Tillage effects on soil organic matter preservation and weed suppression by *Trifolium repens*

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Period: July 1st, 2009 – February 9th, 2010

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Preface

It all started about one year ago. Although I had no clear idea about what my Msc thesis would be about and who would supervise me, I did know for sure that I wanted to do fieldwork in an applied research setting. One year later, I can say to my delight that this is exactly what I ended up doing. From July 2009 until February 2010 I had the honor to be part of the BASIS project, carried out by the farming systems group of PPO Lelystad. This project is dedicated to testing, evaluating and improving alternative forms of tillage, in particular minimum tillage and non-inversion tillage, with respect to their agronomical and environmental performance. In this context, special attention is given to the preservation and improvement of soil quality. Within this project, it has been my task to investigate the interactive effects of tillage and white clover on soil organic matter and weed growth. This topic satisfied my growing interests in nutrient cycling, the function of organic matter in organic farming systems and effects of management practices on weed populations. No less important, the field work associated with the investigation enabled me to combine this interest with my passion for the outdoors.

Supported by Wiepie van Leeuwen and Derk van Balen at PPO Lelystad and Johannes Scholberg at the biological farming system group (BFS), I was able to carry out my fieldwork, data analysis and thesis writing in an enjoyable and productive way. Also, I could not have done without the great support from all BFS and OBS colleagues and the great help from Geert-Jan van der Burgt (LBI) with respect to modeling the nitrogen flows in my plots in NDICEA. Furthermore, I should not forget the lab-analysts at PPO Lelystad and BFS, in particular Hennie Halm, who assisted me with the analysis of soil and plant samples. Thank you all very much for your support, help and advice. And I am also very grateful for the good times we shared. Last but not least, I would like to thank my family, boyfriend and friends for their great care after long days of fieldwork and for being patient and supportive when I had my stressful moments.

By supplying data from field research and relating these to modeling results and current knowledge in the field of minimum tillage and green manures, I hope to have contributed to the accumulation of knowledge within the BASIS project. Only time can tell what the practical relevance of this work will be, but I am confident that the BASIS project and the dedicated researchers associated with it will somehow have a role in assisting farmers to develop sustainable soil tillage techniques. This will hopefully result in the preservation and maybe even improvement of the quality of Dutch the soils.

Nederlandse samenvatting

Grondbewerking versnelt de afbraak van organische stof doordat gewasresten worden ingewerkt en beïnvloedt tevens de bodemstructuur. Minimale grondbewerking wordt daarom gezien als een veelbelovend alternatief voor het preserveren van bodemorganische stof en het behouden van de bodemstructuur. Echter, is grondbewerking nog steeds erg belangrijk voor het bestrijden van onkruiden. Bij minimale grondbewerking vormen onkruiden een groot probleem, met name in de biologische landbouw waarin het gebruik van chemische bestrijdingsmiddelen niet wordt toegestaan. Hier komt bij dat de verminderde stikstofmineralisatie ten gevolge van minimale grondbewerking gecompenseerd moet worden door een verhoogde aanvoer van organische mest, een verminderde afvoer van gewasresten of door het gebruik van groenbemesters in de herfst en winter. Groenbemesters en gewasresten blijken ook een positief effect te hebben op onkruidonderdrukking, maar bij gebruik van granen met een hoge C/N verhouding wordt tevens de mineralisatie van organische stof vertraagd. Door het gebruik van een vlinderbloemige groenbemesters kan dit worden voorkomen. Verder onderzoek naar de interactie tussen minimale grondbewerking en het gebruik van (vlinderbloemige) groenbemesters met betrekking tot de effecten op bodemorganische stof, minerale stiksof en onkruidonderdrukking lijkt daarom veelbelovend.

Dit onderzoek had als hoofddoel het vergelijken en kwantificeren van de (interactieve) effecten van grondbewerking en een vlinderbloemige groenbemester op de bodemorganische stof, minerale stikstof en onkruidonderdrukking. Hierbij werd een vergelijking gemaakt tussen het standaard, in Nederland gebruikelijke ploegsysteem en een minimaal ploeg systeem. Daarnaast werd in de zomertarwe een onderzaai van witte klaver vergeleken met een onbedekte grond. Verder werd er ook een vergelijking gemaakt tussen de resultaten van veldonderzoek en de resultaten van het NDICEA model, met als doel het bepalen van de accuraatheid van NDICEA met betrekking tot het modeleren van de effecten van grondbewerking en witte klaver op bodemorganische stof en minerale stikstof.

Het veldonderzoek werd uitgevoerd van juli tot en met november 2009, op proefboerderij “de Broekemahoeve” nabij Lelystad in de Flevopolder. Alle metingen werden uitgevoerd in vier herhalingen voor twee verschillende ploegsystemen in combinatie met een onderzaai van klaver of een onbedekte bodem. Dit leverde een totaal op van 16 meetveldjes. Maandelijks werden er onkruidmetingen uitgevoerd, waarbij de onkruiddruk en de onkruiddiversiteit op verschillende manieren in kaart werd gebracht. Verder werden er op vier verschillende momenten bodemmonsters genomen: net voor de oogst van de zomertarwe, vlak na het onderploegen van de witte klaver in het standaard ploegsysteem en op twee tussenliggende momenten. Van de eerste en de laatste bodemmonsters werd zowel de bodemorganische stof als de minerale stikstof bepaald. De tussenliggende monsters werden alleen geanalyseerd op minerale stikstof. De bepaling van bodemorganische stof werd gedaan volgens de gloeiverlies methode en de minerale stikstof werd bepaald door extractie met calciumchloride.

De afbraak van organische stof en de stikstofdynamiek in de periode 2005-2009 werden ook gemodelleerd met NDICEA. Voor de data invoer zijn bodem-, gewas-, bemestings- en grondbewerkingsgegevens gebruikt uit de digitale database van “de Broekemahoeve”. Voor de weergegevens werd gebruik gemaakt van wekelijkse temperaturen, ter beschikking gesteld door weerstation Zeewolde en neerslaggegevens verzameld op de proefboerderij. Voor het maken van voorspellingen met betrekking tot de organische stof en stikstofdynamiek gedurende de volgende jaren van het experiment (2010-2012) werd de simulatieperiode uitgebreid met drie extra jaren. Hiervoor werden neerslag en temperatuur gegevens gebruikt van een gemiddeld jaar in de Flevopolder. De invoergegevens voor de gewasrotatie, bemesting en grondbewerkingen zijn gebaseerd op de huidige project plannen.

De resultaten met betrekking tot bodemorganische stof waren niet eenduidig, doordat interpretatie van resultaten uit veldonderzoek belemmerd werd door het effect van twee verschillende voorvruchten (witte kool en ui). Voortzetting van de bodembemonstering in

2010 lijkt daarom vereist. Echter, het NDICEA model voorspelde dat de effecten van de verschillende voorvruchten ook volgend jaar nog zichtbaar zullen zijn, ten gevolge van het aanvoeren van 25 ton ha^{-1} vaste rundermest in het uiperceel. Verder zorgt de aanvoer van grote hoeveelheden organische mest in het standaard ploegsysteem ervoor dat de positieve effecten van minimale grondbewerking op de lange termijn niet zichtbaar zijn. Bij deze voorspelling moet echter wel een kanttekening worden geplaatst, omdat NDICEA de mineralisatie ten gevolge van grondbewerking op de lange termijn lijkt te overschatten.

