nitrogen supply in the Planty Organic system consists of nitrogen fixation; an additional area of 17% is required. The nitrogen supply in the conventional systems is realized by artificial fertilizer, made possible by the use of fossil fuel.
The Planty Organic production, expressed as nitrogen in sold produce per hectare, is half the amount of the conventional production. On return, the nitrogen surplus in the conventional system is twice as big. The environmental impact of the Planty Organic system (volatilization and leaching) is much lower than in the conventional system, but both systems fulfil he European Nitrate Directive. The soil nitrogen stock shows a small plus in Planty Organic whereas the conventional system is slightly negative.

Internal nitrogen processes

In the Planty Organic system average nitrogen uptake by crops is 234 kg N per hectare whereas in the conventional system the uptake is 212 kg. The uptake in Planty Organic is higher, although not much higher. This is partly caused by a higher presence of growing plants in the Planty Organic system: green cover during 82% of the time versus 69% in the conventional system. However, the presence of leguminous plants with a high nitrogen content has more impact (alfalfa, clover, vetch, field bean) in the Planty Organic system.
Contrary to the almost equal uptake, the destination of the plant nitrogen content does show a big difference between the two systems (Figure 14).

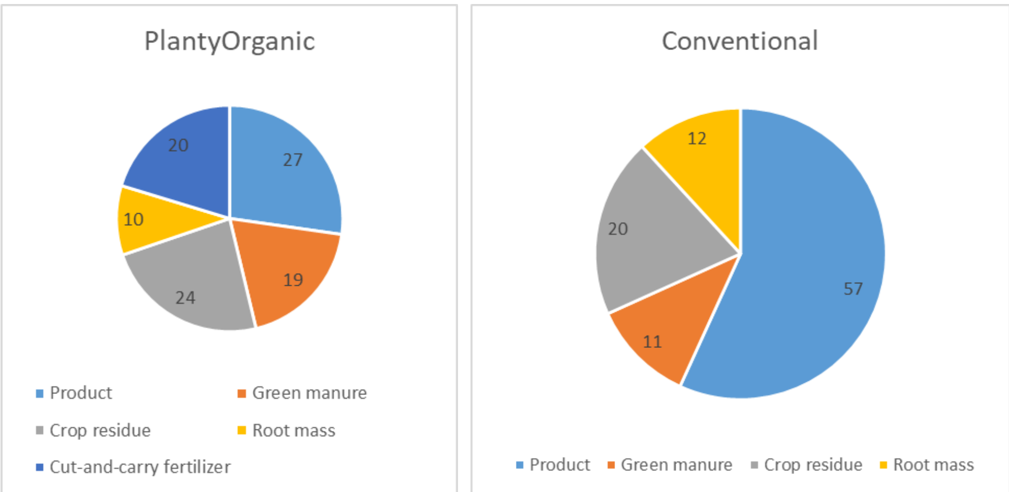

Figure 14: Destination of nitrogen content in %

In the conventional system more than half of the yearly nitrogen content (57%) is taken out of the system by selling produce. In the Planty Organic system this is only 27%, the other 73% being part of the nitrogen cycle delivering nitrogen to future crops.

Nitrogen efficiency

In the Planty Organic farm design 2, an amount of 96 kg N per hectare is added on average each year to the system: 68 kg N by means of N-fixation and 28 kg by deposition. In the conventional system this is double the amount: 186 kg. The destination of the annual nitrogen supply is given in Figure 15.

