Final-report

For the CORE Organic II funded project

Workpackage 5.2

Calibration and adaptation of the NDICEA model to reduced tillage systems

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Abstract

The NDICEA model was used to simulate and evaluate field trials, designed to improve organic cropping system by using reduced tillage and green manures. The model can help to assess whether nitrogen shortages are likely to occur, and to evaluate the effect of green manure and reduced tillage conditions on nitrogen dynamics and soil organic matter pools.

To investigate the effects of tillage and nutrient management on N cycling and soil organic matter pools using the model NDICEA for different experimental sites across Europe. In addition adaptations to the NDICEA model are proposed to cover the effects of reduced tillage in these computer simulations.

Based on experimental field data, the model was calibrated for experimental sites in The Netherlands, Belgium and Switzerland covering conventional tillage with annual ploughing and reduced tillage treatments, with and without a leguminous green manure crop preceding the main crop. Based on these calibrations we introduced tillage as a factor in the model, described by means of an overall soil ‘decay factor’.

Results show that observed and simulated differences in nitrogen dynamics between reduced tillage and ploughing were small in both the Belgian and Dutch sites. NDICEA simulations pointed to low nitrogen availability in spring (<20 kg N ha^{-1}), which may be problematic depending on crop type and timing of crop growth. Simulations on organic matter levels suggest that reduced tillage can contribute to maintain or slightly increase soil organic matter levels (Switzerland, Netherlands, Belgium). Tillage effects could be introduced by means of an overall ‘decay factor’ in the NDICEA model simulation. Stratification within the topsoil, changes in root pattern, organic matter composition, soil organisms, detailed soil temperature, moisture and pH effects are described by their net effect on this ‘decay factor’. A new set of decay factors for conventional, reduced and no-tillage condition with an increase from coarse sand to clay soils could be deducted on basis of a calibration procedure. The hypotheses that treatments with stepwise reduction for tillage can best be simulated within NDICEA using a stepwise lower decay factor could not be confirmed.

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1. Introduction

This report is part of the Core-organic project “Tilman-org”: Reduced tillage and green manures for sustainable organic cropping systems (www.tilman-org.net). The overall goal of the project is to design improved organic cropping systems with enhanced productivity and nutrient use efficiency, more efficient weed management and increased biodiversity, but lower carbon footprints. The NDICEA model (Burgt et al., 2006) is used in this project to simulate field studies and to evaluate production systems as developed by the project partners.

In this study the application of NDICEA to four system studies is evaluated. The model is adapted by introducing tillage in a new NDICEA version. This report describes the background and model adaptations. Finally the adapted model is applied to an additional field study in France.

Organic farming systems contribute to ecosystem services such as the maintenance of soil quality and biodiversity (Mäder *et al.*, 2002). Reduced tillage and green manures are efficient conservation agriculture tools that can be applied to further improve organic crop production systems. The TILMAN-project aims to develop robust and sustainable arable crop production systems via the introduction of reduced tillage techniques combined with a strategic use of green manures in organic crop rotations, while maintaining and improving soil quality and crop productivity parameters. For a successful integration of conservation agricultural techniques in organic cropping systems, a better understanding of nitrogen dynamics and management is essential. The adoption of reduced tillage and/or green manures strongly affects nitrogen quantity and availability during the vegetative period and throughout the crop rotation (Peigné *et al.*, 2007). Specifically, changing soil and water conditions may affect the availability pattern of nitrogen, notably in spring (Berry *et al.*, 2010).

In order to come to a more rational use of green manures and off-farm inputs in reduced tillage systems, enhanced understanding of nitrogen dynamics is such systems is crucial. While measurements of for example soil mineral nitrogen provide insight in the actual soil mineral nitrogen content, they do not provide information over the fluctuations of nitrogen availability over time. As nitrogen is highly mobile in soil, such measurements may be easily affected by precipitation patterns. Additionally, measurements of soil organic matter stocks may suffer from lack of accuracy and field variability. Model simulations of the course of nitrogen and organic matter over time may provide additional insight.

Within the TILMAN-ORG-project, the model was used as a tool to enhance understanding of nitrogen and organic matter dynamics in the field. The model can help to assess whether nitrogen shortages were likely to have occurred, and to assess the effect of green manure and reduced tillage conditions on nitrogen dynamics and soil organic matter stock.

The aim of this study is a better understanding of the nitrogen dynamics and course of organic matter over time under conditions of reduced tillage, and/or when green manures are used. Moreover, we aim to improve NDICEA simulation for reduced tillage systems by calibrating the model to the different nitrogen and organic matter dynamics in various systems across Europe.

To date, few results on this issue have been presented in the scientific literature. We present data of the NDICEA application to different experiments from Belgium, Switzerland and The Netherlands. In those field studies reduced tillage techniques are used in organic cropping systems and green manures are being applied in some of these studies.

Nitrogen and carbon dynamics were modeled and the model was calibrated for these sites. Based on these calibrated version we propose and design an adapted NDICEA model (version 6.2) to cover changes occurring in the soil and especially in soil mineralization levels. This new, and adapted version of the NDICEA model was tested on an additional site in France.

2. NDICEA model

The NDICEA (Nitrogen Dynamics In Crop rotation in Ecological Agriculture) model is a dynamic, process-based model that calculates nitrogen and organic matter balances during a crop rotation. The model consists of four major modules: the water balance, the organic matter balance, crop growth and nitrogen balance. NDICEA has a time step of one day. NDICEA differentiates the soil profile of the root zone into two layers, namely the top-layer (0-30 cm) and sub-layer (30-60 cm). The top layer is the layer where mixing of the soil takes place through cultivation. Rooting of the crops depends on the type of crop but was limited in our simulations to a maximum of 60 cm. Manure and fertiliser additions are applied to the upper soil layer and are mixed into this layer. Storage of water and nutrients can also take place in the sub-layer if leaching occurs from the upper-layer. In general, the partitioning into these two layers seems to be sufficient to represent systems that were described with the model. NDICEA model functioning is described in detail by Van der Burgt et al. (2006).

The water-balance of the model depends on soil texture and is calculated from the water balance of each layer in the soil based on actual rainfall, irrigation and evaporation. This results in leaching or capillary rise in the soil. Inorganic nitrogen is transported with the water down the soil profile depending on a nitrogen leaching factor. Nitrogen that leaches below the rooting depth is considered lost.

The core of the model is the decomposition module in which the mineralization process is described. Mineralization is calculated for each successive application of organic matter, and according to the type and quantity of that organic matter. For each type of organic matter the C:N ratio and the apparent initial age (ranging from 1 for green matter to 24 years for soil organic matter) are used as input. Corrections are applied for soil temperature, soil moisture, texture and pH. The undecomposed part of the organic matter contributes to the soil organic matter pool. The quantity of soil organic matter in the model is based on an initial soil analysis. The organic matter in NDICEA is distributed among three pools starting with 5000 kg organic matter in de young pool (initial age of 3.4 years) and 2000 kg in the fresh pool (initial age of 1.8 years). All other organic matter is distributed into the old organic matter with an initial age of 22.5 years. For initialisation the model is run for a full crop rotation taking into account equilibrium in the young and fresh pools. N mineralization is calculated based on the assimilation:dissimilation ratio of the soil organisms, the carbon:nitrogen ratio of soil organisms, the type of substrate and the rate of organic matter decomposition.

The nitrogen balance is calculated from the crop growth module and the water and organic matter balances. The balance is calculated based on the initial amount of N in a certain layer and the net amount accumulated in a certain week. The net weekly accumulation is the difference between total N input and total N output. The nitrogen balance includes N input fluxes like mineralization, atmospheric deposition, denitrification, fertilizer application, fixation and N input through capillary rise and N outputs like crop uptake, leaching and denitrification. NH_4 volatilisation and water logging are not part of the model. Nitrogen fluxes in the soil are associated with the water fluxes. N leaching is based on an excess of water, the amount of mineral N in the soil and soil physical properties. It is estimated to be the sum of matrix outflow and bypass flux of nitrogen. Denitrification is calculated in the model as a potential denitrification, corrected for soil moisture and mineral N content in the soil.

The NDICEA-model is target oriented: crop yield and crop quality parameters (e.g. dry matter content, nitrogen content) are used as a basis for crop nitrogen uptake calculations. Crop uptake depends on crop-dependent uptake curves and actual yields. Crop nitrogen uptake is calculated based on nitrogen concentration in the crops (product, residues and roots), water uptake, soil moisture content and N concentration in the soil water. N fixation of legumes is estimated from the potential N-fixation and the mineral N content of the soil. Water uptake by a crop is governed by evaporative demand, crop morphology, ground coverage and soil moisture content.

Major outputs of the model consists of expected mineral nitrogen in the soil layers, N uptake of the crops and levels of organic matter in the soil.

Model performance was evaluated in this study by visual observation of the NDICEA-output graphs, notably those on soil mineral nitrogen availability, organic matter evolution and soil mineral nitrogen availability and crop N uptake. It was assessed whether the simulated and the measured data followed the same pattern, and whether simulated data were structurally above or below measured data or randomly deviating.

In addition, the RMSE was calculated to assess model performance. The RMSE is a statistic that has been widely used to evaluate model performance (Moriasi et al., 2007) and indicating the difference between simulations and field measurements. For NDICEA an RMSE of 20 kg N ha^{-1} or less was considered an acceptable model performance indicating field variability and uncertainties in field sampling and variability. For each plot, the RMSE was calculated according to:

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

in which Y = soil mineral nitrogen in kg ha^{-1}. In all cases a distinction was made between subsoil and topsoil.

3. NDICEA adapted to the Merelbeke, Belgium

3.1 Trial description

The Merelbeke trial (Figure 1) is a short-term trial to compare soil tillage and green manure strategies in organic agriculture and their effect on N and P availability, crop performance and soil quality. A third factor includes compost prepared from on-and off-farm inputs. The trial is executed on a sandy loam in Merelbeke, Belgium. Mean annual temperature at this site is 10.5 °C whereas mean annual precipitation is 850 mm.

The experiment was designed as a split-plot design with six treatments and four repetitions. Tillage was the main factor, whereby reduced, deep non-inversion tillage up to 30 cm depth is compared with ploughing up to 30 cm depth.

Green manure is the subplot factor with three levels. In 2012, the levels differed due to both a different timing of mechanical destruction and to a different amount of incorporated shoot biomass of the standing green manure crop (grass-clover). Treatments for the green manure factor in 2012 included early destruction of grass-clover, late destruction with removal of a grass-clover cut and late destruction while mulching by repeated cutting. In 2013, ensilaged grass-clover was applied as a cut and carry fertilizer in 3 different doses of 0, 100 and 200 kg N ha^{-1}.

Application of a soil improver was included as a sub-subfactor, from 2013 onwards:, In 2013, self-prepared farm compost was applied on one side of each individual plot. Splitting the plots resulted in twice as many plots (48 pcs) from the second year onwards.

Figure 1. Experimental lay-out of the Merelbeke field experiment

Previous to the experiment, maize and flax where grown in 2009 and 2010, respectively. In September 2010, grass-clover was sown, in a mixture comprising of 10 kg ha^{-1} *Lolium perenne* (variety Merkem), 10 kg ha^{-1} *Lolium perenne* (Meloni), 7 kg ha^{-1} *Trifolium pratense* (Merviot) and 3,5 kg ha^{-1} *Trifolium repens* (Merwi). No fertilizer or manure was applied. The crop was topped off to remove weeds. In 2011, grass-clover was mowed and removed twice, and also mulched and left on the field twice. In 2012, grass-clover was mulched or removed and destructed as described above. Destruction took place mechanically by a non-inversion tillage with a cultivator, (type Actisol), followed by a rotary harrow. This had to be repeated twice in order to destroy the grass-clover ley.

Soil preparation before planting leek (variety Antiope) in June existed of inversion verus non-inversion tillage. In both experiments and on all treatments, the leek crop developed quite well. On a regularly basis, mechanical weed control was performed. Regrowth of grass from the previous green manure crop occurred in non-inversion tillage treatments, however, to a manageable extent. After the diagnosis of Leek Moth (*Acrolepiopsis assectella*), the entire field was treated twice with XenTari® (*Bacillus thuringiensis*) in August. Leek yield, dry matter, N and P content were determined in October, whereas the entire crop was harvested in December. In May 2013, celeriac was planted, which will be harvested in December.

3.2 NDICEA application

The NDICEA model was used to simulate crop rotations from 2009 until 2012. Six scenarios were simulated, representing six different treatments (Table 1). Since different treatments were only established in 2012, input data for 2009-2011 were the same for all six treatments. These years were included in the scenarios to improve the modeling in 2012.