Ook het interpreteren van de effecten van grondbewerking en witte klaver op de minerale stikstof werd bemoeilijkt door verschillen in voorvrucht. Echter lijken de door NDICEA voorspelde effecten van verschillen in voorvrucht op minerale stikstof wel af te nemen. Voortzetting van het experiment lijkt daarom vereist voor het verkrijgen van een beter inzicht in de stikstofdynamiek op systeemniveau. Ook lijkt er in NDICEA een effect te zijn van witte klaver en grondbewerking. De minerale stikstofgehalten zijn gemiddeld hoger in onbedekte grond en in het standaard ploegsysteem, wat overeenkomt met de verwachtingen. Het is echter de vraag hoe accuraat deze voorspellingen zijn, omdat NDICEA op de lange termijn de hoeveelheid minerale stikstof lijkt te overschatten, met name gedurende het groeiseizoen van de zomer tarwe in 2009. Dit kan gedeeltelijk worden toegeschreven aan een overschatting van de door grondbewerking veroorzaakte stikstof mineralisatie in combinatie met een constante textuur factor. Door deze overschatting worden de waargenomen verschillen tussen ploegsystemen beïnvloed. Daarom kan NDICEA alleen gebruikt worden in wetenschappelijk onderzoek naar de effecten van minimale grondbewerking als er eerst modelverbeteringen worden doorgevoerd met betrekking tot de berekening van de lange termijn effecten van grondbewerking op stikstof mineralisatie.

Op het gebied van onkruidonderdrukking kon geen duidelijk interactie-effect van grondbewerking en witte klaver worden waargenomen. Ook in dit geval werd dit hoogstwaarschijnlijk veroorzaakt door een verschil in voorvrucht. Verder bleek dat binnen de huidige proefopzet geen vergelijking gemaakt kon worden tussen verschillende ploegsystemen met betrekking tot het interactieve effect van grondbewerking en witte klaver. Voor de start van nieuwe experimenten is het daarom van groot belang dat deze proefopzet wordt herzien. De huidige resultaten lijken echter wel veelbelovend, omdat op zichzelf staande effecten van grondbewerking en witte klaver in sommige gevallen al direct aangetoond worden. Verder blijkt uit andere onderzoeken dat duidelijke verschillen pas twee of drie jaar na de omschakeling zichtbaar worden. Op alle fronten is vervolg onderzoek daarom zeer aan te bevelen met als doel de huidige resultaten te onderbouwen, te verbreden en te valideren.

Summary

Tillage affects the decomposition of organic matter by incorporating crop residues into the soil. This increases the aeration and soil-residue contact and buffers the temperature and water level at which decomposition takes place, thereby positively affecting the mineralization rate. Minimum tillage is considered to hold promise for preserving soil structure and soil organic matter (SOM). However, minimizing tillage might also increase weed pressure and the associated labor for weed management, while reducing the efficacy of mechanical weed control. Additionally, the reduced nitrogen mineralization associated with minimum tillage requires increased use of organic manure, crop residues or green manures to retain nutrients in the system and to ensure adequate crop nutrient supply. Green manures and crop residues have also proven to suppress weeds. The downside of this approach might be competition with other uses for crop residue and, in case of cereals, the slow release of nutrients due to the high C/N ratios of straw. Nitrogen fixation by a leguminous green manure reduces the risk of potential N-immobilization. Taken the above aspects into consideration, it seemed relevant to investigate the interactive effects of minimum tillage and use of leguminous green manures on weed suppression and SOM dynamics.

Therefore, the main focus of this research was to quantify and compare the interactive effects of tillage (standard versus minimum tillage systems) and the use of a green manure (*Trifolium repens* versus black fallow) on weed suppression and SOM dynamics. Furthermore, an effort was made to assess the accuracy of NDICEA in modeling the effects of differences in tillage systems by comparing the results from the soil measurements with NDICEA-predicted values.

Field measurements were carried out from July until November 2009 on the experimental farm “de Broekemahoeve” in Flevoland, the Netherlands. The measurements were carried out in four repetitions for two different tillage systems (standard and minimum tillage) combined with white clover undersown in spring wheat or a black fallow, resulting in 16 different field plots. These measurements involved monthly weed surveys in which weed incidence and weed diversity were assessed. Additionally, soil samples were taken before harvesting spring wheat, at time of ploughing in the standard tillage system and in between both dates using approximately monthly intervals. The first and the last soil samples were analyzed for mineral nitrogen (Nmin) and SOM whereas in the interim period only soil Nmin content was determined. SOM analysis was performed using loss on ignition whereas the Nmin content was determined by extraction with 0.01M $CaCl_2$ using an auto-analyzer.

In order to model the SOM and nitrogen dynamics with NDICEA for the period 2005-2009, input data including soil parameters, crop rotation, tillage practices and manure applications were obtained from the digital database of the experimental farm. For the weekly temperature, region specific data were used supplied by the weather station in Zeewolde. Rainfall data were provided by the experimental farm itself. In order to predict the course of Nmin and SOM trends in future years of the experiment, the simulation runs were extended with three years (2010-1012). For these years, regional climate data for an average year were used and inputs regarding crop rotation, manure applications and tillage practices were based on the current project plans.

With respect to the effects of tillage and white clover on SOM preservation, the results appeared to be inconclusive. The field research showed no significant effect of tillage, due to a confounding effect of preceding crops. Continuation of the soil sampling and SOM analysis during subsequent years of the experiment therefore seems worthwhile. However, the NDICEA results also show that differences between pre-crops will persist, due to the application of 25 t ha^{-1} of cattle manure in onion plots. Furthermore, from NDICEA simulations it also appears that the beneficial effects of minimum tillage on SOM will not prevail, as a result of the application of larger amounts of organic manure in the standard tillage system. However, it should be noted that the NDICEA results are biased as a result of the tillage induced accumulation of Nmin and enlarged mineralization of SOM in the model, which appears to be an artifact of the model.

With respect to the effects of tillage and white clover on Nmin, differences in pre-crop again proved to hamper the interpretation of field data. However, the effects of pre-crop on Nmin are expected to decrease over time, which is supported by the NDICEA results. Therefore, continuation of the experiment might very well provide better insight on tillage effects on actual system processes.

The NDICEA results also indicated that on average the Nmin levels are higher in control plots and under standard tillage conditions, which is in agreement with the expectations and initial hypothesis. However, the results from NDICEA seemed to be inaccurate due to inherent model limitations. Especially during the growing season of spring wheat in 2009, the Nmin was greatly overestimated. This could be partly attributed to a tillage induced accumulation of Nmin over time in combination with a fixed texture factor. As a result, the differences between tillage systems become biased, by overestimating the Nmin in the standard tillage system. Therefore, for NDICEA to be used in scientific research concerning the effects of minimum tillage, it is essential to improve the model with respect to the calculation of long-term effects of tillage induced mineralization.