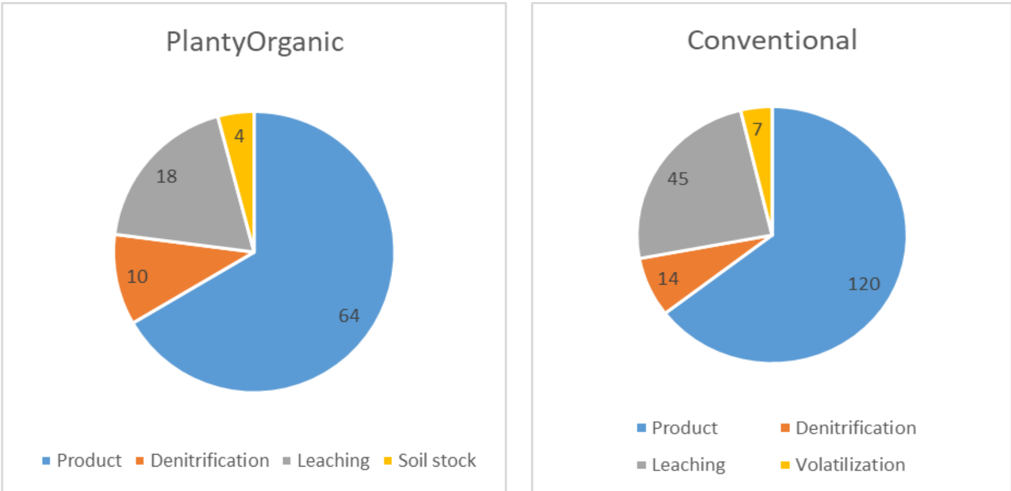

Figure 15: Destination of yearly nitrogen supply, kg N/ha

In the Planty Organic system 64 kg (69%) of the yearly nitrogen supply results in product-N whereas in the conventional system this is 120 kg (65%). The Planty Organic system is a bit more efficient with regard to nitrogen input and product nitrogen output. The losses in the Planty Organic system are 28 kg (31%) and there is a small gain in soil N stock: 4 kg (4%). For the conventional system the losses are 66 kg (36%) and soil N stock is a little bit reduced (Table 5). So the *pattern* of nitrogen utilization and losses is more or less comparable between the two systems, Planty organic being a bit better than the conventional system, but *expressed in kg N per hectare* the losses in the conventional system are twice as much as in the Planty Organic system. It gives the impression that a choice for a high internal turnover of organic matter and nutrients (cut-and-carry fertilizers, green manures, crop residues) does reduce the direct production potential but also considerably reduces the nitrogen (and other nutrients?) losses. This can be investigated more thoroughly.

Calculating the nitrogen efficiency in the usual way ("farm gate") the Planty Organic system has an infinitely large N-efficiency since no nutrients are purchased. Another approach includes nitrogen fixation in the calculation, not nitrogen deposition. In this calculation the nitrogen efficiency is 94%. This is presumably the highest efficiency ever measured in field scale experiments in the Netherlands.

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5 Discussion

Production

The production level of the Planty Organic arable system is comparable to other organic farms (Minderhout en Troost, 2008; www.biowad.nl ; Rijswick en Pals, 2006; www.cbs.nl). If taken into account the requested area for nitrogen fixation and other soil quality improvements, the production is 17% lower. On the other hand, almost no external costs are connected to this system, the external costs of fossil fuel being the exception (Bos et al., 2007). Unfortunately the prevention of external costs and the care for societal benefits is not yet paid for.
Measures focussing on higher yield potential within the system's conditions can be carried out, but no big effects can be expected with one exception. The system is most likely nitrogen-limited, and a substantial increase in nitrogen availability is hardly possible. This is discussed below..

N-fixation

Increase of the nitrogen fixation is to a limited extend possible by an increase of the cut-and-carry fertilizer yield. The expected average yield of 9.5 tons dry matter with 3% nitrogen content might be increased a bit. The field bean has, so far, shown a rather low yield. A higher average yield would increase the nitrogen fixation. There are four green manures in het farm system design, but only one of them contains a leguminous species (after oats harvest). Being sown after squash or carrot, it is too late in the season to use a leguminous crop. After the field bean / spring wheat cultivation, the stubble can be undisturbed with the bean continuing its growth and thus the nitrogen fixation. That saves time and costs for soil cultivation and seed purchase. Weed pressure in the following year must of course stay controllable.
In short: measures focussing on increased nitrogen fixation have a limited potential but will be explored in the coming years.