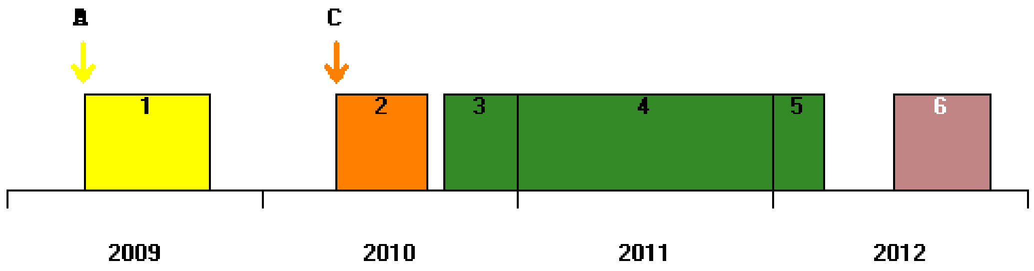


Figure 2. Schematic representation of crop rotation on a timeline from 2009-2012 for the Merelbeke trial for scenarios PG1 and RTG1. Blocks with numbers represent type and growth period of crops: 1. Maize, 2. Flax (seed), 3-5. Grass-clover 6. Autumn leek. Letters above arrows represent timing of organic inputs.

For each scenario, following data were considered: soil mineral nitrogen, growth period of grass-clover, grass-clover shoot biomass and whether it was incorporated or harvested, leek yield, leek dry matter and nitrogen content. Weather data on temperature and precipitation registered at ILVO were used whereas data on solar irradiation were obtained from a nearby weather station.

Organic carbon content was measured once in all four blocks on 23 February 2012, before the establishment of different treatments. Organic matter content was calculated based on these measurements and a carbon content in organic matter of 58%. Mineral nitrogen was measured four times in 2012.

Table 1 Scenario's at Merelbeke simulated with the model NDICEA

Scenario name	Main factor Tillage	Subfactor Grass-clover 2012
PG1	Ploughing	Early destruction
PG2	Ploughing	Late destruction & removal
PG3	Ploughing	Late destruction & mulching
RTG1	Reduced tillage	Early destruction
RTG2	Reduced tillage	Late destruction & removal
RTG3	Reduced tillage	Late destruction & mulching

P = Ploughing; RT = Reduced tillage; G1, G2, G3 = Green manure levels

3.3 Results

Little differences in soil mineral nitrogen content was observed between treatments with and without ploughing. This was confirmed by our model simulations of the soil mineral nitrogen content in treatments with and without ploughing. Therefore only results of reduced tillage are shown in Figure 3.

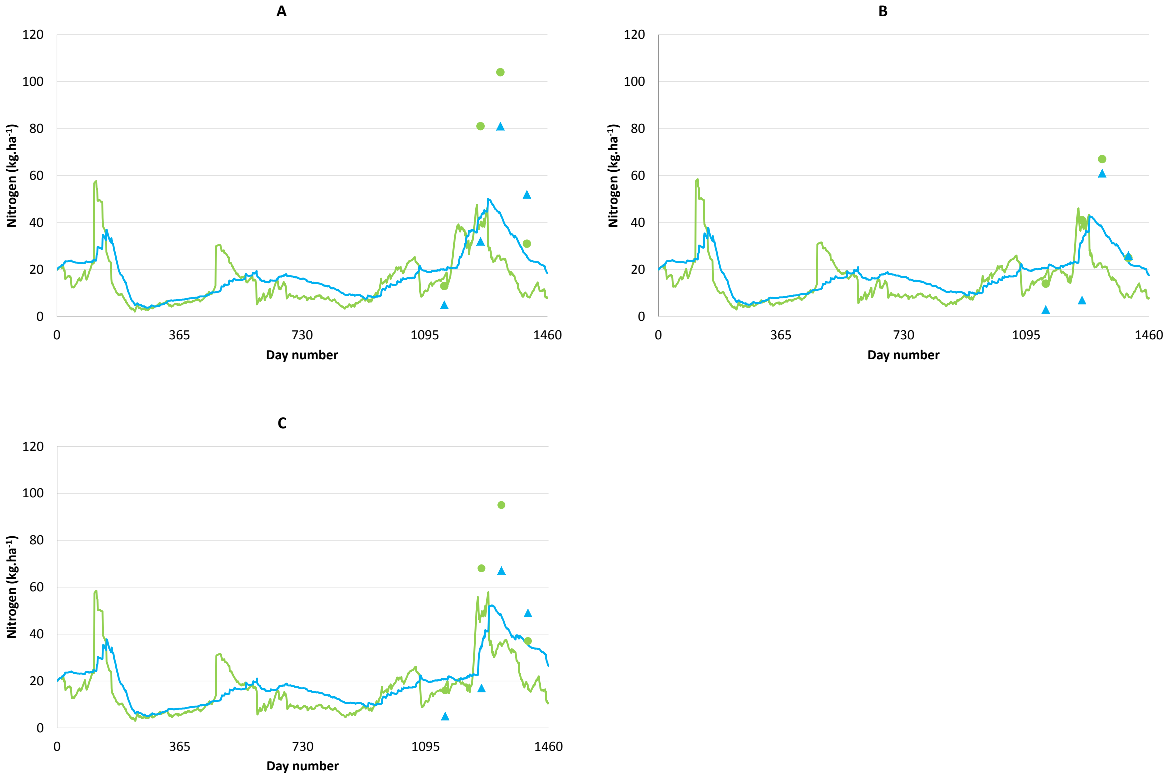


Figure 3. Simulated (line) and measured (dots) soil mineral nitrogen in the 0-30 cm (green) and 30-60 cm (blue) soil layers for scenario RTG1 (A), RTG2 (B) and RTG3 (C). Day #0=1 January 2009. Differences between the scenarios are to be expected in the fourth year (after day 1095).

In none of the scenarios, simulated soil mineral nitrogen availability was limiting crop growth (Figure 4). Small differences between treatments differing in green manure-management were observed: due to early incorporation of grass-clover (A), only one grass-clover cut was simulated, whereas two were simulated at later sward destruction. Simulated nitrogen uptake by grass-clover was higher in the scenarios with a higher spring biomass production and increased in the order RTG1 < RTG2 < RTG3. In treatment RTG2 (Figure 4B), uptake of mineral nitrogen in leek was lower than in treatment RTG1 and RTG3, and so was the calculated nitrogen availability. This could indicate that nitrogen was limiting crop growth in RTG2. Scenarios for ploughing and for reduced tillage looked fairly similar (not shown).

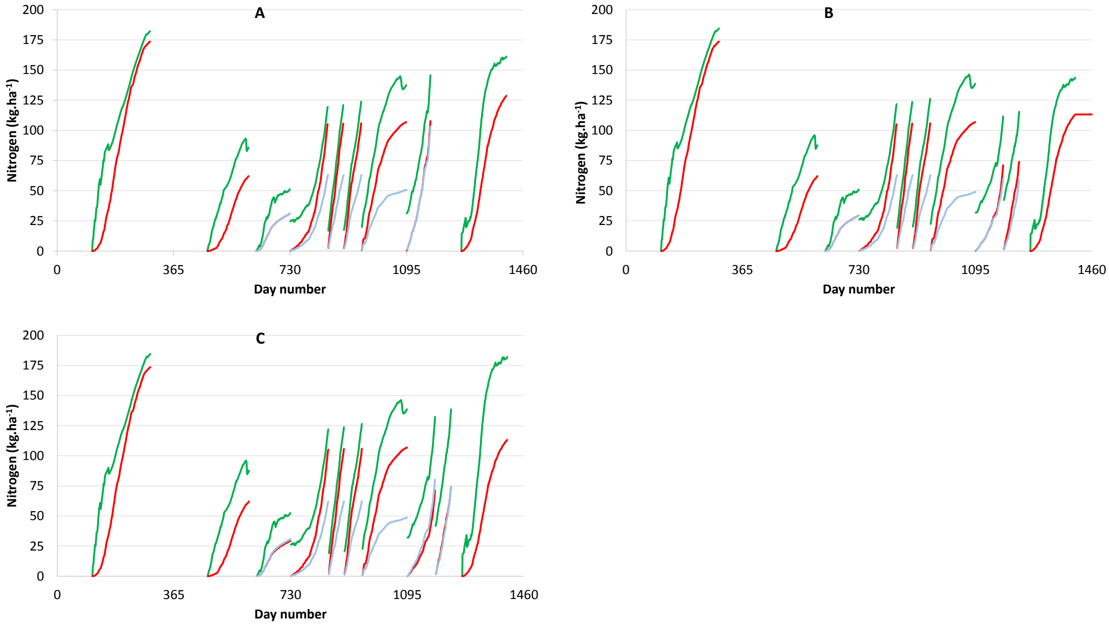


Figure 4. Soil available nitrogen (green line), nitrogen uptake (red line) and fixation (blue line) over time for scenario RTG1 (A) RTG2 (B) and RTG3 (C). Day #0 = 1 January 2009.

Simulated organic matter level showed a slight increase in all scenario's, from 1,8% to 1,9% or slightly above 1,9% (Figure 5). A peak is observed after destruction of the grass-clover-sward in spring 2012. Modelled organic matter level showed small differences between green-manure-scenarios. No differences between ploughing and reduced tillage were observed.

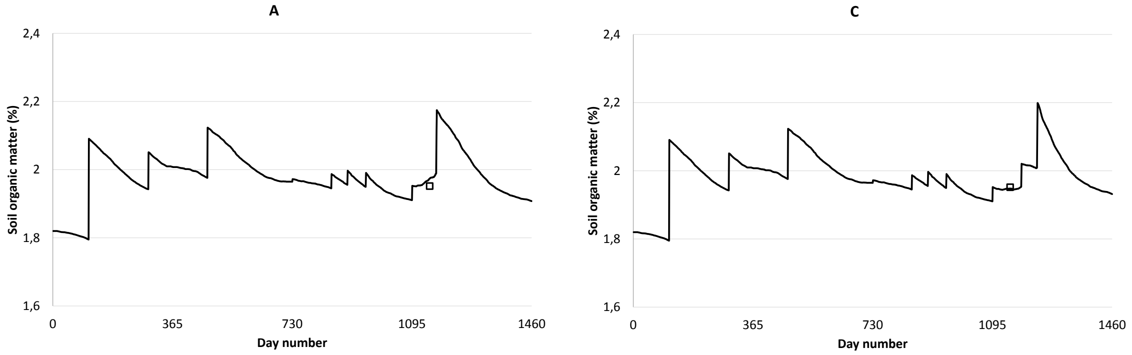


Figure 5. Simulated (line) soil organic matter levels for scenario RTG1 (A) and RTG3 (C). Dots represents soil organic matter levels as calculated from measured soil organic carbon (0-30 cm). Day #0 = 1 January 2009.

In this crop rotation, soil organic matter increased slightly over the period 2009-2012, mainly related to a build-up of soil organic matter during grass-clover-growth and after incorporation of the sward.

Differences in organic matter level stem from different amounts of grass-clover incorporated: the observed (peak) increase in organic matter is largest in the scenarios were grass-clover is mulched three times (Figure 5C) and smallest in the scenarios were the sward was destructed early in March (Figure 5A).

As the scenarios did not give reason for calibration, the decay factor was not adapted in the scenarios with reduced tillage. Therefore, differences between ploughing and reduced tillage stem from differences in yield, dry matter content and nitrogen content of leek between the treatments. Since these differences were small, differences in the course of soil organic matter level were negligible.

3.4 Evaluation

RMSE is shown in Table 2. For scenarios G2 and G3 model performance is reasonable, whereas for scenarios G1 it is quite poor. Visual observation of the results revealed that this is mainly due to the peak in mineral nitrogen measured in August, which was not adequately modeled by NDICEA (Figure 3A). In contrast, measured mineral nitrogen in February and June was well in accordance with simulated mineral nitrogen availability.

Table 2. RMSE in kg N ha^{-1} for six scenarios for topsoil (0-30 cm.) and subsoil (30-60 cm.), n=4. P=ploughing, RT=reduced tillage, G1. Early destruction of grass-clover, G2. Late destruction with removal of a grass-clover cut, G3. Late destruction while mulching by repeated cutting.

Scenario	RMSE topsoil	RMSE subsoil
PG1	40.8	27.6
PG2	29.5	21.9
PG3	23.4	24.3
RTG1	46.4	28.0
RTG2	24.6	19.3
RTG3	33.2	16.9

Model performance was better for the scenarios with late green manure incorporation than for those with early destruction of the grass-clover sward, but showed no difference with respect to tillage (Table 2). Observed differences between tillage treatments were small. Moreover, both mineralization of nitrogen and organic matter decomposition seemed to be underestimated rather than overestimated in all treatments, including the ones with reduced tillage. Therefore, a reduced decay factor for the treatments with reduced tillage -which would lead to a *decreased* decomposition of organic matter and hence a decreased mineralization- was not considered sensible. The measured results (yield, mineral nitrogen content) showed little difference between tillage treatments, and, as a consequence, there were little differences in the way NDICEA captured the dynamics in both treatments with ploughing and reduced tillage.

The simulation of soil mineral nitrogen did not point to nitrogen shortages throughout the growing season. However, the observed soil mineral nitrogen levels of 10 to 40 kg N ha^{-1} may lead to yield reduction, depending on crop type. There were no differences between the treatments that were ploughed and that were cultivated by reduced tillage in this respect.