With respect to the effects of tillage and white clover on weed suppression, no interaction effect could be proven for weed incidence. Also in this case, the variation as a result of differences in pre-crop might have masked potential differences. Additionally, it was observed that the current experimental set-up did not allow for the comparison of interactive effects between tillage systems, which should therefore be reconsidered before starting the measurements in subsequent years. However, since separate effects of tillage and white clover can be detected on respectively weed density and weed DM and other experiments only report results after the 2nd or 3th year, the future prospects are promising. Continuation of the experiment is therefore highly recommended to support and proof this year’s findings.

1 Introduction

1.1 Societal background

In European countries, soil organic matter (SOM) content is rapidly declining. This is also recognized by the European union and in their soil strategy presented in 2006, the decrease in SOM was regarded as one of the 7 major risks for European soils (Smit et al. 2007).This decline in SOM is highly affected by human activities, such as land use, agronomic practices such as tillage, residue management and nature management. The preservation of SOM is of major importance, not only because it is a source of nutrients for arable crops, but also because soil organic matter has a beneficial effect on water retention and soil structure (Kristiansen et al. 2006). Organic farmers in particular are highly depended on the internal cycling of nutrients facilitated by the decomposition of organic matter, since the use of chemical fertilizers is not allowed under organic certification. Moreover, in the face of climate change, the sequestration of carbon in SOM is of major importance for the reduction of CO_2 concentrations (Yadav et al. 2009). This illustrates the need to preserve and improve SOM levels while maintaining its function in the supplying nutrients.

1.2 System approach

Because organic matter decomposition is a complex process, investigating the effects of agronomic practices on SOM and mineralized nitrogen (Nmin) requires a system approach. For this purpose, the use of computer models such as NDICEA (Van der Burgt et al. 2006) can be very helpful. This model assists farmers and researchers in predicting the on-farm nitrogen flows, which allows them to optimize their management practices and increase nitrogen efficiency at the farm-level. Next to external inputs from manure and crop residue, the decomposition of organic matter is an important component of this model.

Organic matter is added to the soil by incorporation of plant residues. In the soil, residues are decomposed by the joined action of soil biota and micro-organisms, resulting in the formation of CO_2, energy, water, plant nutrients and stable humus. This results in a carbon flow that is visualized by the black arrows in Figure 1. SOM can be divided in a labile fraction consisting of recently added SOM that is easily decomposable and a stabile fraction that is more recalcitrant. Most of the organic matter decomposition occurs in the labile organic matter fraction (Arrouays and Pelissier 1994;Cambardella and Elliott 1992;Schlesinger 1991;Harrison et al. 1993;Janzen et al. 1997). The rate of decomposition is influenced by many factors, such as the amount of micro-organisms in the soil, temperature, pH, moisture content, oxygen availability, clay content, the C/N ratio of organic matter, micro-organisms, and the amount of recalcitrant material such as lignin in the substrate (Miller and gardiner 2001;Prasad and Power 1997).

Many of the previously mentioned parameters influencing decomposition can be affected by agronomic practices. Currently, the negative effects of soil tillage on SOM receive increased attention. The reliance on tillage for weed management and improving soil structure has negative effects on soil organic matter by increasing the rate of mineralization (Buhler 1995). Tillage results in favorable conditions for SOM decomposition, by incorporating the plant material into the soil (Cherr et al. 2006;Schomberg et al. 1994). This buffers the temperature and water levels at which decomposition takes place and increases the soil aeration and soil-residue contact, thus improving the availability and conditions for soil biota and micro-organisms (Cherr et al. 2006;Schomberg et al. 1994). Therefore there is an increased interest in minimum tillage, which reduces soil erosion and fossil fuel use, enhances soil structure and preserves soil organic matter and nutrient accumulation (Buhler 1995;Peigne et al. 2007).

Nonetheless, disadvantages of minimum tillage practices have also been reported. First of all, Giller *et al* (Giller et al. 2009) pointed to the potentially competing uses for crop residues and lack of external inputs as being major constraints for its implementation. Furthermore, the reduction of tillage results in many cases in increased weed pressure and therefore a larger reliance on herbicides or an increased labor demand for weed control (Buhler 1995;Giller et al. 2009). This is accompanied by a reduced efficacy of mechanical weed control due to an increase in soil surface residue (Buhler 1995). Furthermore, Peigné *et al* (Peigné, 2007) reported a restricted crop choice and a reduced nitrogen availability as important disadvantages. This poor nitrogen availability is a result of the slow nutrient release from crop residue with a high C/N ratio and the reduced mineralization rate under minimum tillage conditions. Therefore, especially in organic systems, in which the internal cycling of nutrients is very important and the use of chemical herbicides is prohibited, the successful adoption of minimum tillage practices can be challenging.