N-preservation

Reduction in denitrification is almost impossible: it is already very low. The two main driving factors, organic matter decay and soil mineral nitrogen level (Bradbury et al., 1993), are system-specific and very low respectively. The third factor, being anaerobic soil conditions, will be prevented in any case. This third factor is not part of the Ndicea model. With regard to the leaching of nitrogen, it will also be hard to reduce. In the farm design 2 rye is thought as green manure after carrots. Because of the late harvest of the carrots, green manure dry matter production is expected to be very low (600 kg d.m. per hectare) in case the sowing and germination are a success. If by good management and lucky weather conditions one or more weeks can be 'gained' both in the beginning and at the end of the field period, a higher yield and a higher nitrogen uptake could be realized. This is also true for the other green manure crops. If the gap between the end of the green manure and the beginning of the next crop could be reduced, there would be some potential advantages: a bit less leaching, a bit more dry matter production, a bit more nitrogen uptake and a bit more nitrogen fixation.

Nitrogen in regional circulation

The circular arable farming of the future might be a system with 100% recycling of household wastes, creating an as much as possible closed production and consumption cycle. If realized, it can be expected that the return of phosphorus in this cycle will be high (Schoumans et al., 2008). For nitrogen the expectations are different, nitrogen being prone to losses to water and air. Differences between N and P uptake in human consumption will also result in a change in the N/P ratio. For

other water-soluble nutrients such as Potassium a 100% return will be impossible, just like nitrogen.
The output of farm design 2 is 64 kg N and 32 kg P_2O_5 per hectare each year (Table 5). Suppose that 30 kg P_2O_5 could be returned to the farm as (processed) household waste, with this waste containing 8.9 kg N and 4.4 kg P_2O_5 per ton fresh weight (www.handboekbodemenbemesting.nl). In that case 61 kg N per hectare per year (out of a circular process, but originating from the farm itself! would be brought additionally in the system. A very limited fraction of this amount will become available within one year (mineral N fraction < 10% ; slow speed of decay). The major part of this nitrogen will be added to the soil as nitrogen-containing organic matter. Modelling this added organic matter input shows an overall substantial increase over time of the soil organic matter content, going up to 3% after decades (not shown here). However, within a few years this will lead to higher nitrogen availability, and Planty Organic being a nitrogen limited production system, to an increased production potential. In this calculation the N/P ratio if the sold produce equals the supposed N/P ratio of the household waste, which is very unlikely. It seems more realistic to suppose that the N/P ratio of the returned household waste will be lower than 2, so the nitrogen input will be lower than calculated above.

Nitrogen availability
In 2012 and 2013 the crop following the cut-and-carry fertilizer sward was cauliflower. A good production, both quantitative and qualitative, turned out to be impossible. Despite the addition of Monterra organic fertilizer pellets in 2012 and cut-and-carry fertilizer pellets in 2013 no acceptable nitrogen availability could be realized. Therefore, since 2013 squash is cultivated at that place in the crop rotation, which turned out to be a good choice.
In general the soil mineral nitrogen level is low, many times very low. This should not be mixed up with a (too) low nitrogen availability for the crops. If the mineralization of nitrogen out of soil organic matter equals the crop's daily nitrogen demand, the crop can grow with a very low measured or modelled soil mineral nitrogen level. The conditions for this process are an active soil life, sufficient soil organic matter to be broken down and set free nitrogen, and a root system which enables the uptake of this steady nitrogen release. These preconditions are the challenge for any organic production system, and also for the further development of the Planty Organic system.

Soil organic matter
The measured soil organic matter quantity shows a small increase of 0.03% per year. The modelling in Ndicea indicates a very small decline in organic matter and a small increase in soil organic N (4 kg per hectare per year, Table 5) due to an increase in C/N ratio. Both expectations are uncertain.
For the farm design 2 the standard procedure for calculation of the soil organic matter balance has been followed (www.kennisakker.nl ; www.handboekbodemenbemesting.nl) including an expected decay of 2% per year (Janssen et al., 1990). In this calculation a lower-than-standard dry matter production of the green manure is taken into account. The result is an expected equilibrium of 2.1% soil organic matter. If this is realistic, the amount of soil organic matter can increase since the experiment started at 1.8 – 1.9% organic matter. This potential of 0.2 – 0.3% increase in the top 30 cm of the soil is equal to 18-25 ton CO_2 sequestration during time. In the completed project 'Credits for Carbon Care' (Rietberg et al., 2013) and the running project 'Koolstofboeren' the options are explored to provide payment since this is a societal service. In Austria a system has already been implemented for this purpose (www.oekoregion-kaindorf.at).
There is another (Dutch) way of calculating the organic matter balance, an online tool on www.kennisakker.nl. This tool calculates with more or less the same dataset for the organic matter