Generally yield was satisfactory (G2) to good (G1, G3) in both the ploughed and reduced tillage treatments. Lower yield in G2 was most likely caused by lower input of fresh grass clover biomass in G2 compared to G1 and G3. In G3, the grass-clover sward was mulched three times leading to a higher nitrogen content of the grass-clover samples. Both the higher N content and the higher biomass input by G3 compared to G2 resulted in a higher nitrogen input in G3 than G2. Because the grass-clover sward was mulched once before destruction in G1, input of fresh biomass was higher in G1 than in G2 as well.

The application of grass-clover as a green manure is thus also feasible in organic agriculture in combination with reduced tillage. Timing of grass-clover destruction may play a role in the optimization of systems with green manures in organic agriculture both in systems with conventional soil cultivation as in systems with reduced tillage.

4. NDICEA adapted to the Broekemahoeve, the Netherlands

4.1 Trial description

Dutch organic and conventional farmers are concerned about the decline of their soil quality. There is a large interest in soil non-inversion techniques and controlled traffic systems. The combination of these techniques has theoretically a large potential to improve soil quality, to minimize emissions and to enhance biodiversity. However, there is little experience and knowledge about the effects of the combination of these techniques under Dutch circumstances and rotations including root crops like potatoes, carrot and sugar beets.

The objective of the Broekemahoeve trial (Figure 6) is to test, improve and measure agronomic and environmental effects of non-inversion soil tillage techniques in combination with controlled traffic under Dutch circumstances in organic and conventional rotations. Table 3 summarizes the crop sequence of the two systems.

The Broekemahoeve dataset covers also three types of soil cultivation within a six-year organic and conventional rotation: ploughing; reduced tillage; minimal tillage.

Each year, two crops out of the full rotation are grown. The experiment has four replicates and started in 2009.

Table 3 The crop sequence for the organic and conventional systems at the Broekemahoeve, the Netherlands.

Organic rotation	Conventional rotation
Seed potato; Clover-Grass	Spring barley
Clover-Grass	Onion
Cabbage	Seed potato
Spring wheat, undersown with clover	Sugar beet
Carrots	
Peas	

4.2 NDICEA application

Four scenarios were simulated within NDICEA: organic with ploughing (ORGPLO) and organic with reduced tillage (ORGRED), conventional rotation including ploughing (CONPLO), conventional including reduced tillage (CONRED). A schematic representation of the crop sequence is given in Figure 7.

Since detailed agronomic information from the years before 2009 was available, NDICEA scenarios were built for the period 2006 – 2008. From these historic scenarios the starting values for the three soil organic matter pools (old humus, young humus and fresh organic matter) in NDICEA in the 2009-2012 scenarios were derived. For each pool, there are three parameters: initial age (a reciprocal parameter for speed of decay, in virtual years); N-content (in % of dry matter) and quantity (in kg ha^{-1}). This means that there is to be expected a relative reliable simulation already in the first year (2009) of the soil cultivation experiment.

Sowing and harvest dates and yields of crops were used as input data. Since crop and residue nitrogen content were not measured, default model N-content of crops and residues were used. For manures, measured nitrogen and dry matter content data are used. The average data of the four replicates were used to create NDICEA scenarios. Temperature, evapotranspiration and rainfall data were obtained from the farm.

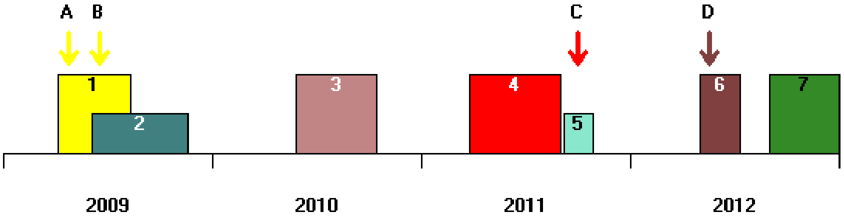
In NDICEA, the so-called decay factor is a parameter affecting the speed of decomposition of both fresh and soil organic matter: a higher decay factor indicates faster decay, a lower decay factor indicates slower decay. This factor could be used to calibrate the modeling to reduced tillage conditions, as reduced tillage may lead to less oxygen in the top soil and reduced exposure of soil organic matter to air, thus reducing breakdown of organic material.

Measured soil organic matter and mineral nitrogen levels were below observed soil organic matter and mineral nitrogen levels in most cases in this trial. These differences seemed slightly larger for the systems with reduced tillage than for the systems that were ploughed. Therefore, the decay factor was adapted in the systems with reduced tillage. This was done in an iterative process, whereby the decay factor was lowered to the point that simulated nitrogen uptake did not exceed simulated nitrogen availability (as this would be erroneous results). In the organic minimum-tillage-system, the decay factor was decreased from 0,82 to 0,60. In the conventional minimum-tillage-system, the decay factor was decreased from 0,82 to 0,65.

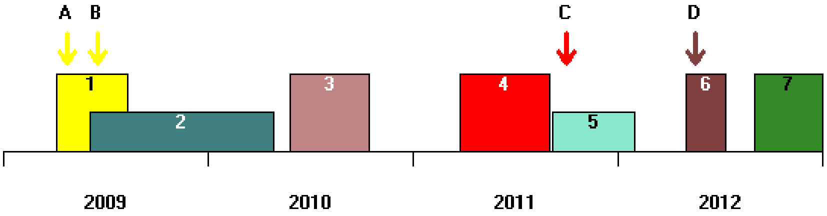
Model performance was evaluated by visual observation of the results. Additionally, soil mineral nitrogen data were used to compare measured and simulated values by means of the RMSE.

Figure 6. Field of the BASIS-trial at the Broekemahoeve.

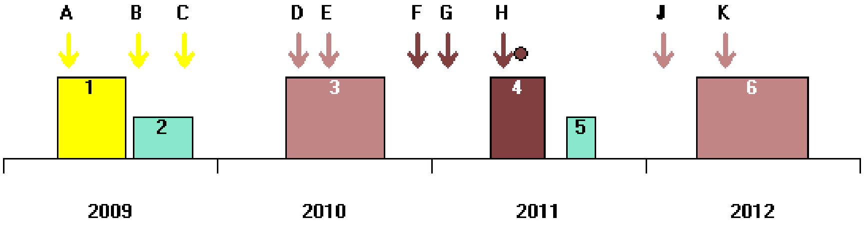
ORGPLO: *1. Seed potato undersown with 2. Clover-grass, 3. Cabbage, 4. Spring wheat, undersown with 5. Clover, 6. Carrots, 7. Peas.*



ORGRED *1. Seed potato undersown with 2. Clover-grass, 3. Cabbage, 4. Spring wheat, undersown with 5. Clover, 6. Carrots, 7. Peas. Arrows represent fertilizer & organic inputs.*



CONPLO *1. Spring barley, 2. Perennial ryegrass 3. Onion, 4. Seed potato, 5. Rye 6. Sugar beet. Arrows represent fertilizer & organic inputs, dots represent irrigation.*



CONRED: *1. Spring barley, 2. Perennial ryegrass 3. Onion, 4. Seed potato, 5. Rye 6. Sugar beet. Arrows represent fertilizer & organic inputs, dots represent irrigation.*

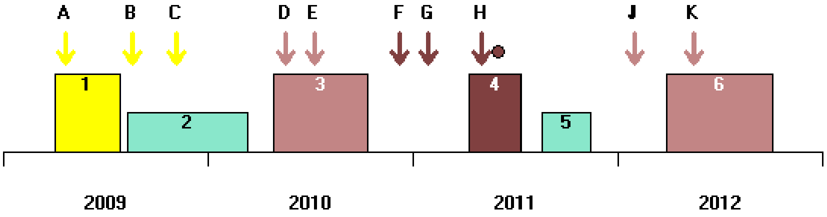


Figure 7. Schematic representation of the four NDICEA scenarios: organic with ploughing (ORGPLO) and organic with reduced tillage (ORGRED), conventional rotation including ploughing (CONPLO), conventional including reduced tillage (CONRED). Numbered block represent growing period of crops, arrows represent fertilizer and organic inputs, dots represent irrigation.

4.3 Results

Little differences were found between nitrogen dynamics in the organic scenarios ORGPLO and ORGRED (Figure 8). Simulated soil nitrogen levels were slightly lower in the reduced tillage scenario. Simulated nitrogen availability was notably low at the end of the cultivation period of cabbage (2010) and carrots (2012). In spring, measured nitrogen availability was low in 2010 and 2011 in both scenario's, and simulated nitrogen availability was low in 2010 in the reduced tillage system only. Likewise, both simulated and measured nitrogen availability were low in both scenarios at the onset of the growth of clover in 2011 - which would not be problematic given the nature of this crop. These results indicate that limited nitrogen availability in spring may be a challenge in organic crop rotations, but that this seems related to type of soil cultivation only to a limited extent.

Up to 2012, soil mineral levels in the conventional systems were considerably higher compared to the organic system. Between CONPLO and CONRED however, differences were small. Both measured and simulated nitrogen availability was low in spring in 2010, 2011 and 2012 in both scenarios, whereby measured mineral nitrogen availability was lower in the treatments with reduced tillage than in the ploughed treatment. Thus, nitrogen availability in spring may also be problematic in conventional systems - although this may be prevented more easily than in organic systems by using mineral fertilizer. Simulated mineral nitrogen availability showed higher peaks during the growing season in both conventional systems than in the organic systems.

Soil organic matter levels seem to go down in all scenarios at the Broekemahoeve (Figure 9). The course of soil organic matter over time was similar in both ORGPLO and ORGRED, and follows a rolling pattern. The largest temporary increase was observed after incorporation of rye. These results, over a relatively short lapse of time (four years) do not support the idea that adopting reduced tillage practices may contribute to keeping soil organic matter stocks at a constant level and preventing soil organic matter decline.

A steady decrease of the soil organic matter stock of little over 0,1% was observed for the conventional scenarios CONPLO and CONRED. As in the organic scenarios, these results do not point to the option that organic matter stocks may be maintained more easily in systems with reduced tillage. The fluctuations in the conventional system were smaller than in the organic system - only little inputs of organic materials could be observed in the conventional trials.

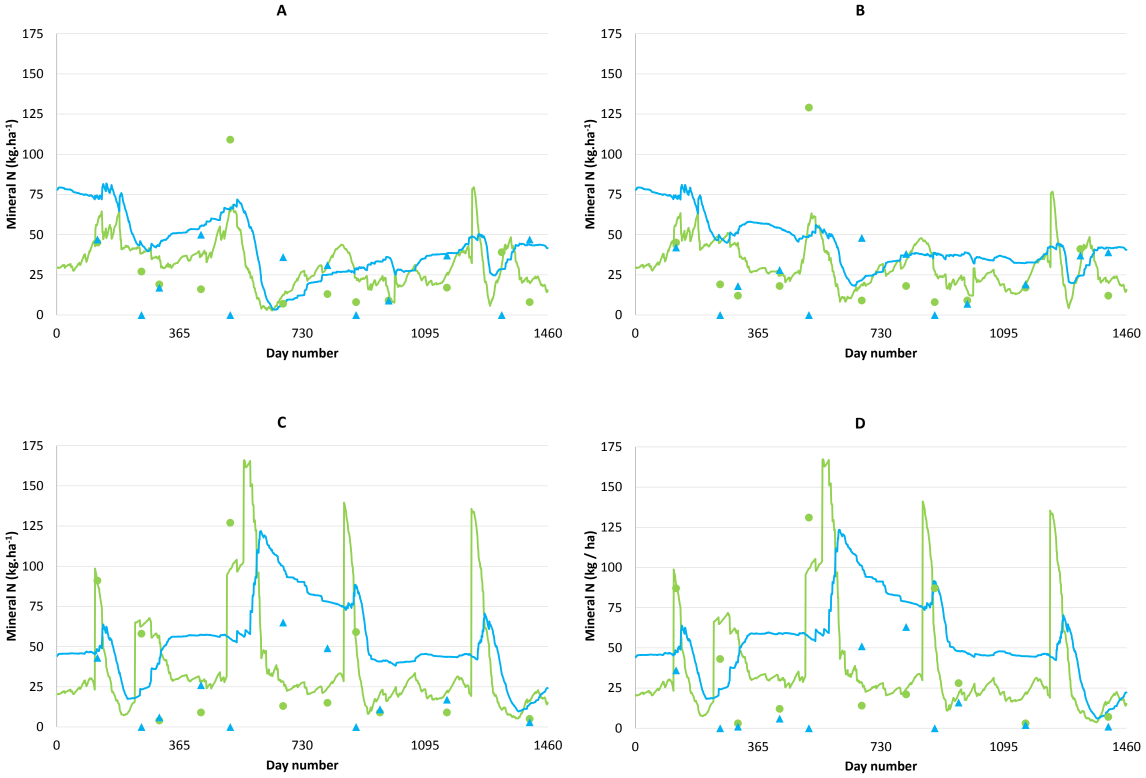


Figure 8. Simulated (line) and measured (dots) soil mineral nitrogen in the 0-30 cm (green) and 30-60 cm (blue) soil layers for scenario organic with ploughing (ORGPLO, A), organic with reduced tillage (ORGRED, B), conventional rotation including ploughing (CONPLO, C), conventional including reduced tillage (CONRED, D). Day #1 = 1 January 2009.