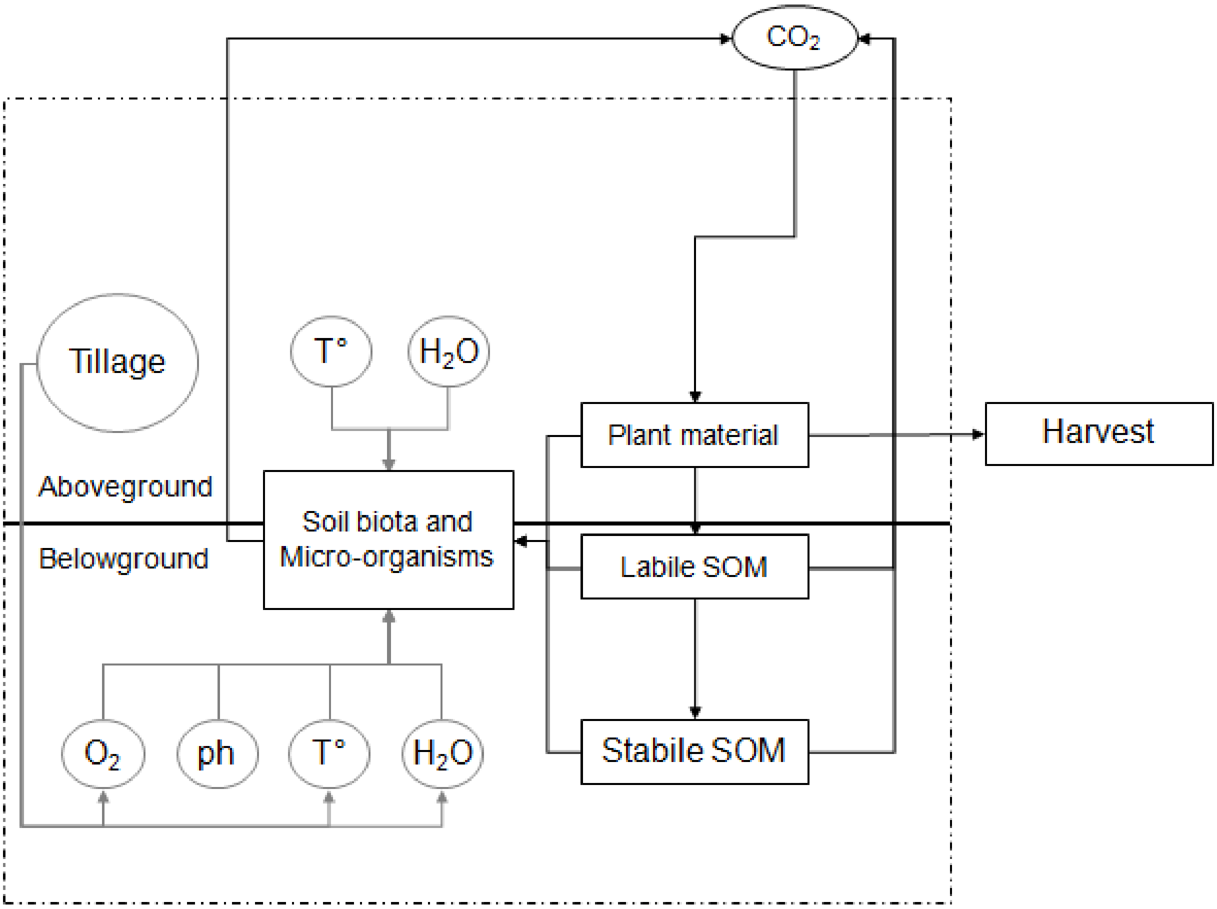

Figure 1: Schematic representation of carbon flows in a field
Carbon fixed by plant material is incorporated into the soil making it available for decomposition by micro-organisms and soil biota. The black arrows represent carbon flows between carbon stocks whereas the gray lines represent factors affecting the process of decomposition.

Another strategy to increase and preserve SOM in organic systems is to include green manures into the crop rotation. These crops may increase inherent soil fertility and crop performance by reducing soil erosion, retaining nutrients and adding organic matter to the soil (Cherr et al. 2006;Teasdale 1998). By using a leguminous green manure, subsequent crops can also benefit from the nitrogen fixation during autumn. Moreover, it has been shown that green manures are capable of suppressing weeds by preventing weed germination and reducing the development and growth of weed seedlings (den Hollander et al. 2007b).

However, the beneficial effects of green manures on SOM might be counteracted by soil tillage. Therefore, a promising solution might be to combine the use of green manures with minimum tillage. It is assumed that this might result in an increase in SOM, while the increased weed establishment associated with minimum tillage is being counteracted by the weed suppressive effects of the cover crop. In case of a leguminous green manure, which fixates nitrogen resulting in a decreased C/N ratio, the reduced nitrogen availability associated with minimum tillage might also be overcome. Although several institutions are working on the interactive effect of tillage and green manures or a related topic, little scientific publications could be found on this topic that are relevant to the Netherlands. In the Netherlands, minimum tillage is still in its infancy and research projects on this topic have just been started. Additionally, little research was performed under conditions with minimum tillage and zero herbicides (Teasdale 1998). Therefore investigating the performance of green manures under minimum tillage conditions in organic systems is essential for its large-scale adoption in organic farms in the Netherlands.

1.3 Objectives and hypotheses

This research aims to investigate the interactive effects of using a green manure and soil tillage in an applied research context. The focus will be on SOM preservations and weed suppression by white clover (*Trifolium repens*) undersown in spring wheat (*Triticum aestivum*) on an organic arable farm in the Northern part of the Netherlands. The beneficial effects of this practice on SOM and Nmin have already been observed in applied farming systems research conducted by researchers from Praktijkonderzoek Plant en Omgeving (PPO) (Van Leeuwen-Haagsma and Schröder 2003). Also, the weed suppressive effects of white clover have been confirmed in studies from den Hollander *et al* (den Hollander et al. 2007a, 2007b). However, former research did not investigate the effectiveness of undersowing white clover under minimum tillage conditions. Furthermore, it is unknown whether the effects of differences in tillage systems on SOM decomposition can be accurately predicted by NDICEA.

Therefore, the main focus of this research is to quantify and compare the interactive effects of tillage (standard versus minimum tillage systems) and the use of a green manure (*Trifolium repens* versus black fallow) on weed suppression and SOM dynamics. Furthermore, an effort was made to assess the accuracy of NDICEA in modeling the effects of different tillage systems by comparing the results from soil measurements with NDICEA-predicted values. An effort was made to answer the following research questions:

1) What are the differences between the minimum and standard tillage system with regard to the effects of undersowing white clover in spring wheat on:
   a) soil organic matter?
   b) N mineralization?
   c) weed suppression?
2) How accurate does NDICEA model the interactive effects of white clover and tillage on SOM and N mineralization?

It was hypothesized that changes in tillage and undersowing white clover (1a), will only result in detectable differences in SOM after a number of years. Therefore, effects are not expected to be statistically significant during the first year of the experiment. However, with regard to the effects of tillage and white clover on Nmin (1b), higher levels are expected in the standard tillage system compared to the minimum tillage system, since soil tillage results in an increased mineralization rate (Buhler, 1995). Additionally, the Nmin content will probably be lower in clover plots than in control plots due to nutrient uptake by white clover. With regard to the effects of tillage and white clover on weed growth and weed suppression (1c), a lower weed incidence (in terms of density, dry matter (DM) production and cover) is expected in white clover-based systems compared to a black fallow control as related to an increased competition for light, water and nutrients (Hoffman and Regnier 2006;Radosevich et al. 1997;Teasdale 1998;Teasdale et al. 2007;Teasdale and Mohler 1993). Furthermore, it is assumed that the weed incidence will be lower in the standard tillage system than in the minimum tillage system (Buhler 1995;Carter 1994;El Titi 2003;Giller et al. 2009;Rickson 1994;Rieck 1981;Tebruegge and Boehrnsen 1997). Consequently, it is hypothesized that weed suppression by white clover is most efficient in the standard tillage system. The differences in tillage system will probably be accompanied by a shift in weed population from mostly annual weeds in the standard tillage system to an increased incidence of winter annuals, bi-annuals and perennials in the minimum tillage system (Buhler 1995;El Titi 2003). Finally, species diversity is expected to be higher under minimum tillage conditions (Murphy et al. 2006).

1.4 Structure chapters

An outline of the experimental design and the statistical analysis is provided in Chapter 2. This includes descriptions of the location, the different tillage systems and the field history with regard to manure applications and tillage practices. Chapter 3 will be dedicated to the effects of tillage on SOM preservation in white clover-based systems as investigated in field research. In the first part, a brief review is provided on effects of tillage and green manures on SOM dynamics. This will be followed by a description of the methodology, a discussion of the results and preliminary conclusions. Chapter 4 will deal with effects of tillage on weed suppression by white clover in the same manner. In Chapter 5, the effects of differences in tillage systems will be assessed with NDICEA. After describing the methodology and presenting the modeling results, a discussion will focus on comparing model simulations with field measurements. Chapter 6 aims to integrate separate system components, thereby providing a more holistic perspective for discussion, conclusions and recommendations.

2 Experimental design and statistical analysis

2.1 Experimental design

This research is part of the BASIS project, which assesses the effects of different tillage practices for 6 organic crops and 4 integrated crops. The experiments are located at the experimental farm “De Broekemahoeve”, Elandweg 84, Lelystad, the Netherlands, in a former sea area, “de Flevopolder”. The study site has a clay loam soil with a clay content of 18%. Each crop is grown under standard, intermediate, or minimum tillage conditions which are compared and evaluated with respect to several indicators. In this case standard tillage involves ploughing to a soil depth of 25 cm with reduced seedbed preparation. Under minimum tillage conditions, the soil is not being plowed and seeding is preceded by reduced seedbed preparation or direct seeding. Under intermediate tillage conditions, the soil is not being ploughed but loosened without inverting the soil. This type of “non-inversion tillage” is followed by and/or combined with reduced seedbed preparation and seeding. The experiment is carried out in 4 replications, allowing for scientific research as well as applied research with the aim of system innovation.