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input, but differs in the speed of decay, here being dependent on soil type and pH. In case of the Planty Organic soil the decay is supposed to be 2.46% instead of the before-mentioned 2%. In literature values are reported varying from 1.6 up to 3.2% per year (TCB 2016). The yields in this tool are fixed default values, resulting in an overestimation of the organic matter input. The result is a slightly positive balance, resulting in a new equilibrium at 2.0% soil organic matter. If the organic matter input is corrected with -10%, 1.8% soil organic matter will be resulting at the end, this is the same value as at the beginning of the experiment.

Both approaches (fixed value for decay and manually corrected input; variable decay and fixed input) are based on standard soil tillage practice, so ploughing included. In case of reduced tillage the overall decay is supposed to be lower (Balen en Haagsma 2017). The Planty Organic system is a non-ploughing system, so both ways of calculating the organic matter balance will overestimate the decay.

Taken all together, it is reasonable to argue that the Planty Organic experimental field has a small amount of soil organic matter increase. This can become more confident if more accurate analysis methods are used on the preserved soil samples or if the system can run for some more years

Nutrient content of soil and crops

Despite the absence of nutrient input (apart from nitrogen) no decline in nutrient status of soil and crops is observed.

With regard to the soil this is not a surprise. It is a rich clayish loam soil with a big nutrient stock. Even if the stock in 0-30 cm is depleted to some extent, the uptake will be very small compared to the stock and it is hard to analyse small changes in the stock. Another process could be the extraction of nutrients from 30-90 cm depth and release in the topsoil by crop residues and cut-and-carry fertilizers. It is a challenge to investigate this process quantitative or quantitative.

Since the soil does not show a decrease in nutrient status, it is no surprise that the crop content doesn’t show a change either. .

For both soil (release) as crops (uptake) the role of soil life is an interesting factor. The one and only soil parameter with a consistent and considerable increase over 2014 – 2016 is ‘soil life’ (Table 4). This is a ‘black box’ parameter, covering a complex of processes. Research into soil life and its functions can shed light in this darkness. In the Ndicea model the decay of organic matter is summarized in one algorithm, with only two driving parameters related to (average) soil biomass.

6 General conclusions

After five full production years in the Planty Organic arable farming system we conclude that a promising system has been designed, tested and proven worthy. It is a robust system with important internal regulation mechanisms, which can teach us a lot more in the coming years. Looking at the items treated in this evaluation we conclude:

- Feasible
  Several minor and major questions are still to be answered, but this system with 100% farm-own nitrogen supply by means of cut-and-carry fertilizers with a regime of non-ploughing soil tillage is feasible.
- Yield level
  The yield level is comparable to other organic arable farms in Holland. If taken into account the land area needed for nitrogen fixation, the production per hectare is lower. A complete CO_2 footprint analysis opens the opportunity to compare this system with other organic farms using purchased manure and with conventional arable farms.
- Soil fertility
  There is no evidence that the soil fertility has decreased during five years in this system without nutrient input. A small increase in soil organic matter might be realized. According to measurements soil life has increased substantially.
- Crops
  Nutrient content of the crops has not decreased.
- Environment
  The environmental performances of the system are excellent: very low nitrogen leaching, no ammonia emission, no emission of crop protection products.
- Climate
  Probably there is CO2 sequestration in the soil. Methane and nitrous oxide emissions are very likely close to zero. No claim can be laid on performances with regard to fossil fuel use.

For the organic arable farming a pathway has been explored which turns out to be feasible. An increased part of farm-own nitrogen can be pursued by all arable farmers. The use of green manures and giving attention to these crops is worthwhile. Care for or increase of the soil organic matter content can be taken up by all farmers. The change towards a non-ploughing system has advantages, and meanwhile there is enough experience in the organic sector to minimize the risks.