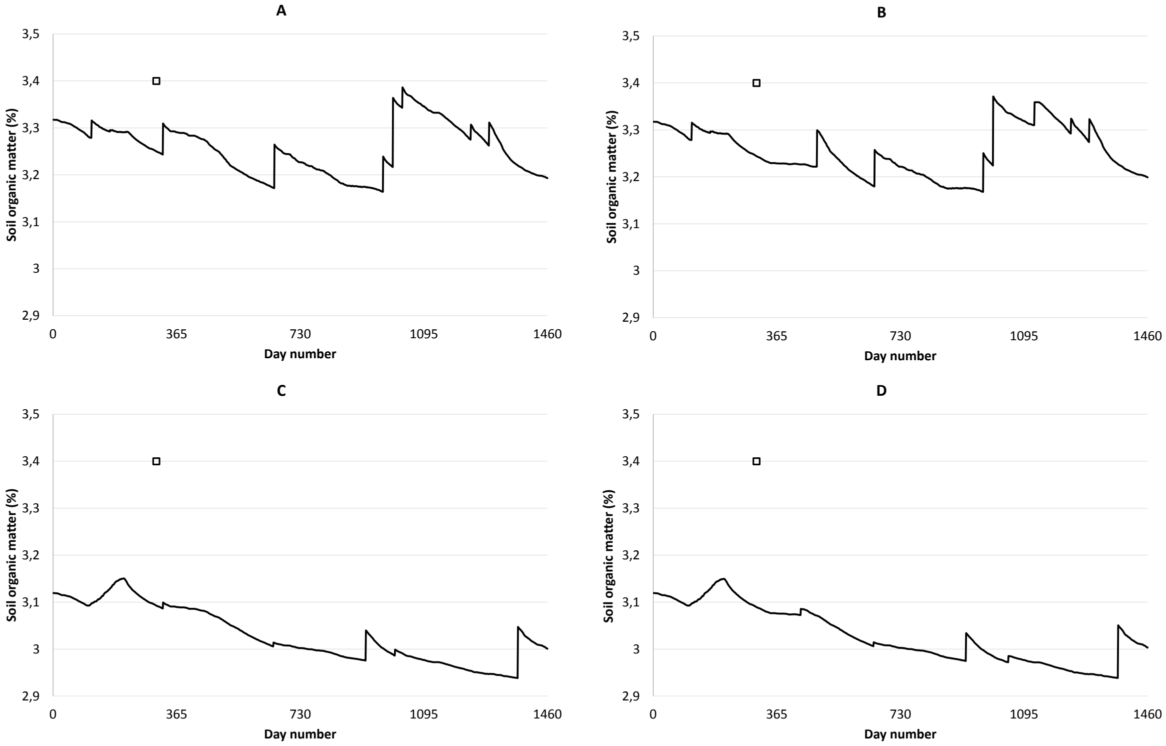


Figure 9. Simulated (line) and observed (dots) soil organic matter level in organic with ploughing (ORGPLO, A), organic with reduced tillage (ORGRED, B), conventional rotation including ploughing (CONPLO, C), conventional including reduced tillage (CONRED, D). Day #1 = 1 January 2009.

4.4 Evaluation

In the ORGPLO scenario, RMSE values for topsoil and subsoil are below 20 kg N ha^{-1} and model performance can thus be considered satisfactory. In a similar fashion, simulations in the conventional system with ploughing CONPLO where reasonably in line with measurements, especially in the topsoil (Table 4).

Both systems with reduced tillage show values above 20 kg N ha^{-1} for topsoil and subsoil. Especially, subsoil mineral nitrogen wasn't modeled very accurately in the conventional system with reduced tillage. Overall, measured soil mineral N levels in the soil were lower than simulated levels (Figure 8).

In the systems with minimum tillage, decreasing the value of the decay factor lead to decreased mineralization of organic matter, thus in lower soil mineral nitrogen values and higher soil organic matter values, in line with the observations. This is reflected in a lower RMSE for the calibrated conventional scenario with reduced tillage CONRED. In the ORGRED scenario, hardly any improvement in RMSE can be observed. These results might further be improved by automatic calibration.

Table 4: Root mean square error (RMSE) of modeled versus measured soil mineral N (kg N ha^{-1}) for the topsoil (0-30 cm) and subsoil (30-60 cm), n= number of measurements on which the calculation of RMSE is based, calibration indicates scenarios in which the texture facture was calibrated.

	Topsoil		Subsoil		Total	
	n	RMSE	n	RMSE	n	RMSE
ORGPLO	12	18.2	8	19.6	20	18.8
ORGRED	12	26.4	9	23.3	21	25.1
ORGRED calibrated	12	25.6	9	23.5	21	24.8
CONPLO	11	21.4	8	27.7	19	24.2
CONRED	11	25.1	8	36.3	19	30.3
CONRED calibrated	11	23.4	8	29.0	19	25.9

The measured organic matter level (fall 2009) was higher than the simulated level in all four treatments. It was determined by loss on ignition, which generally does not provide very accurate information on soil organic matter levels. Therefore, lack of accordance between model simulation and measurement may be related to the measurement more than to the simulation. Organic matter levels were closer to observed organic matter levels after calibration by adapting the decay factor in the scenarios with minimum tillage. The effect however was small.

5. NDICEA adapted to Frick, Switzerland

5.1 Trial description

The dataset brought in by the Research Institute for Organic Farming (FiBL) is a factorial trial in which the effect of soil tillage and fertilization on crop performance and soil quality is assessed.

The trial run from 2003 to 2009. Crop rotation is shown in Table 5. Data on crop yield, crop nitrogen content and fertilization dry matter and nitrogen content were used as input values in NDICEA. Local weather data were used.

Table 5. Crop sequence of the trial

Year	Crop
2003	Spring wheat
2004	Sunflower
2005	Spelt (+ Clover-grass)
2006	Clover-Grass
2007	Clover-Grass
2008	Silage maize
2009	Winter wheat

There are two factors with two levels each, leading to four scenarios (Table 6).

Table 6. Scenario for the Frick trial as simulated with NDICEA.

Scenario	Factor	
	Tillage	Fertilization
CONSM	Ploughing	Slurry and manure
CONSlu	Ploughing	Slurry
REDSM	Rototiller	Slurry with manure
REDSlu	Rototiller	Slurry

5.2 NDICEA application

Soil organic matter data were used to visually assess the degree of accordance between simulation and measurement. No soil mineral nitrogen field samples were analyzed, implying that the RMSE for soil mineral nitrogen could not be used as a tool for model performance evaluation. Theoretically, the RMSE for soil organic matter could be calculated – however, a number of two measurements was deemed too low to obtain a meaningful indicator of model performance. Moreover, a reference value for model evaluation (i.e. which soil organic matter percentage difference between simulated and measured data is considered acceptable) is currently not available for soil organic matter.

Within the NDICEA model, the so-called ‘decay factor’ affects the speed of organic matter decay. This factor can be adapted to simulate differences in soil tillage, reflecting possible differences in soil biomass quantity and activity (Chapter 7). This decay factor is a fixed value for the whole calculation period. Other characteristics of the soil microbial community that could be affected by reduced tillage include the C/N-ratio and the assimilation/dissimilation-ratio. However, an adapted version of NDICEA to cover reduced tillage by means of adapting the decay factor was not available at the time of these simulations. NDICEA-scenarios were built for the whole period 2003 – 2009. These scenarios were calibrated on the data on soil organic matter. This did not lead to satisfactory model performance (not shown).

During the growth of grass-clover, no soil cultivation took place. Therefore, the factor ‘soil tillage’ played a role in 2003 – 2005 and in 2008 – 2009 only. Since we expected differences between the three sub-periods due to the lack of soil tillage in 2006 - 2007, we made three scenarios for each treatment (2003 – 2005 ; 2006 – 2007 ; 2008 – 2009). The final values of parameters related to soil organic matter pools of the previous period were introduced as starting values for the following period. In this way, for each period a different decay factor was established by calibration, as shown in Table 7. Afterwards, the three resulting graphs were united in Excel.

Calibration took place on the basis of two soil organic matter level measurements in each treatment. For the period 2006 – 2007 there was no measurement to fit the graph on. Due to the small number of measurements, the results have to be interpreted with care.

Table 7. Values of the decay factor after calibration for four different treatments in the Frick-trial used in the NDICEA-modeling. Last column: model default value for this type of soil.

	Scenario				
Period	CONSM	CONSlu	REDSM	REDSlu	Default
2003-2005	1.20	1.20	0.88	0.71	0.71
2006-2007	0.30	0.30	0.30	0.30	0.71
2008-2009	0.71	0.95	0.30	0.30	0.71

5.3 Results

Simulated nitrogen availability was high enough to cover crop uptake in all years for all scenarios, except for silage maize (2008) and winter wheat (2009) in the rototilled treatments (figure 10). This will be further discussed in the section 5.4 on model evaluation.

In the periods of grass-clover growth, adaptations in the decay factor affected the ratio between nitrogen taken up from soil and nitrogen taken up via fixation of aerial nitrogen: as explained earlier, nitrogen fixation by clover starts when soil mineral nitrogen levels drop below the nitrogen fixation threshold. Thus, when a lower texture value leads to decreased decomposition of soil organic matter and thus decreased availability of soil mineral nitrogen, soil nitrogen levels drop below this threshold value earlier and a larger proportion of nitrogen is obtained via nitrogen fixation. Therefore, at low to moderate levels of soil mineral nitrogen, the nitrogen fixation threshold is of higher importance in determining simulated soil nitrogen availability than the decay factor.

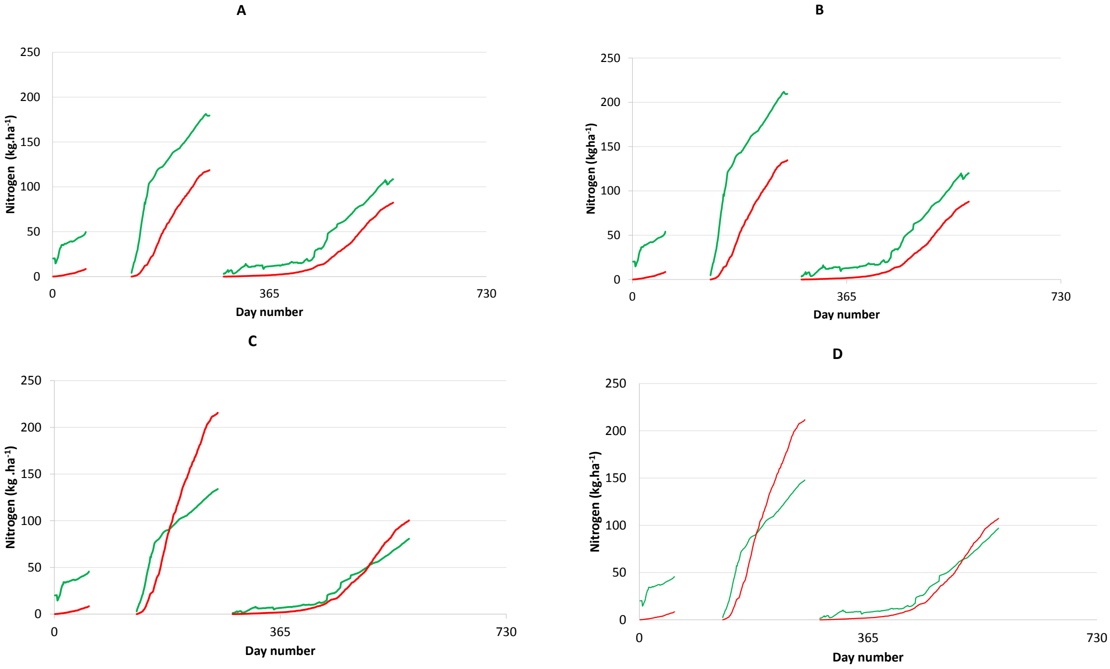


Figure 10. Nitrogen availability (green line) and uptake (red line) as simulated by NDICEA for scenarios CONSM (A), CONSlu (B), REDSM (C) and REDSlu (D) Day #1 = 1 January 2008.

Both simulated and measured soil organic matter levels were higher in the treatments that were rototilled (REDSM, REDSlu) than in the treatments that were ploughed (CONSM, CONSlu). In the ploughed treatments, simulated soil organic matter content was approximately at the same level at the beginning and the end of the rotational period, whereby soil organic matter build-up took place during and directly after the grass-clover period, and breakdown after the growth of spring wheat (2009). In addition, in all four scenarios, soil organic matter levels initially declined after the growth of winter wheat (2003) and during the growth of sunflower (2004). The decline after winter wheat is remarkable and probably related to initialization. The initial age of different soil organic matter pools may have been underestimated, resulting in enhanced simulated breakdown of organic matter compared to the actual situation in the field. In the rototilled treatments, soil organic matter content was higher at the end of the rotational period than at the beginning.