Within this setting, the effects of white clover, undersown in spring wheat, on SOM, Nmin and weed suppression were investigated in a field experiment on a field plot of 1.68 hectares. The variety of spring wheat used was Lavett. Sowing took place on April 6th, 2009 and the wheat was harvested on August 10th, 2009. During the growing season, mechanical weed control (harrowing and hoeing) was applied several times using a 3.15 meter wide tractor with a GPS system on permanent tracks. These tracks were also used to apply 2.3 t ha^{-1} of Activit (4,3,2) on April 24th, 2009 and 0.2 t ha^{-1} of Monterra-N+ (13,0,1) on June 18th, 2009. For the wheat harvest, a 6 meter wide standard combine was used.

Preceding crops during previous years included spring wheat (2005) and potatoes (2006) after which one year of grass/clover lay (2007) was grown to improve inherent soil fertility and to enhance soil structure. During 2008, the field was split in two with onion being grown on one half and white cabbage on the other half. Both crops received a different amount of manure, being 1.2 t ha^{-1} of Activit for onion which was applied in spring and 25 t ha^{-1} of cattle manure applied in autumn. White cabbage fields received 40 t ha^{-1} of cattle slurry which was applied during spring. Additionally, different tillage practices were being applied due to crop specific requirements. Therefore, the pre-crop was also included as a factor in the experiment, resulting in an experimental unit with 2 blocks and 2 replications per treatment.

For the experiment, a split plot design was used including 8 different plots that measured 12.9 x 85 m. Half of the plots was managed using standard tillage techniques while for the remainder minimum tillage practices were used. In addition to this, each plot was split up in 2 subplots with a gross size of 3.15 x 6 m and a net size of 4 x 2.15 m. The GPS coordinates of the corner plots have been summarized in Table 1.

Table 1: GPS coordinates of the corner plots

Nord	East
506486.9618	167950.4522
506406.8456	167949.6462
506406.8943	167968.0748
506481.8151	167967.7636

On June 4th, 2009, white clover was undersown in spring wheat in one of the 2 subplots whereas the other subplot served as a control without clover and could be characterized as a black fallow. The resulting experimental design is represented in Figure 2.

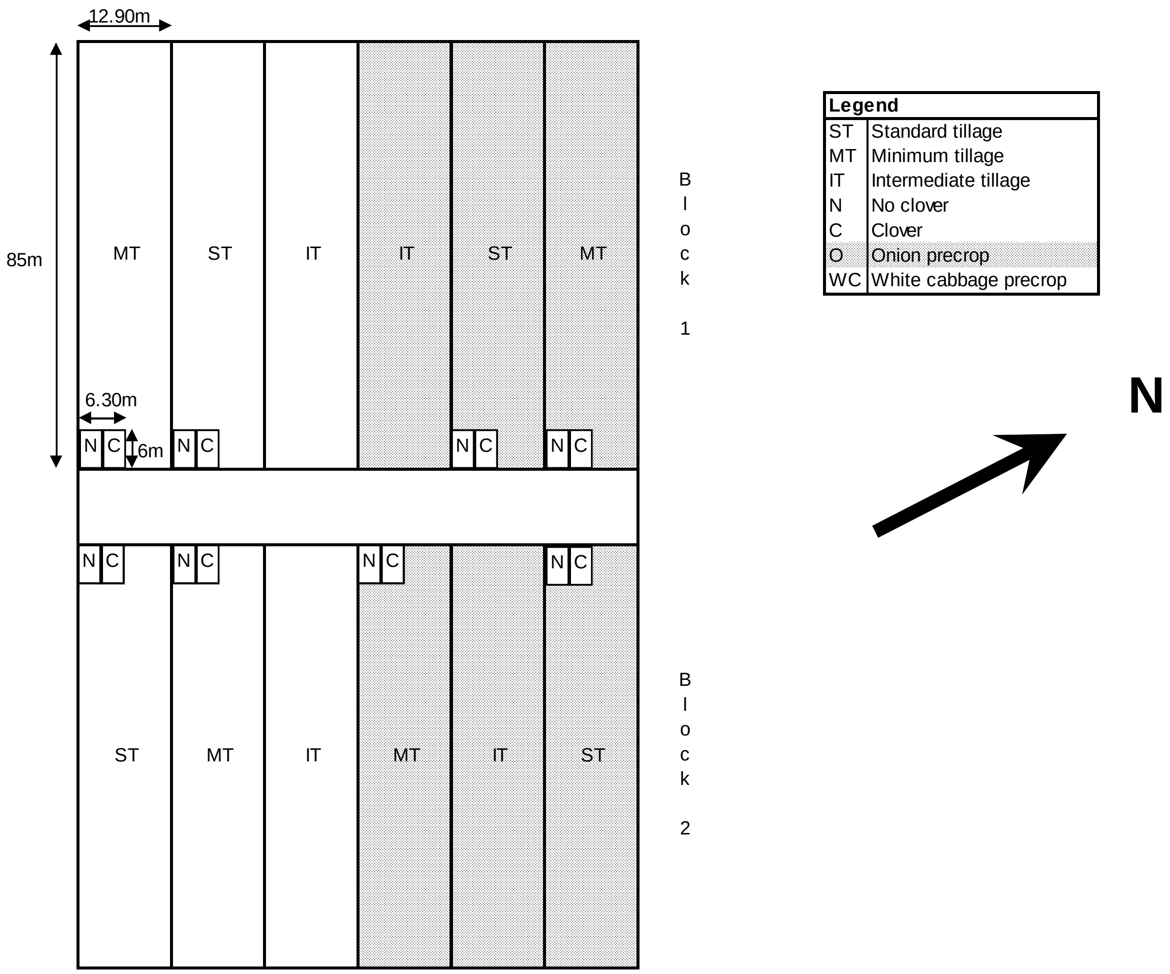

Figure 2: The statistical design of the experiment

2.2 Statistical analysis

The results were evaluated by comparing the effects of tillage, pre-crop and their interaction between plots and the effect of clover, sampling time and their interaction within plots using a repeated measures ANOVA procedure. Within this ANOVA procedure, the block effect has also been included as a factor. If interaction effects were significant, linear contrasts were used to further investigate differences between groups. Statistical analysis had initially been performed on the raw data. Analysis on log- and square root transformed data were performed to check the results of the unprocessed data. It was assumed that the data were normally distributed and that different groups had equal variances, although this could not be proven by statistical tests (Levene's test) due to the small sample sizes.

The loss of one standard control plot resulted in an unbalanced design. Although this loss is accounted for in the calculation of the total degrees of freedom it resulted in a larger MS_r and a lower F-value. However, this loss does not appear to affect the calculation of the means. The minimum tillage plots and clover subplots having a larger share in the calculation of the means, might increase the possibility of a Type-1 error making the test too liberal. However, since the effect of this missing value on the averages is considered to be minor, the statistical significance of observed differences was evaluated at a P-value of 0.05. Furthermore, weighed averages in the form of estimated marginal means were used to visualize the results.