For the conventional arable farming it has become clear that taking care of the internal organic matter and nutrient processes can be beneficial. As is the case for organic colleagues, integration of green manures in the rotation can be paying. When possible, for example after a cereal crop, that might be a leguminous green manure, thus saving on the purchase of nitrogen fertilizer. It is a challenge to extend the number of growing weeks of the green manures, both at the beginning of the growth (for example early sowing after onions) and at the end (no autumn ploughing but spring soil cultivation). Another challenge is the (re)introduction in the crop rotation of crops which improve soil fertility by itself. Good experiences have been gained in the ‘Veldleeuwerik’ project (www.veldleeuwerik.nl).

7 Recommendations

Together with experiences in the Planty Organic project, enough knowledge and experience is available to be worked out for practical purposes:

- Manual cut-and-carry fertilizers. All aspects related to the production, harvest, storage and application can be dealt with. This would be an update of an earlier publication. This publication is mainly focussed on organic farming.
- Manual farm-own nitrogen supply. This is about everything a farmer will encounter when choosing for more farm-own nitrogen supply. This publication is mainly focussed on organic farming too.
- Orientation on a wider crop rotation. This is about everything a farmer will encounter when choosing for more crops in the crop rotation with soil fertility improving features. This could be done in close cooperation with the 'Veldleeuwerik Foundation' and is focussing on conventional farmers.

These are questions for further research:

- Nitrogen dynamics: is it possible, with minor changes in crop choice, agronomy and fertilizer properties to increase nitrogen availability and yield potential?
- Soil organic matter: how much CO_2 can be fixed into soil organic matter and what are the societal and enterprise benefits of an increased soil organic matter level?
- System stability: what is the role of depth and intensity of root systems and the internal organic matter and nutrients turnover in productivity and production stability?
- Soil life: what is the role of soil life in the overall system dynamics (for example: mycorrhiza's) and how can it be managed?
- Phosphorus dynamics: which part of the phosphorus uptake originates directly from mineralization out of soil organic matter, and is it possible to use this knowledge in adapting the Dutch phosphorus recommendation systematics?
- Phosphorus dynamics: what is the contribution of the crops in mobilizing phosphorus out of the soil stock?
- CO_2 footprint: what is the CO_2 footprint of this arable farming system without manure application and with reduced tillage, compared to other arable farming systems, both conventional and organic?

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Internet courses:

www.biowad.nl

www.cbs.nl

www.handboekbodemenbemesting.nl

www.kennisakker.nl

www.oekoregion-kaindorf.at

www.veldleeuwerik.nl

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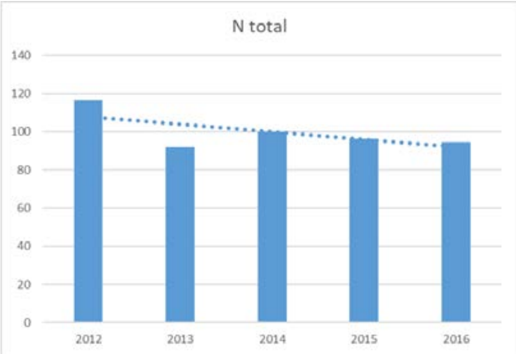
Appendix 1: Observed and simulated mineral N level

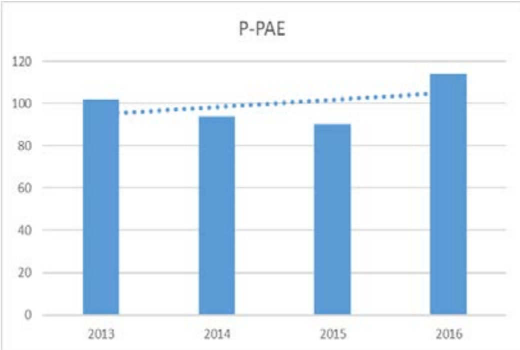
Field	A Sim	A Obs	B Sim	B Obs	C Sim	C Obs
0-30 cm	19	23	16	10	7	5
	20	20	5	18	36	80
	7	9	2	5	39	95
	8	10	20	9	21	18
	10	1	12	1	27	1
	43	36	4	18	19	6
	24	20	5	22	8	28
	31	29	10	20	6	24
	30	7	2	29	16	131
	18	36	20	32	28	65
	6	25	44	72	3	19
	24	37	40	8	14	24
	39	16	18	8	16	11
	9	1	8	21	15	7
			7	7	5	10
			31	15	24	32
			1	4	23	2
					16	1
30-60 cm	21	24	5	8	5	10
			31	36	4	29