In addition, soil organic matter levels were slightly higher in scenarios with manure and slurry (CONSM, REDSM) than in treatments with slurry only (CONSlu, REDSlu). These differences were small however compared to the differences between the soil cultivation scenarios. These results suggest that reduced soil cultivation may have a larger effect on sustaining soil organic matter stocks than fertilization. However, it should be noted that the simulated organic matter levels are based on adapted decay values, which in turn where adapted based on the measured values of soil organic matter.

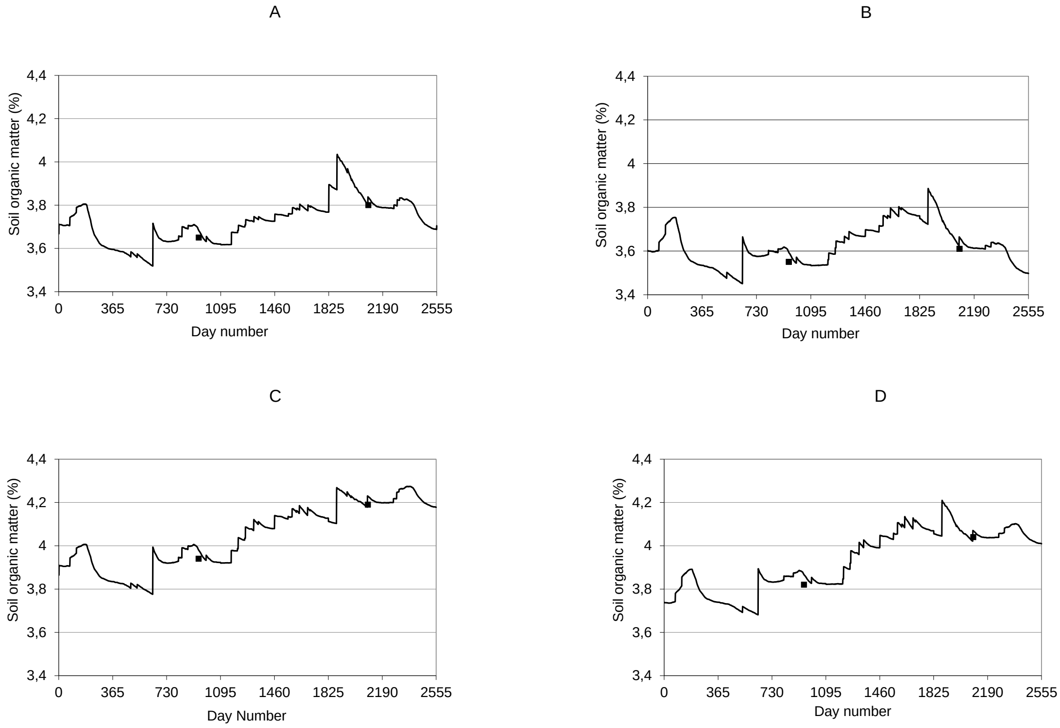


Figure 11. Observed (squares) and simulated (line) soil organic matter levels for scenarios for scenarios CONSM (A), CONSlu (B), REDSM (C) and REDSlu (D). Day#0 = 1 January 2003..

5.4 Evaluation

Due to the lack of soil mineral nitrogen measurements, simulation of mineral nitrogen by NDICEA cannot be evaluated visually or by means of the RMSE.

The adaptation of the soil decay factor in different periods of the rotation lead to good model performance regarding soil organic matter level. In adapting the decay factor, the value 0,3 was chosen for the clover grass period (2006-2007). This is the lowest value allowed in the model. A lower value would have resulted in a higher calculated soil organic matter level in January 2008, and the fitting on the measured data in 2008 would have resulted in overall higher decay factor values in 2008-2009. This might be more realistic than what is shown now, because the decay factor values in 2008-2009 are low compared to those in 2003-2005. This may explain the deviated modeling of soil nitrogen availability in the rototilled plots in 2008-2009. Here, simulated nitrogen uptake exceeds nitrogen availability, which is not possible in practice. A higher decay factor for 2008-2009 might (partly) solve this problem, since a higher decay factor implies a faster decay of soil organic matter and thus higher nitrogen mineralization rates. Alternatively, the lack of simulated available soil mineral nitrogen might be related to the crop parameterization of the grass clover crop, but this cannot be further explored in this dataset[1].

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[1] *In NDICEA, nitrogen release after grass-clover is determined by two main processes: the overall decay factor (a soil parameter) and several grass-clover related parameters. For calibration of the FIBL datasets, only the decay factor is used. Default values were used for the grass-clover related parameters affecting nitrogen release. Contrary to annual crops, some of the parameters related to grass-clover are hard to validate. There are three main reasons for that. First, in the model there is a relation between above-ground grass-clover production ("yield") and crop residue. The default crop parameter describing distribution of dry matter production over 'product' and 'crop residue' is derived from literature. Second, there is an algorithm introduced to set virtually aside crop residue during crop growth, and add it virtually to the soil when the sward is ploughed. This is done to be able to describe a strong nitrogen release after ploughing, which is reported in several publications. Third, an amount of soil life is modelled to become available for decomposition after ploughing, also to simulate the strong nitrogen release after ploughing. These parameters are not validated yet. The simulated shortage of available nitrogen after the grass-clover crop could be due to a suboptimal estimation of these parameters under these specific conditions.*

6. General discussion of the NDICEA calibration

We aimed at a better understanding of the nitrogen dynamics and course of organic matter over time under conditions of reduced tillage, and/or when green manures are used.

Observed and simulated differences in nitrogen dynamics between reduced tillage and ploughing were small in both the Belgium and the Dutch trials. NDICEA simulations pointed to low nitrogen availability in spring (<20 kg N ha^{-1}), which may be problematic depending on crop type and timing of crop growth. However, these differences did not seem to be larger in reduced tillage systems than in systems that were being ploughed. Moreover, the conventional trial at the Broekemahoeve experiment indicated that lower nitrogen availability in spring may also play a role in conventional systems.

The Merelbeke-trial showed that application of grass-clover as a green manure is feasible in organic agriculture in combination with reduced tillage. Timing of grass-clover destruction may play a role in the optimization of systems with green manures in organic agriculture in systems with conventional soil cultivation as in systems with reduced tillage.

Both simulated and measured data on organic matter suggest that reduced tillage can contribute to maintain or slightly increase soil organic matter levels (Frick, Broekemahoeve, Merelbeke).

Moreover, we aimed to improve NDICEA simulations for reduced tillage systems by calibrating the model to the different nitrogen and organic matter dynamics. The adaptation of NDICEA towards reduced tillage conditions focused on the ‘decay factor’. This factor regulates the overall speed of decay of all types of soil organic matter. Supposedly, overall decay of organic matter is reduced when reduced soil cultivation techniques are applied. In terms of the model parameter, this means a lower value for the decay factor.

The model can be extended with a user-friendly choice button regarding overall soil cultivation intensity, for example containing of the categories normal (ploughing or deep intensive cultivation), reduced and minimal tillage. Each of these categories relates to a default value for the decay factor. Such a model adaptation was performed in Chapter 7 and complemented by a written appendix to the current user manual (www.NDICEA.org). It contains additional information about the decay factor, and on what to do if the model results are not adequate and show a structural overestimation or underestimation of soil mineral N or soil organic matter.

Model performance, evaluated on the basis of RMSE and visual observation, was –with some exceptions- acceptable for both the Belgium and Dutch trials, notably for the top soil. Calibration by adapting the decay factor slightly improved model performance for the reduced tillage treatments in the Broekemahoeve trial of the Netherlands. The results from Belgium gave no reason for calibration.

The Frick trial showed that adapting the decay factor can lead to better fit of simulated and observed data, and better simulation of soil organic matter levels in reduced tillage systems. However no data to evaluate the model performance in terms of nitrogen dynamics were available, thus these results should be interpreted with care.

In NDICEA, differences in simulation are driven by differences in yield, crop dry matter level and crop nitrogen content - if treatments do not have effect on those, model adaptations do not seem necessary to capture differences in nitrogen and water dynamics under reduced tillage conditions. Thus, NDICEA simulations can be adapted to reduced tillage conditions by changing the decay factor as outlined in Chapter 7. This is only useful when experimental data give reason to do so. This was the not the case in the Merelbeke trial and only to a limited extent in the Broekemahoeve trial.

7. Introducing tillage effect in the NDICEA model

7.1 Impact of tillage on soil organic carbon dynamics

Gadermaier et al. (2011) summarize the effects of tillage on carbon content and carbon distribution in the topsoil. They indicate that the intensity of tillage operations has effect on the carbon distribution in the topsoil. They found an increase in soil organic carbon in the superficial soil layer and controversial results related to organic C when the whole soil profile is taken into account. According to Kay and VandenBygaart (2001), differences between tillage systems with regard to soil parameters become more clear if experiments last for a longer period of time, preferably more than 15 years. These authors confirm finding of others. Angers et al. (1997) describe an experiment in which no difference in organic C in 0-60 cm was reported after 11 years of tillage with or without ploughing. Berner et al. (2008) present an increase in organic carbon in 0-10 cm but no difference in 10-20 cm due to differences in soil tillage. In a paper by Schultz et al. (2008) no differences in organic C are reported. Karlen et al. (1994) report substantial differences in soil organic C due to different tillage practices. Emmerling (2007) reports an increase of organic C in the topsoil and a decrease in the subsoil of the same order. Conant et al. (2007) present a review on short-term effects of tillage, concluding that soil organic C declines significantly following even one tillage event.

Several authors state that due to reduced tillage or non-inversative tillage, the bulk density of the subsoil is increased and that of the topsoil decreased (Kay and VandenBygaart, 2001; Alvarez and Steinbach, 2009; Rasmussen, 1999; Emmerling, 2007; Schultz et al., 2008; Peigné et al., 2007; Tebrügge and Düring, 1999).

The process of accumulation of organic carbon in the topsoil (although not consistently reported) is explained by the compaction of the soil with a reduced aeration as consequence (Weide et al., 2008; Rasmussen, 1999), intermingling with other processes such as increased decay of organic carbon (Kay and VandenBygaart, 2001), temperature effects (Alvarez, 2005) and slightly lower pH in the topsoil (Berner et al., 2008). The process is very site-specific (Alvarez, 2005), and there must be quite some interfering processes to explain the wide range of results in C-accumulation so far.

The amount of C accumulation, if any, varies strongly. Time plays an important role in this process of accumulation (Holland, 2004; Kay and VandenBygaart, 2001) as does the amount of organic matter applied to the soil (Holland, 2004). At world scale a potential increase of 10% soil organic carbon is mentioned (Steinbach and Alvarez, 2006; Lal, 2011). Ogle et al. (2005) mention an increase of 16% of soil organic carbon in the moist temperate climatic zone, if no tillage is compared to conventional tillage after 20 years. Tebrügge and Düring (1999) mention an increase of around 20% in the top 10 cm, and a reduction in deeper layers of a few % points due to no tillage if compared with conventional tillage. In the experiment described by Gadermaier et al. (2011) an increase in 6 years of 19% in 0-10 cm is measured, comparing conventional tillage with reduced tillage, whereas the 10-20 cm depth remained constant in soil organic carbon. Conant et al. (2007) describe long-term model outcomes which indicate differences of 25-35% in soil organic matter level at the long term, comparing no tillage with conventional tillage. Holland (2004) mentions in his overview increases of 8%, 0,5%, 20% and 8% increase of organic carbon in the topsoil without evidence that the subsoil is depleted.

The experiments within the Tilman-org project show an accumulation of soil organic carbon content of 15-35% in reduced tillage soils as compared to the ploughed systems (Fliessbach et al., 2014). Already mentioned is the Swiss experiment (Gadermaier et al., 2011) in which an increase of 19% in soil organic carbon is reported within six years in the 0-10 cm layer. In the BASIS experiment (Rietberg et al., 2014) only minor differences in yield and in nitrogen dynamics are reported within four years, leading to the temporary conclusion that there are no substantial differences in C and N dynamics. The France THIL trial (Chapter 8) shows only minor differences in N-dynamics, and a clear trend in soil organic carbon was not found.

For modelling purposes we conclude that the modelling procedure should result in an increase in organic matter in case of reduced or no tillage, at least in the topsoil, but the local and temporal circumstances should have a dominant influence on the net result. The net result can vary from no change in soil organic carbon in the total soil profile up to an increase of 20% in the topsoil (0-10 cm) without depletion in the subsoil, and up to 10% increase in soil organic carbon as a potential worldwide average (Steinbach and Alvarez, 2006; Lal, 2011). The experiments within the Tilman-org project, all of relatively short duration, also show a large variation in results.

Given the unexpected high variability in experimental results from literature our approach of introducing a tillage effect in the model NDICEA should be taken with care. The high variation in trial outcomes and uncertainty in underlying processes and strong influence of local conditions, confirms that our approach should be seen as a first attempt and hypotheses how to introduce a tillage effect in a model focusing on practical use and practical circumstances at the farmer level.

7.2 Use of the 'decay factor' as a means to account for tillage effects

The NDICEA model is subdivided in a soil and water model, a nitrogen dynamics model and a plant growth model. For introducing the tillage factor only the soil and water sub model is taken into account.