3 Tillage effects on SOM preservation by white clover

3.1 Scientific background

3.1.1 Green manures and soil organic matter dynamics

The main purpose of including green manures into crop rotation is to reduce soil erosion and add organic matter and nutrients to the soil (Cherr et al. 2006). By providing a permanent soil cover, the soil is protected against nutrient and soil losses due to soil erosion. Furthermore, large amounts of carbon can be fixed during the growing season of the green manure in the process of photosynthesis resulting in the accumulation of organic matter. In addition to being a source of carbon, green manures can effectively trap residual soil nutrients, which reduces potential nutrient leaching during autumn and winter. When leguminous crops are used, substantial amounts of nitrogen can be biologically fixed from the atmosphere. Green manures might therefore provide a renewable source of nutrients if properly integrated into the existing production systems.

When selecting a green manure, its place within the existing cropping system is an important factor to be taken into account. Not only should the growing period of the crop match the fallow period, its nitrogen fixing capabilities should also be considered (Hoffman and Regnier 2006). Other important characteristics of a green manure are dry matter production, rapid root growth, canopy closure, C/N ratio, nutrient retention, winter hardiness and ease of incorporation. Leguminous crops might accumulate a lower amount of dry matter than non-leguminous crops and decompose more readily (Hoffman and Regnier 2006), although research from Askegaard and Eriksen (Askegaard and Eriksen 2007) shows the opposite to be true. Furthermore, there might be an increased risk of nitrogen leaching after leguminous cover crops due to slow initial growth and lower C/N ratios, as observed by van Leeuwen *et al* for a white clover undersowing (Van Leeuwen-Haagsma and Schröder 2003). Therefore it is preferred to use non-leguminous crops when their main purpose is to add organic matter and no additional nitrogen is required.

Another aspect to consider is the prevailing soil type. Usually the best performances of green manures as a source of nutrients and organic matter are to be expected on loamy soils, "due to their relatively high inherent fertility, water and nutrient retention capacity and microbial biomass" (Cherr et al. 2006). On the contrary, on sandy soils, there is a high risk of nutrient leaching as a consequence of a lower water retention and increased decomposition rates (Cherr et al. 2006). This is related to a relatively low protection of organic matter in soil aggregates and fewer associations between organic matter and minerals such as clay in sandy soils (Cherr et al. 2006). However a very high clay content is also not desirable since it reduces soil aeration. Therefore, the choice for a suitable green manure crop is also affected by prevailing pedoclimatic conditions.

Additionally, residue management should be fine-tuned to increase the efficiency of organic matter incorporation. Incorporation of residues into the soil might speed up the mineralization process because of the resulting buffering capacity of the soil after incorporation which reduces temperature and moisture fluctuations (El Titi 2003;Schomberg et al. 1994), increased soil residue contact and an increased exposure to soil organisms (Brown and Dickey 1970;Cogle et al. 1987;Douglas jr et al. 1980;Minderman 1968;Pekrun et al. 2003;Schomberg et al. 1994;Unger and Parker Jr 1975). This hypotheses is being supported by research from Hargrove *et al* (Hargrove et al. 1991), who reported increased mineralization rates for four different crops when incorporated into the soil (Schomberg et al. 1994). Therefore, proper timing of incorporation is critical to ensure that nitrogen mineralization from residue is synchronized with crop needs thus reducing nitrogen leaching risks.

Optimal management practices and favorable environmental conditions are essential for an effective build-up of organic matter. When they result in an enhanced mineralization of organic matter in the crop residue, the increase in soil organic matter might be relatively small (Cherr et al. 2006). Especially when the initial soil pool is relatively large, the amount of organic matter added might be insignificant. However, some current research studies show a promising increase in organic matter related to green manure applications ranging from 0-1%

of total organic matter per year. (Cherr et al. 2006;Reddy et al. 2003;Utomo et al. 1990). Unfortunately, these studies are usually relatively short, which implies little is known about the long-term benefits of applying a green manure with respect to soil organic matter management (Cherr et al. 2006).

3.1.2 Tillage and soil organic matter dynamics

It is generally acknowledged by scientists as well as farmers that soil tillage speeds up the mineralization process. Tillage results in the incorporation of residue into the soil which increases the decomposition rate of organic matter as explained previously (Schomberg et al. 1994). Nonetheless, this does not imply that intensive tillage results in an increased mineralization rate indefinitely. The reduction in the total amount of organic matter as a result of the increased mineralization caused by tillage results in a negative feedback loop, counteracting the increased mineralization as a result of tillage. Therefore, after a certain period, a new steady state is reached in which the production and mineralization of organic matter are again in balance (Janzen et al. 1997;Pekrun et al. 2003). The adoption of new agricultural management practices alters this balance, resulting in an increase or decrease of organic matter until a new steady state is reached (Janzen et al. 1997). In case of reduced tillage intensity, the speed of mineralization is being reduced, resulting in an increase in organic matter or reduced organic matter losses, depending on the stage the agricultural ecosystem is in. This is because residues are not incorporated in the soil but left at the soil surface, which slows-down the decomposition process. However, the steady state of the system is also being altered in this case. This indicates the need for research on both the short-term and long-term effects of reduced tillage on organic matter decomposition.

Initially, a conversion to conservation tillage changes the soil structure resulting in a reduced porosity, a less homogeneous distribution of organic matter and nutrients and a reduced water infiltration (Pekrun et al. 2003;Schomberg et al. 1994). These short-term effects also accumulate over time, resulting in additive effects on a system-level. Long-term adoption of conservation tillage should thus result in an accumulation of nutrients and organic matter near the soil surface, the formation of soil layers differing in characteristics, a larger microbial population and an increased moisture content (Pekrun et al. 2003). This accumulation of nutrients is illustrated by Hargrove *et al*, who observed higher nutrient concentration near the soil surface (0-7.5 cm) under conservation tillage than under than under conventional tillage (Hargrove et al. 1982; Schomberg et al. 1994). In conventional tillage, the distribution of nutrients appeared to be more homogeneous due to the mixing of soil layers after plowing. The results from Hargrove *et al* are supported by results from many other experiments as compared in a review from Pekrun *et al* (Pekrun et al. 2003). All studies included in the comparison confirmed the increase in organic matter in the topsoil under conservation tillage conditions. In some studies, this was the result of a decrease in organic matter in the subsoil whereas in others the organic matter content of the subsoil was not significantly altered. Therefore it can be concluded that conservation tillage results in a redistribution or accumulation of organic matter (Pekrun et al. 2003).

The effects of tillage are closely related to the effects of residue management. For this reason, an increase in organic matter content with conservation tillage is mainly due to the reduced decomposition rate of crop residues at the surface (Schomberg et al. 1994). However, it should be mentioned that optimal practices are highly depended on pedoclimatic conditions, residue quality, and specific crop requirements. For example in cool, wet climates or on poorly drained soils, conservation tillage and surface residues might reduce the crop yields along with an increase in nitrogen loss due to denitrification or leaching.