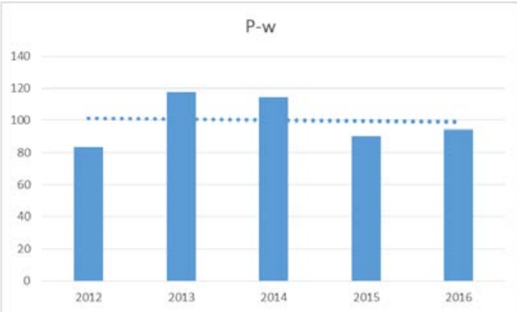
Field	D Sim	D Obs	E Sim	E Obs	F Sim	F Obs
0-30 cm	16	14	6	5	6	5
	16	1	26	12	8	1
	14	1	27	84	40	1
	32	37	12	12	70	84
	1	7	23	24	58	78
	6	23	10	19	61	25
	16	1	7	1	27	29
	13	1	5	1	15	53
	22	12	8	16	39	1
	9	1	7	13	48	1
	7	14	25	67	75	18
	4	56	11	10	43	18
	11	39	10	2	22	11
	7	31	4	1	32	140
	8	4			12	16
	9	1			18	19
	7	2			17	1
					6	1
30-60 cm	0	8	15	23	13	1
	5	19	4	18	48	16
	10	1				

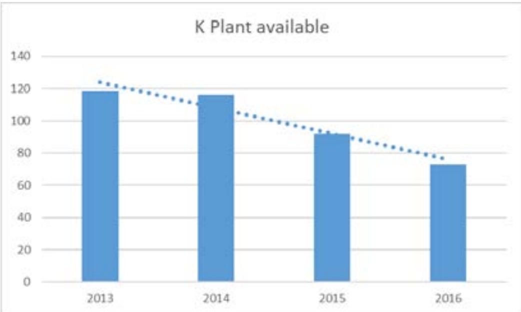
Appendix 2: Selection of indexed soil parameters

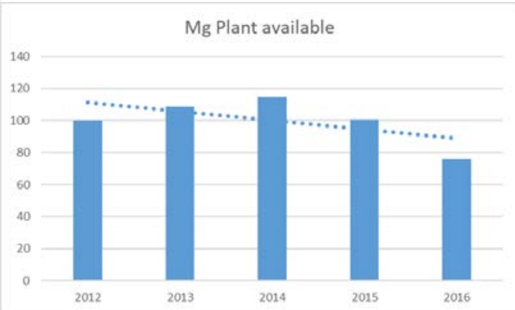
Graphs are selected of parameters only which show a trend. All values: Table 2.