NDICEA is based on a two-layer soil model. Depth of the topsoil can be defined by the user between 10 and 30 cm in intervals of 5 cm. The topsoil is supposed to be the soil layer in which the major part of the soil organic dynamics take place. In ploughed systems this is most of the times equivalent to ploughing depth. Depth of the subsoil is also defined by the user, being an estimate of maximum rooting depth on the specific soil in question. Plant residues, manure and compost are recycled via the top soil. The organic matter in the subsoil does not play a role in the organic matter dynamics. Root residues in the subsoil are neglected, which is equivalent to the assumption that added and decayed organic matter in the subsoil are always in balance.

The soil organic matter in the topsoil is distributed in three pools with specific characteristics (Table 8). Total organic matter level is calculated out of a measured % organic matter in topsoil, depth of the topsoil and a bulk density of 1.35 gr cm^{-3} as fixed value in the model. The N-content has default values but can be changed by the user. Initial Age (IAge) is a model specific parameter, being a virtual age related to the speed of decay (Janssen, 1984). A high Initial Age means a low speed of decay.

Table 8. Pools of organic matter and their characteristics used by the NDICEA model.

	Quantity (kg ha^{-1})	N-content (% in dry matter)	IAge
Fresh	2800	3	1.4
Young	6600	4.5	4.0
Old	Variable	5.8	24.0

Topsoil pH can be inserted by the user. This value is static all over the calculation period.

The soil water characteristics are related to the type of soil, chosen by the user. It is mainly texture-based, and the specific organic matter level does not influence the water-related calculations. Soil structure does not play a role in the model.

Organic matter dynamics is temperature driven. In NDICEA the average daily air temperature is used, not a (measured) soil temperature.

The overall speed of decay of any type of organic matter in the model is driven by one parameter: the ‘decay factor’. Soil organic matter is thought to be to a certain extend protected to decay by the inorganic soil particles depending on soil texture. On clayish soils this decay is lower than on sandy soils, resulting in a lower overall speed of decay represented by a lower decay factor. Soil tillage is supposed to have a direct effect on the decay of soil organic matter by disturbing the decay of organic matter, by aeration of the soil and by other processes. Systematic (long-term) differences in tillage can be simulated, as a consequence, by means of the decay factor.

Soil life is supposed to be a constant amount with invariable characteristics in time (C:N-ratio, assimilation:dissimilation ratio). However, parameters is question can be adapted manually.

The distribution of the roots over topsoil and subsoil, root density in topsoil and subsoil are crop parameters, independent of soil type or soil structure. Maximum rooting depth is both a crop and a soil parameter, with the soil maximum rooting depth representing the potential rooting depth and the crop maximum rooting depth, the crop related depth. Crop maximum rooting depth is limited by soil maximum rooting depth.

The model structure has shown to be effective, without including all (detailed) soil processes occurring most of the time at scales not relevant for the field scale. The field scale is targeted by the NDICEA model and process descriptions are according to this target. As a result of this model structure, several processes described in literature referring to tillage effects *in detail* cannot be simply introduced in a field-scale model like NDICEA.

We therefore propose to introduce tillage as a factor described by means of the overall ‘decay factor’. This approach means that details like stratification within the topsoil, changes in root pattern, changes in organic matter fraction compositions, soil organisms composition, detailed soil temperature, moisture and pH effects are described by their net effect on the ‘decay factor’, which reflects the level and detail at which processes are described in the field-like-model NDICEA.

7.3 Method for deriving the tillage dependent ‘decay factor’

Within the NDICEA model a ‘decay factor’ was introduced describing and accounting for the rate of decomposition of soil organic matter under different soil types (Burgt et al., 2006). Default values used in the model for different soil types are summarized in table 9.

Table 9. Default values of the decay factor with soil type as variable used in the design of the NDICEA model

Soil type	Default decay factor in case of conventional soil tillage
Peat soil	1.00
Corse sand	1.00
Loamy sand	1.00
Sandy loam	0.96
Silt	0.92
Sandy clay loam	0.89
Loam	0.86
Silt loam	0.82
Clay loam	0.78
Clay	0.71

Since these default values account for conventional tillage including ploughing once a year, the challenge is to find new default values for 'reduced tillage' and 'no tillage'.

No converging quantitative effects for soil organic matter levels due to reduced tillage or no till are reported in literature. Experimental results report soil organic matter levels after introducing reduced tillage techniques but often equilibrium levels reached after longer periods of time (15-100 years) are uncertain.

To overcome this problem we used an iterative process within the model NDICEA to determine the relationship between the value of the decay factor and the effect on the soil organic matter for different soil types. NDICEA scenarios were created with a crop rotation and fertilizer application which resulted in a stable soil organic matter level, given a fixed soil type (Sandy loam, 1.92% organic matter) and certain climatic conditions (middle part of the Netherlands). Crop and fertilizer choices are common practices within organic farming in the Netherlands (Table 10) but another choice of crops and fertilizer will not essential influence the results. The final criterion for this step in the process is a simulated stable soil organic matter level in the time lapse of a complete rotation (Figure 12).

Table 10. Crop sequence and fertilizers used for the iterative process, using the NDICEA model.

Year	Crop	Yield Kg ha^{-1}	Fertilizer type	Amount ton ha^{-1}
1	Potato	27000	Cattle manure deep litter	20
1	Grassclover year 1	1500		
2	Grassclover year 2	8000	Farmyard manure	18
3	Grassclover year 3	1000		
3	Maize	9000		
4	Pea	4500	Cattle manure deep litter	18
5	Winter wheat	6500	Slurry	15
5	White clover	1770		

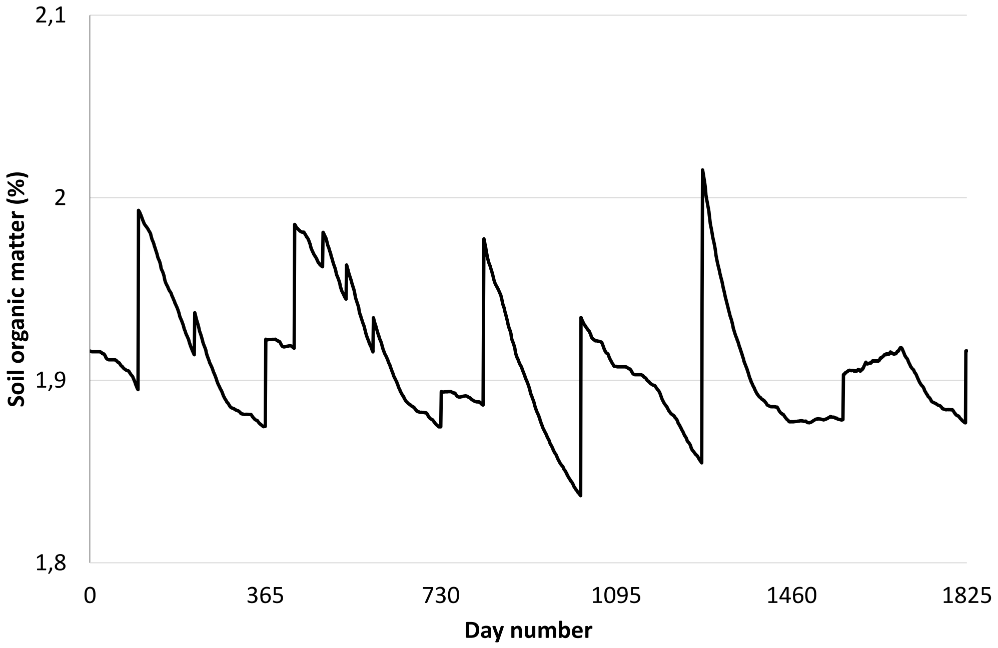

Figure 12. Course of soil organic matter in the topsoil (0-30 cm).

Fifteen and hundred year model runs were calculated using different values of the decay factor, creating calibration graphs on which a chosen effect (x percent of growth in 15 respectively 100 years) could be linked to the decay factor needed for a certain result. The choice of 15 and 100 years was based on creating references for the mid-term and long-term effects.

The outcomes of the 15 and 100 year model runs are presented in Annex I and II, from which Figure 13A and 13B are derived. The graphs relate to the final amount of soil organic matter found in the soil using different soil decay factors. The word 'final' used here means 'after 15 respectively 100 years'. It does not mean that a new equilibrium has been reached in soil organic matter level. The trend lines in the graphs are logarithmic, giving slightly better fits than exponential ones.

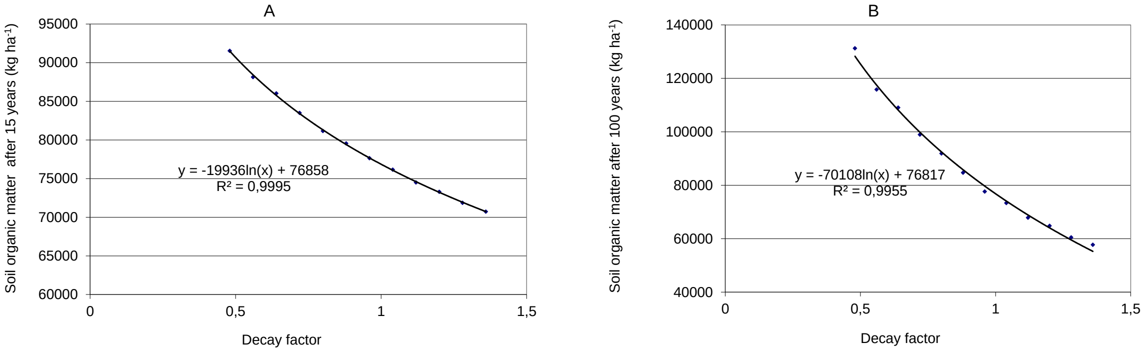

Figure 13. Results of iterative process within the model NDICEA to determine the calibration line between organic matter levels found in the soil and the decay factor for 15 year (A) and 100 year (B) runs.

After having created these calibration graphs, the question remained how to choose the default values of the decay factor in case of reduced tillage and no tillage. In other words, what is the expected effect of reduced and no tillage on the soil organic matter level, and what is the corresponding decay factor. The references show a wide range in effects, and here distinct values are needed.

7.4 Use of the decay factor under reduced or no tillage

It is proposed here, for the time being and based on the range as reported in literature, to assume an increase of 9% soil organic matter in 15 years as a result of no tillage compared with conventional tillage. In the same model calculations this results in an increase in soil organic matter of about 30% in 100 years, which is in the range mentioned by Conant *et al.* (2007). Using the calibration graph in Figure 13A, this results in a reduction of the decay factor from 0.96 to 0.68, so 0.28 units.

Calculating the different decay factors corresponding to the default values we know for conventional tillage (Table 9) results in a series of decay factors to be used for no tillage conditions (Table 11).

No-tillage is relatively well-defined. This is not the case with reduced tillage. For practical reasons we propose the effect of reduced tillage will roughly be half as big as the effect of no tillage, compared to conventional tillage. In the same way as for no tillage, the decay factors for reduced tillage conditions could be calculated (Table 11).

Table 11. Values of the decay factor with soil type and tillage as variable.

	Default decay factor		
Soil type	Conventional tillage	Reduced tillage	No tillage
Peat soil	1.00	0.85	0.71
Corse sand	1.00	0.85	0.71
Loamy sand	1.00	0.85	0.71
Sandy loam	0.96	0.81	0.68
Silt	0.92	0.78	0.65
Sandy clay loam	0.89	0.75	0.62
Loam	0.86	0.73	0.60
Silt loam	0.82	0.69	0.57
Clay loam	0.78	0.66	0.54
Clay	0.71	0.60	0.49

NDICEA version 6.2. includes soil tillage as a variable, using the soil decay factor as described in this document. The values of Table 11 are used in this version of NDICEA.

Within the NDICEA soil screen a new item was created for the user: soil tillage. The user is offered a choice between conventional tillage, reduced tillage and no tillage. As a consequence of this choice a different decay factor is used in the NDICEA simulations, using the default values of Table 11. The user can change this preset value manually, depending on the findings in his experiments or use it for calibrating the model according to his experimental results.

8. Application of the tillage-adapted NDICEA model

8.1 Introduction

Within the Tilman-org project, data obtained from a few trials are used as input for NDICEA in order to validate the model for changes in soil tillage. This report is about the THIL trial in France.

The THIL trial is located in the commune Thil which belongs to the Ain department in the Rhône-Alpes region at proximity to Lyon in Eastern France. The experimental field is situated on null slope at 180 m altitude at coordinates: 45°49'9.44''N latitude, 5°2'2.62'' E longitude. The region has a continental and degraded oceanic climate. The mean annual normal temperature is 11.4 °C and the mean annual rainfall is 825 mm as is measured by the farmer on the experimental field. The experimental field has a calcareous sandy-loam soil (0.58 g/g sand, 0.27 g/g silt, 0.15 g/g clay) and pH of 8.2.

The field has been managed according to organic production standards (regulation EU 2092/91) for 14 years, since 1999. It has a surface of 1.5 ha. The experiment at Thil is a long-term experiment on comparison of different tillage systems in organic farming that has as general aim to adapt reduced and no tillage to organic grain system as well as to understand and study the effects of different tillage treatments on the physical, chemical and biological soil characteristics. Ploughing at 25 cm depth was the tillage practice used on the experimental field before the establishment of the experiment in 2005. The experiment started in spring 2005 after 3 years of alfalfa.