Several researchers have studied the interactive effects of tillage and residue management on organic matter decomposition. However, most of the studies were conducted on vertisoils or in (sub)tropical areas. Stanley *et al* (Schomberg et al. 1994;Stanley et al. 1990) reported that organic matter losses were the largest under conventional conditions where disk tillage was used and residues were removed. This was supported by research from Unger (Unger 1968), who showed for a wheat-fallow system a decline in organic matter of 35% under conventional tillage conditions compared to 17% when a delayed stubble mulch system was used in which residues remained on the soil surface (Schomberg et al. 1994). Under continuous cropping of wheat, the differences were insignificant. Bauer and Black compared tillage effects on soil organic carbon for different soil types (Bauer and Black 1981;Schomberg et al. 1994). They found a significantly smaller decline in organic matter for fine-textured soils with conservation tillage compared to conventional tillage, whereas for medium-textured soils tillage did not affect SOM accumulation. Moreover, tillage effects on soil organic matter appear to be also affected by crop rotation (Havlin et al. 1990;Schomberg et al. 1994).

Furthermore, the timing of tillage also comes to play since decomposition of organic matter is enhanced by an adequate moisture content and high temperatures. As a consequence, it is better to till the soil under cool and relatively dry conditions if organic matter formation is one of the main objective. This statement is supported by research from Francis *et al*, who reported reduced Nmin levels in winter when tillage was postponed to the winter period instead of being performed in autumn (Francis et al. 1995;Pekrun et al. 2003). An optimal timing of tillage is therefore essential in managing the seasonal nitrogen mineralization pattern and formation of organic matter. Also in conservation tillage, where cover crops have to be incorporated in the soil before the subsequent crop is being planted, the effects of temperature and moisture on the timing of incorporation should be considered as well. Although incorporation in spring might decrease the nitrogen leaching during winter time, the slow increase in mineralization due to rising temperatures during spring might not be optimally synchronized with crop nitrogen demand.

3.2 Material and methods

3.2.1. Soil sampling

The effect of white clover on the soil organic matter (SOM) content and Nmin was assessed by frequent soil sampling during the growing season of white clover. Before starting the experiment, a standard field description was made and a qualitative plot observation was carried out with a special focus on crop stand, disease presence and weed diversity. Furthermore, a baseline was established by soil sampling every plot at 3 different depths (0-15 cm, 15-30 cm and 30-60 cm) and analyzing samples for Nmin and SOM prior to the harvesting of spring wheat, since it was assumed that clover was not yet established during this period and therefore had a very minor effect on SOM. Because effects of clover may more readily affect Nmin, baseline measurement for Nmin was carried out just after sowing white clover by sampling the soil to a depth of 30 cm.

After harvesting wheat, three subsequent soil samples were taken in each plot with time intervals of approximately one month. The last sample was taken at time of plowing of the standard tillage system. At this time, in the beginning of November, the Nmin content has been shown to be a good indicator for the potential nitrogen leaching during the winter. The first sample was taken at a depth of 0-30 cm, just after the harvest of the spring wheat and was analyzed for Nmin. The last sample was taken at 3 different depths (0-15 cm, 15-30 cm and 30-60 cm) for which both Nmin and the SOM content were determined. The second soil sample was timed in between the other two samples and taken at a depth of 0-30 cm after which it was analyzed for Nmin. A summary of the timing of soil samples, the sampling depths and the measured parameters is given in Table 2.

Table 2: Summary of soil sample timing, sampling depths and sample analysis

	Date									
	June 16th, 2009		**July 21th, 2009**		**August 17th, 2009**		**October 5th, 2009**		**November 3th, 2009**	
	Nmin	SOM	Nmin	SOM	Nmin	SOM	Nmin	SOM	Nmin	SOM
Soil depth										
0-15 cm			x	x					x	x
0-30 cm	x				x		x			
15-30 cm			x	x					x	x
30-60 cm			x	x					x	x

Soil samples consisted of composite samples obtained by taking 20-25 subsamples in between the 2nd and the 3th row of each field plot. Although this poses a risk of border effects influencing the soil organic matter content and nutrient status, it was impossible to penetrate the plot further without disturbing the white clover and weed populations. From these subsamples, composite samples of approximately 150 grams were taken per sampling depth. The samples were dried at 40℃ for 48h after which they were stored at -18℃ for the analysis of Nmin and SOM. To reduce the effect of measuring errors, all samples were analyzed in one batch.

3.2.2. Total soil organic matter analysis

The total SOM content was determined using the loss on ignition procedure. Oven-dried samples were grinded and dried at 105℃, after whic h they were combusted for 4 hours in a furnace at 530℃ (Heiri et al. 2001). The differenc e between dry weight of non-combusted samples at 105℃ and dry weight after combustion at 530℃ is used as an estimate of the total amount of organic matter. The results were not corrected for the $CaCO_3$ content of the samples, since results from Kasozi et al (Kasozi et al. 2009) indicate calcium decomposition is energy-dependent rather than time-dependent requiring a minimum temperature of 600℃ to start the decomposition process. The combustion of clay soil is accompanied by an increased loss of structural water (Howard and Howard 1990). Therefore, comparison to data from other experiments on other soil types requires a clay correction to be applied on the results. However, for the comparison of the SOM content of different plots within this experiment this clay correction is not necessary, since it can be assumed that the clay content is relatively constant across the field.

3.2.3. Analysis for total mineralized nitrogen

The Nmin content of the soil constituting both NO_3^--N and the NH_4^+-N , was determined for oven-dried samples. For this purpose, soils were extracted with 0.01M $CaCl_2$ and extracts were analyzed with a segmented-flow analysis system using an auto-analyzer to measure light-absorption at a wavelength of 540 nm (Houba et al. 1999). A calibration curve was constructed by determining the light-absorption for a standard nitrate solution containing 0, 100, 200, 300 mg NO_3^- L^{-1}.

3.3 Results

3.3.1 Soil organic matter

The effects of tillage, pre-crop, clover and soil depth and some of the interactive effects on SOM are summarized in Table 3 for both July and November. Raw data can be found in Appendix 1. In July, there appears to be a clear tillage effect. The average SOM content is higher in the standard tillage system than in the minimum tillage system ($P<0.01$), being 28.9 g kg^{-1} and 27.6 g kg^{-1} respectively. Since the measurements in July serve as a baseline-measurement, it can be assumed that any significant difference observed is an indicator for differences in initial situations. Nonetheless, it should be mentioned that some different tillage practices had already been implemented at this time. In November (Table 3), the initially significant difference between tillage systems disappeared. This might be caused an increase in SOM under minimum tillage conditions, which is in compliance with our expectations and former research as illustrated by Pekrun *et al* (Pekrun et al. 2003). Thus, although subsequent sampling is required to further investigate and proof this change in SOM related to tillage practices, these results appear to be promising.