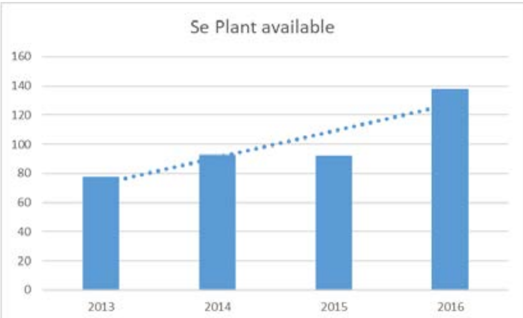


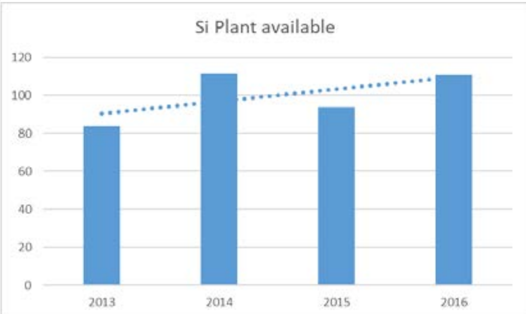


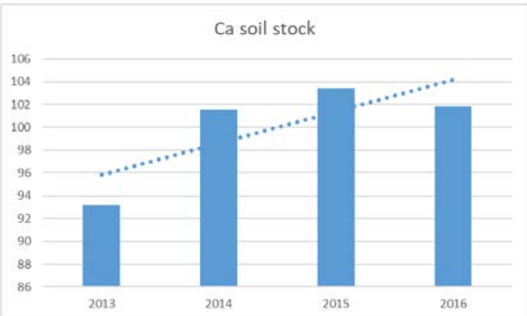


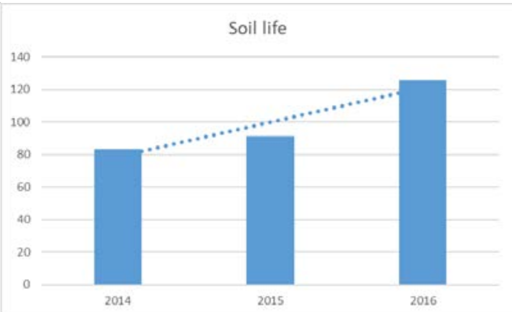












Appendix 3: Crop nutrient content

2012		Potato	Carrot		Spring wheat	Cauliflower
N	%	1,38	0,94		1,73	3,48
P_2O_5	%	0,6	0,53			1,35
K_2O	%	3,05	3,40			5,09

2013		Potato	Carrot	Oats	Spring wheat	Cauliflower
N	%	1,32	0,83	1,70	1,68	2,59
P_2O_5	%	1,01	1,11	2,64	1,91	2,49
K_2O	%	3,01	3,15	0,67	0,47	5,38
Ca	g/kg d.m.	1,15	3,59	1,35	0,53	3,02
Mg	g/kg d.m.	0,93	1,11	1,43	1,21	1,00

2014		Potato	Carrot	Winter wheat	Squash	Rye
N	%	1,01	1,36	1,55	1,58	1,32
P_2O_5	%	0,60	0,71	0,80	0,62	0,94
K_2O	%	2,71	3,72	0,56	3,01	0,66
Ca	g/kg d.m.	0,71	3,20	0,33	1,10	0,47
Mg	g/kg d.m.	1,1	1,2	1,0	1,1	1,0
S	g/kg d.m.	1,4	1,9	1,3	1,5	1,2
Cu	mg/kg d.m.	6,9	7,6	4,2	4,5	4,6
Fe	mg/kg d.m.	56,7	36,2	27,3	39,8	29,9
Mn	mg/kg d.m.	2,6	2,9	5,4	1,8	11,8
Zn	mg/kg d.m.	19,7	34,5	39,9	28,0	40,0

2015		Potato	Carrot	Oats	Squash	Field bean/ Spring wheat
N	%	1,16	1,26	1,92	1,70	4,41
P_2O_5	%	0,48	0,60	1,10	0,76	1,40
K_2O	%	2,72	3,32	0,67	2,47	1,50
Ca	g/kg d.m.	0,6	3,4	0,9	0,9	1,7
Mg	g/kg d.m.	1,0	0,9	1,5	1,2	1,5
S	g/kg d.m.	1,3	1,1	1,8	1,5	1,9
Cu	mg/kg d.m.	4,3	5,0	4,0	5,7	14,9
Fe	mg/kg d.m.	90	61	106	83	57
Mn	mg/kg d.m.	6	5	18	5	15
Zn	mg/kg d.m.	15	21	34	26	47

2016		Potato	Carrot	Oats	Squash	Field bean/ Spring wheat
N	%	1,53	1,10	1,67	1,28	3,49
P_2O_5	%	0,85	0,69	0,98	1,03	1,63
K_2O	%	3,42	2,32	0,71	3,26	1,48
Ca	g/kg d.m.	1,3	3,5	1,0	1,5	1,7
Mg	g/kg d.m.	1,3	1,0	1,3	1,2	1,8
S	g/kg d.m.	1,9	1,0	1,9	2,6	2,4
Cu	mg/kg d.m.	7,07	6,86	3,05	8,09	12,3
Fe	mg/kg d.m.	284	149	76	337	88
Mn	mg/kg d.m.	12	7	23	6	13
Zn	mg/kg d.m.	17	16	26	24	46