The crop rotations of the experimental field are presented below. These crop rotations are quite common in this region where we can find irrigated stockless grain system in organic farming.

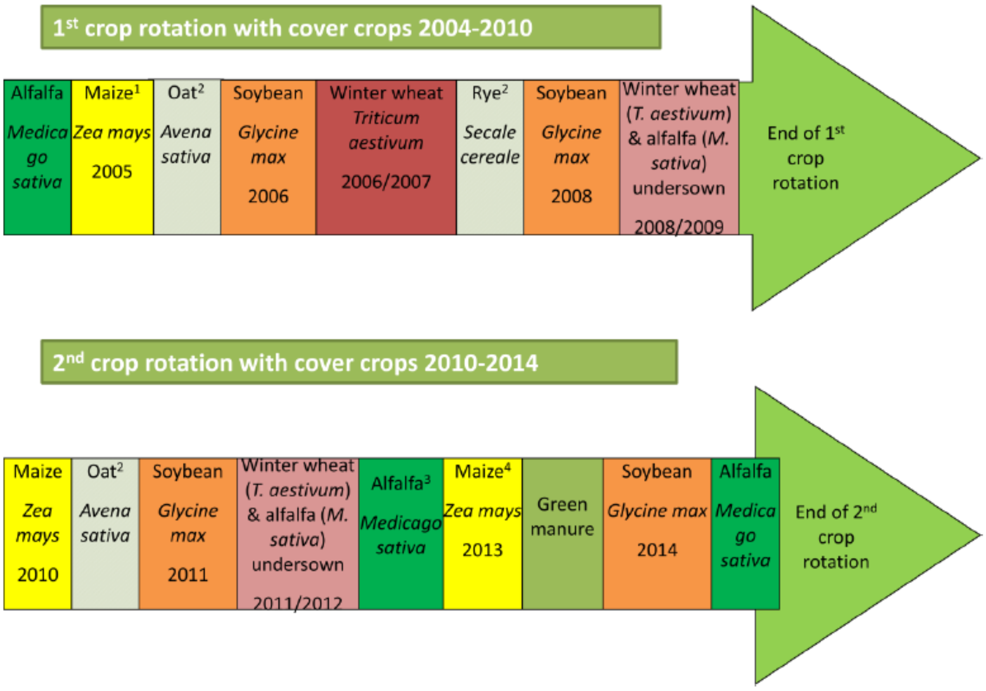

Figure 14: Crop rotation of the experimental field. [1]: Beginning of the experiment. [2]: cover crop. [3]: Cover crop as relay cropping.

8.2 Materials and methods

Four tillage managements are compared, using a completely randomised block design with 3 replicates (12 experimental plots – see Figure 15):

- Traditional mouldboard ploughing (MP) (tilling to a depth of 30 cm),
- Shallow ploughing (SP) (20 cm depth)
- Reduced tillage (RT) with tined tools (15 cm depth)
- Very superficial tillage (5 cm depth) /or no tillage (ST). For the ST treatment the maize in 2005 and the soybean in 2008 were directed seeded in a living mulch of alfalfa and rye respectively. This living mulch was controlled by a roller crimper.

For all the treatments, in 2009 and 2012 alfalfa was directly sown as a relay cropping in the wheat in the early spring and buried mechanically in March 2010 and 2013 before the maize sowing. For each crop the weeds were mechanically destroyed by multiple operations by hoeing for the row crops (maize and soybean) and by harrowing for the wheat according to the weeding level of each treatment.

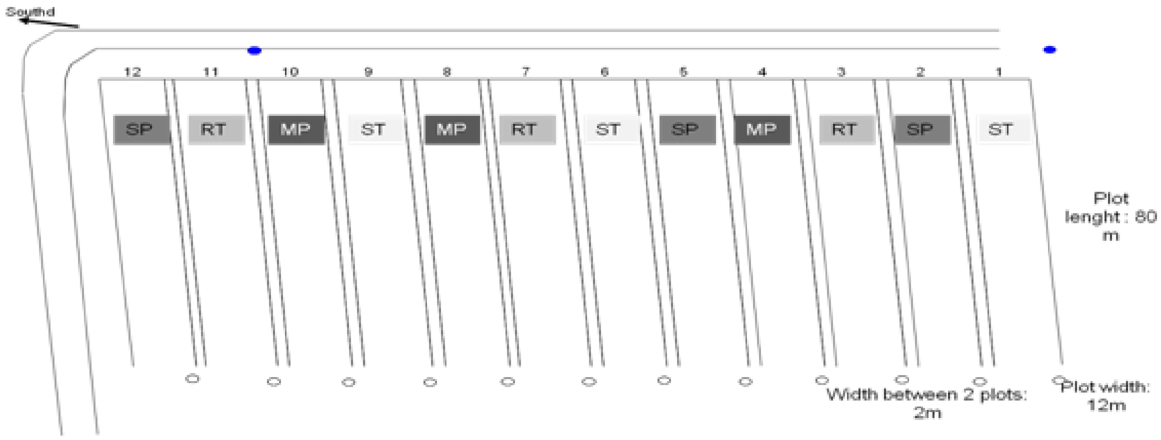

Figure 15: Experimental design of the THIL trial

8.3 Application of the model

Four treatments were simulated representing the four treatments of the experimental site and including (1) ploughing, (2) shallow ploughing, (3) superficial tillage and (4) very superficial tillage. For the simulation within NDICEA, averages of replicates were used in the simulation.

The effect of tillage is in the model represented by the value of the decay factor. This parameter is a general parameter for decay of soil organic matter. A high value means a high rate of decay (so: a low decay); a lower value results in a lower rate of decay (a higher decay). The general hypothesis is that reducing the tillage activities will result in a reduced decay of soil organic matter. In terms of the NDICEA model approach the hypothesis is that in case of reduced tillage, a lower value of the decay factor will increase the model results of treatments with reduced soil tillage.

The crops, fertilizer applications and irrigation activities of the field experiment were introduced into NDICEA leading to a crop sequence representing several years and including fertilizer additions (Figure 16).

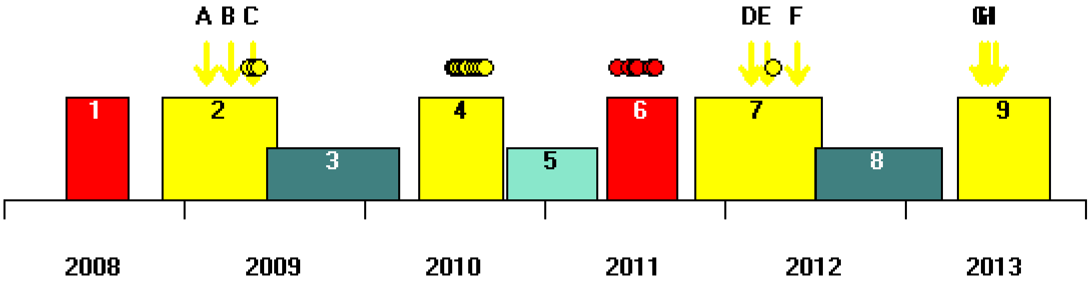

Figure 16. Crop sequence, fertilizer application and irrigation during the trial. Numbers represent crops grown: (1) Soybean, (2) winter wheat, (3) alfalfa, (4) grain maize, (5) cereal green manure, (6) soybean, (8) winter wheat, (9) alfalfa and (10) grain maize. Capitals represent fertilizer additions of pig bristles and dots reflect time of irrigation representing 30 mm each.

For the four treatments we simulated four scenarios and evaluated the effect of an introduction of an adjustable decay factor in the NDICEA model:

- The first default scenario consists of running the scenarios with the default NDICEA decay factor and evaluate the model outcomes;
- The second manual scenario is to calibrate the scenarios using the decay factor as one and only variable, in order to scout the potential of the model adaptation (different values of the decay factor in case of different tillage systems). The decay factor with default value 0.86 could vary from 0.1 up to a maximum of 1.6 These limits are model fixed limits which are far below the lowest default value respectively far above the default highest value.
- The third automatic scenario is to improve results by using the calibration function of the model (Burgt et al., 2006). In this function 11 soil parameters are adapted, among them the decay factor.
- The fourth combined scenario is a combination of the second and the third approach. The ploughing treatment was automatically calibrated, and the resulting soil parameters were used as input for the other three treatments. After this the decay factor was manually calibrated.

8.4 Performance statistics of the model

The quality of the model results were evaluated by means of three criteria:

- The root mean squared error of simulated and measured soil mineral nitrogen (RMSE N-min), with low values representing better model results than high values. For the RMSE of the soil mineral nitrogen a threshold of 20 kg N ha^{-1} is suggested by Van der Burgt et al. (2006) with levels below 20 kg N ha^{-1} being considered as acceptable for field scale results.
- The number of occasions (%) in which nitrogen availability (N-a) is lower than total crop nitrogen uptake (N-u). In reality these occasion cannot exist: a crop cannot take up more nitrogen than available. Therefore less that 10% is considered by us as acceptable in case of default N-content data of the crops and catch crops. When crop N-content and crop residue N-content are measured, no underestimation of N-availability should be accepted as model result.

Besides these quantitative criteria the model results can be visually examined. An important qualitative aspect is a pattern in observed and measured soil mineral N, for example a structural overestimation or underestimation of results. This visual judgement can be replaced and quantified by a combination of average error and number of measurements below and above simulated level. In this study this is not done.

The RMSE could also be calculated using the soil organic matter as criteria. This is not done because the input data of soil organic matter are considered by us as too unreliable (next paragraph).

8.5 Results

Evaluating the input data

Measured yields in the first two years vary considerably over the four treatments, with lower yields in the treatments with reduced tillage. In time they show a tendency to converge. In Figure 17 the relative yield for each year is plotted against time. In each year, average yield is equal to 1.00.

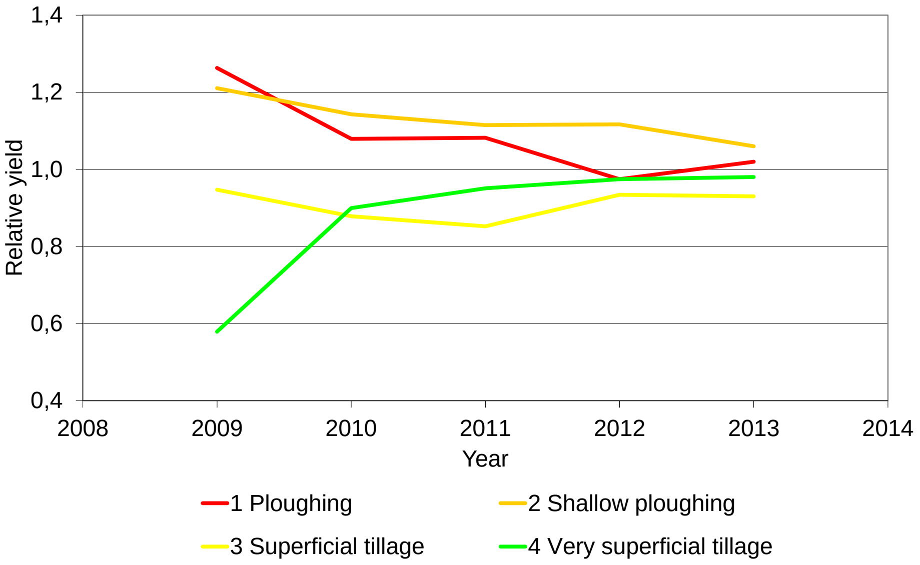

Figure 17. Relative yields as calculated for the four treatments.

Soil mineral-N (Figure 18) was simulated close to experimental results for most years. A level of around 150 kg N.ha^{-1} was found in 2010 in all four treatments; this could not be simulated by the model and could not be explained otherwise than a wrong analysis result and was considered unreliable. It was not taken into account in further simulations and evaluation.

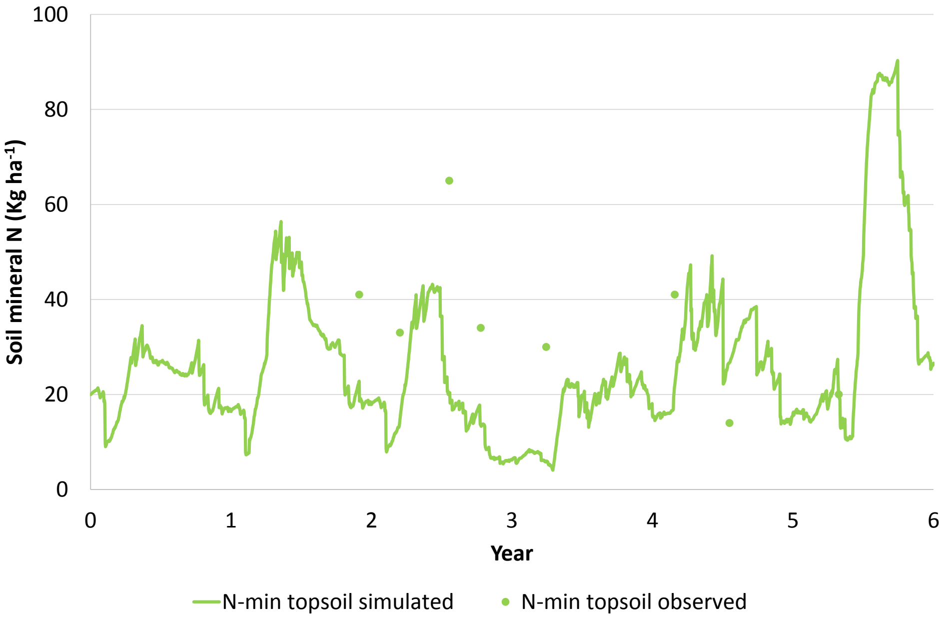

Figure 18. Illustration of the soil mineral N (N-min in 0-30 cm. Treatment 1, default scenario.

In Figure 19 the measured percentage of soil organic matter is plotted against the years, The starting value of soil organic matter was different for each treatment, varying from 1.63 % in treatment 1 up to 1.85 % in treatment 4. Therefore the graph is harmonized for the average starting value of the soil organic matter of the four treatments, being 1.78%.

The measured soil organic matter data show some year-to-year variations which cannot be explained by actual scientific knowledge about organic matter input and decay. In general, organic matter measurements are not very reliable, which might contribute to this disputable data set. Based on these input data, it is hard to conclude that reduced tillage leads to a build-up of soil organic matter.

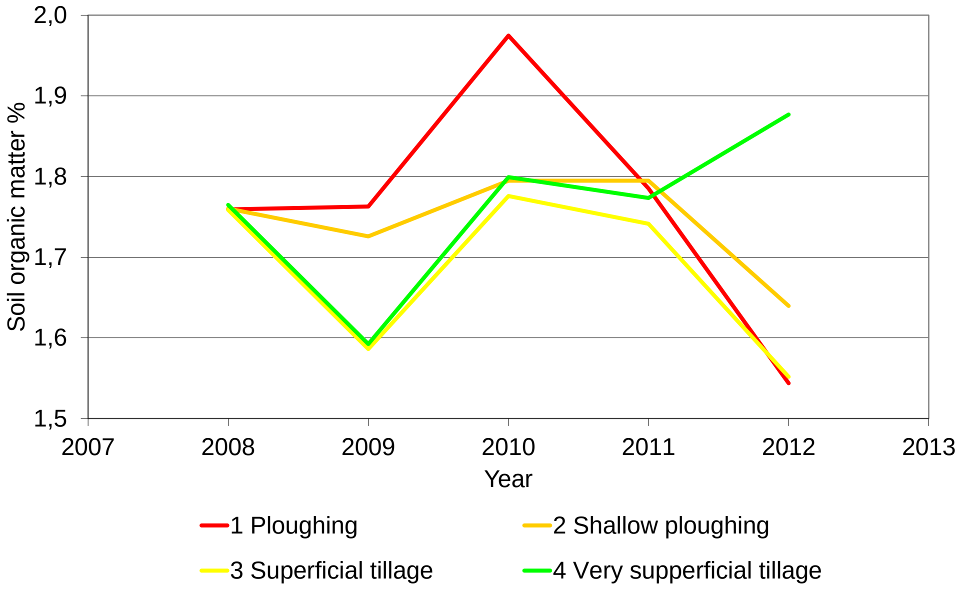

Figure 19. Course of soil organic matter in time; harmonized at the start value in 2008 of 1.78%, being the average of the four treatments.

8.6 Evaluating model results

Default scenario

Results presented in Table 12 show that simulating the experiments with the default decay factor of 0.86 for a loam soil results in two treatments in a RMSE for the N-mineral above the acceptable level of 20 kg N ha^{-1}. The shallow ploughing treatment (2) showed one exceptional and very unrealistic high value for N-mineral which was left out of this evaluation, resulting in n=7 for this treatment; the others have n=8.

There is no occasion in which the calculated available nitrogen is not sufficient to cope with the crop uptake. This indicates that there is no underestimation by the model of available N.

Visual assessment of results showed that there is a general trend for the simulated soil mineral nitrogen to be lower than observed. This is also the case for the soil organic matter. These results contradict each other. An increased decay of soil organic matter might increase the level of soil mineral N and thus make a better match with the observed values, but this will worsen the soil organic matter match between observation and simulation.

As a kind of control, the default scenarios were run with another soil type: clay loam respectively sand instead of loam. This results in another set of default soil parameters with among them a lower decay factor (clay loam) and a higher decay factor (sand). None of these two alternatives results in a better model performance than the default loam soil parameter set (data not shown). In other words, the soil parameter set related to loam, selected because of the given soil characteristics in the dataset, gives the best results.

Table 12. Performance statistics of the four scenarios simulating the four tillage treatments of the experiment in southern Franc.

	Scenario	Ploughing	Shallow ploughing	Superficial tillage	Very superficial tillage
RMSE N-min (kg ha^{-1})[1]	Default	23	21	15	20
	Manual	15	14	13	15
	Automatic	13	13	14	17
	Combined	13	13	14	17
N-a< N-u (%)[1]	Default	0	0	0	0
	Manual	0	0	0	0
	Automatic	0	0	0	0
	Combined	0	0	0	0

[1] n=8 except for shallow ploughing where n=7

Manual scenario

In the manual scenarios the decay factor could vary from the default value of 0.10 to a maximum of 1.60. The RMSE of the soil mineral nitrogen was taken as reference for calibration.
In all tillage treatments the RMSE improved (all values <20) but decreased until the decay factor reached its maximum value of 1.60. This means that a decay value higher than 1.60 might still increase the model result. However, this is not realistic. A value of 1.60 or higher results in a very high decay of soil organic matter and is, so far, never found using the NDICEA model.
Calculated available nitrogen remained above crop uptake in all treatments

Automatic scenario

The RMSE of soil mineral nitrogen improved substantially (Table 12) when automatic calibration was applied using the 11 soil parameters including the decay factor (Table 13). In other words, the automatic calibration function creates improved and more realistic tillage model effects than the manual calibration with the decay factor as floating variable alone.

Table 13 shows the resulting parameters from the automatic calibration. There are three parameters with big differences between default and calibrated values and with substantial influence on the outcome: the decay factor, the topsoil N-leaching factor and the IAge of the old organic matter pool in the soil.

- Higher value of the decay value results in an overall higher decay of soil organic matter;
- The lower value of the IAge of the old organic matter pool also results in a higher decay. Both result in a higher N-mineralization and to a potentially increased soil mineral nitrogen level;
- The result of the higher value of the topsoil N-leaching factor is more complex to interpret. Overall it will decrease the level of soil mineral nitrogen in the topsoil.

Table 13. Resulting soil parameters applying the automatic calibration scenario.

Parameter[1]	Default value	Ploughing (n=8)	Shallow ploughing (n=7)	Superficial tillage (n=8)	Very super-ficial tillage (n=8)
Decay factor	0.86	1.05	1.10	1.04	1.01
N leaching factor topsoil	0.85	0.79	0.97	1.00	1.09
IAge old	24.0	17.7	15.16	17.95	17.34
IAge young	4	6.11	9.42	6.67	6.57
IAge fresh	1.4	2.0	1.9	1.9	2.0
N leaching factor subsoil	0.85	0.86	0.74	0.93	0.83
MWO	0.75	0.79	0.80	0.80	0.83
C/N	6.50	7.46	7.74	6.67	7.31
A/D	0.40	0.35	0.40	0.40	0.34
N-fixation barrier	15	12	14	15	15
Denitrification factor	0.10	0.05	0.06	0.11	0.08

[1] Decay factor: general factor on rate of decay of organic matter; N-leaching factor: ratio between n-leaching and water leaching; IAge old: virtual age of the pool 'old soil organic matter', IAge young: virtual age of the pool 'young soil organic matter'; IAge fresh: virtual age of the pool 'freshly applied soil organic matter', MWO: defines relative water uptake from topsoil and subsoil; C/N: Carbon / Nitrogen ratio of soil life; A/D: assimilation / dissimilation ratio of soil life; N-fixation barrier: soil mineral N level at which N-fixation by leguminous crops is hampered; Denitrificaton factor: general factor on rate of denitrification.

Calculated available nitrogen remained above crop uptake in all treatments

Combined scenario

In the combined scenarios all calibrated soil parameters except for the decay factor have the value from the Ploughing treatment, Table 13, 3rd column. The decay factor was manually calibrated, resulting in acceptable RMSE values (Table 12) and decay values as presented in Table 14.

Table 14. Resulting decay factor for the treatments in the combined calibration scenario.

Parameter[1]	Ploughing (n=8)	Shallow ploughing (n=7)	Superficial tillage (n=8)	Very super-ficial tillage (n=8)
Decay factor	1.05	1.15	0.69	0.85

8.6 Discussion and conclusion

Tillage treatments could not be satisfactorily simulated by NDICEA using a default soil parameter set related to loam, but replacement of the soil parameter set by soils with another texture worsened the results. Manual calibration of the decay factor, using soil mineral N data, improved the RMSE but resulted in unrealistic values of the decay factor. This indicates that other soil parameters are at least covariants in the process.

The automatic calibration, including 11 soil-related parameters, results in both acceptable RMSE levels and decay factor values within a realistic range. Nevertheless there is no clear trend in decay factor value going from conventional soil tillage (treatment 1) to very reduced soil tillage (treatment 4) (Table 13). The resulting values of the decay factor show a small range (1.10 – 1.01). The combined approach results in acceptable RMSE levels and decay factor values within a realistic range, but the range is much wider than in the automatic calibration scenario (Table 14: 1.15 – 0.69). Again, there is no clear relation between decay factor value and treatment, although the non-ploughing treatments (3 and 4) show a substantially lower decay factor value than the ploughing treatments (1 and 2).

The original dataset has some limitations. Differences in yield do not coincide with differences in (modelled) nitrogen dynamics. The observed soil organic matter data show year-to-year variations which cannot be explained by organic matter input and decay and are not taken into consideration.

The default soil parameter set, with the same decay factor for all treatments, did not result in an overall acceptable model result.

Differentiation of the decay factor, as was part of our hypothesis, leads to better model performance: a reduced RMSE of observed and simulated soil mineral N level. Automatic calibration (11 soil parameters) and combined calibration (10 soil parameters automatic, decay factor manually) lead to acceptable model results and decay factor values within a realistic range. This range is very small for the automatic procedure (1.10 – 1.01) and wide for the combined procedure (1.15 – 0.69). The range proposed for loam is 0.96 – 0.60 (Chapter 7).

The hypothesis that treatments with stepwise reduction of tillage can best be simulated within NDICEA using a stepwise lower decay factor is confirmed nor rebutted. The treatments with the least intensive tillage have indeed the lowest decay value, but there is not a clear order from ploughing up to very superficial tillage. Other datasets must be used to contribute to confirmation of the hypothesis.

Acknowledgements

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Annex I

Simulated soil organic matter levels by the NDICEA model after a time frame of 15 years with different values of the decay factor. The default value of the decay factor, 0,96, results in a stable soil organic matter level.

Decay factor	Soil organic matter after 15 years (kg ha^{-1})	Soil organic matter after 15 years (%)	Organic matter increase (%)	Organic matter increase (kg o.m.)	Organic matter increase (kg C)
1,36	70727	1,75	-8,9	-6910	-4008
1,28	71858	1,77	-7,4	-5779	-3352
1,20	73289	1,81	-5,6	-4348	-2522
1,12	74496	1,84	-4,0	-3141	-1822
1,04	76153	1,88	-1,9	-1484	-861
0,96	77637	1,92	0,0	0	0
0,88	79547	1,96	2,5	1910	1108
0,80	81152	2,00	4,5	3515	2039
0,72	83494	2,06	7,5	5857	3397
0,64	86018	2,12	10,8	8381	4861
0,56	88123	2,18	13,5	10486	6082
0,48	91527	2,26	17,9	13890	8056

Annex II

Simulated soil organic matter levels by the NDICEA model after a time frame of 100 years with different values of the decay factor. The default value of the decay factor, 0,96, results in a stable soil organic matter level.

Decay factor	Soil organic matter after 100 years (kg ha^{-1})	Soil organic matter after 100 years (%)	Organic matter increase (%)	Organic matter increase (kg o.m.)	Organic matter increase (kg C)
1,36	57695	1,42	-25,7	-19942	-11566
1,28	60462	1,49	-22,1	-17175	-9962
1,20	64785	1,60	-16,6	-12852	-7454
1,12	67836	1,67	-12,6	-9801	-5685
1,04	73356	1,81	-5,5	-4281	-2483
0,96	77637	1,92	0,0	0	0
0,88	84697	2,09	9,1	7060	4095
0,80	91873	2,27	18,3	14236	8257
0,72	98939	2,44	27,4	21302	12355
0,64	109031	2,69	40,4	31394	18209
0,56	115806	2,86	49,2	38169	22138
0,48	131239	3,24	69,0	53602	31089