At both sampling dates, there appeared to be no effect of pre-crop, clover and soil depth on the SOM status of the soil. The lack of a clear effect of soil depth was not expected, because at all sampling times, the soil appeared to be visibly lighter below the plow layer... Furthermore, in a German study on a Loess soil, a clear stratification of soil organic carbon (SOC) was reported under conservation tillage, most of it being concentrated in the upper 5 cm of the soil after 20 years of conservation tillage (Stockfisch et al. 1999). In this case, the mass of SOC in the upper 50 cm of the soil appeared to be about 8% higher under conservation tillage compared to conventional tillage. This finding is supported by results from other experiments (Pekrun et al. 2003;Schomberg et al. 1994), as referred to previously in the scientific background. Stratification of the soil is regarded as a long-term effect of minimum tillage. Hence, prolongation of the experiment is required to verify whether the distribution of SOM will also occur over time at the “Broekemahoeve”.

Further analysis revealed that no effect of sampling time could be observed, meaning no significant changes in SOM have occurred during the first six months of the experiment. The lack of clear effects does not necessarily contradict the expectations, since changes in SOM occur very slowly. However, based on findings from other research, long-term continuation of the experiment might result in a higher SOM content under minimum tillage conditions and in plots covered with white clover during autumn (Cherr et al. 2006;Pekrun et al. 2003).

Due to the large pool size of SOM, effects of tillage and other agronomic practices might possibly be masked by the inherent variability in overall SOM measurements. Alternative techniques and approaches may thus be required to assess the effects of tillage practices on both short- and long-term SOM dynamics. One alternative approach is to focus on different SOM fractions, referred to as particulate organic matter (POM). This requires the fractionation of organic matter on a functional basis. For this purpose, physical fractionation procedures appear to be the most suitable (Christensen 1992;Hassink 1995;Sohi et al. 2001).

Table 3: Effects of tillage, pre-crop, clover and soil depth on SOM and Nmin during 2009

Factor	SOM July ($g\ kg^{-1}$)	SOM November ($g\ kg^{-1}$)	Nmin June (mg/kg)	Nmin July (mg/kg)	Nmin August (mg/kg)	Nmin October (mg/kg)	Nmin November (mg/kg)
Pre-crop (PC)							
Onion	28.4	29.8	8.65	3.82	6.11 a	3.42 a	5.87
White cabbage	28.2	29.0	9.43	3.80	5.78 b	2.65 b	6.26
Significance	ns	ns	ns	ns	*	x	ns
Tillage (T)							
Standard tillage	28.9 a	29.8	8.43	3.86	6.39 a	3.23	6.51
Minimum tillage	27.6 b	29.0	9.65	3.75	5.52 b	2.83	5.63
Significance	**	ns	ns	ns	**	ns	ns
Green manure (GM)							
Clover	27.9	29.2		3.94	5.69	2.82	6.48
Control	28.6	29.7		3.68	6.21	3.24	5.66
Significance	ns	ns		ns	ns	ns	ns
Soil depth (SD)							
0-15 cm	29.2	31.1					
15-30 cm	28.5	30.1					
30-60 cm	27.1	27.0					
Significance	ns	ns					
PC*T							
Significance	ns	ns	ns	ns	*	ns	ns
T*GM							
Significance	ns	ns		ns	ns	ns	ns
T*SD							
Significance	ns	ns					
GM*SD							
Significance	ns	ns					

SOM and Nmin averages are presented for each month of sampling. SOM has been measured at 3 different soil depths (0-15 cm, 15-30 cm and 30-60 cm) whereas Nmin was only measured for a depth of 0-30 cm. Different letters within a column indicate significant differences. x significance at P<0.1 * significance at P<0.05 ** significance at P<0.01

The different fractionation procedures available and the corresponding soil organic matter fractions retrieved are the main focus of a literature review which is to be published in a subsequent PPO report. The objective of this review will be to identify a suitable procedure for linking POM measures to modeling approaches. Such an approach might proof worthwhile in the context of the ongoing research as well.

3.3.2 Mineral nitrogen

The effects of pre-crop, tillage, clover and interaction terms on Nmin are summarized in Table 3. Raw data can be found in Appendix 1. Since Nmin was only determined for a soil depth of 0-30 cm, the effect of soil depth could not be assessed. No effects of any factor could be observed in June. Since these measurements serve as a baseline, it might therefore be conducted that the field was relatively uniform. However, just as for the SOM baseline, some differences between tillage systems had already been implemented at this time of year. Moreover, the baseline measurements were taken just after the clover had been sown. Although the lack of effects justifies the use of these measurements as a baseline, some fields still had distinctly different field histories which should still be taken into consideration when interpreting the results.

Clear differences between plots could only be observed during August and October (Table 3). In August, there appears to be a clear effect of pre-crop ($P<0.05$). In plots that had onion as a pre-crop, the average Nmin content was higher than in plots that had white cabbage as a pre-crop, being 6.11 mg kg^{-1} (26.3 kg N ha^{-1}) and 5.79 mg kg^{-1} (24.9 kg N ha^{-1}) respectively. Based on knowledge about crop needs and manure applications before and during the growing season of both crops, this was not expected. White cabbage requires more nitrogen for crop growth than onion. Therefore white cabbage received 40 t ha^{-1} cattle slurry, whereas 1.2 t ha^{-1} Activit was applied to the onions. In terms of nitrogen, this translates to 112 and 43 kg N ha^{-1}, respectively This would imply that in plots that had onion as a pre-crop, the soil contained less nutrients than in plots that had white cabbage as a pre-crop. However, in order to provide good growing conditions for the spring wheat in 2009, 25 t ha^{-1} cattle manure (178 kg N ha^{-1}) was applied to the former onion field. Therefore, it is very likely that differences between pre-crops with regard to Nmin disappeared. On the contrary, since the absolute amounts of nitrogen applied in the onion field were larger than in the white cabbage field and the organic matter in cattle manure is more stable than the organic matter in Activit and cattle slurry, the Nmin content in the onion plots might even be higher than in the white cabbage plots. This is in concordance with the Nmin measurements in August, as mentioned previously.

In August 2009, the Nmin values were higher for standard tillage than for minimum tillage ($P<0.01$) (Table 3). The Nmin content under standard tillage conditions was 6.39 mg kg^{-1}, which was higher than 5.52 mg kg^{-1} under minimum tillage conditions, translating to approximately 27.5 and 23.7 kg N ha^{-1} respectively. This is expected, since tillage loosens the soil which speeds up the decomposition of organic matter resulting in increased Nmin levels. However, an interaction effect of tillage and pre-crop also appears to be present ($P<0.05$) as shown in Figure 3. From this figure it is apparent that under standard tillage conditions, the Nmin content in the onion and white cabbage plots was similar. The Nmin content in the minimum tillage onion plots was higher than the Nmin content in the minimum tillage white cabbage plots, but appears to be similar to the Nmin content in the standard tillage plots. This indicates that in this case, tillage only effects Nmin when white cabbage was used as a pre-crop. The history of manure applications, indicating a higher Nmin content in the onion plots as explained previously, also provides support for this finding. The differences caused by a tillage effect , were relatively large when the initial Nmin content was low. This explains why a clear effect of tillage can be observed in white cabbage plots, whereas in onion plots the differences are not yet large enough to be significant.

In October 2009, pre-crop was the only factor having an effect on Nmin. However, since this difference was just significant at $P<0.1$, subsequent experiments are needed to confirm these results. The lack of clear effects in October might be explained by the fact

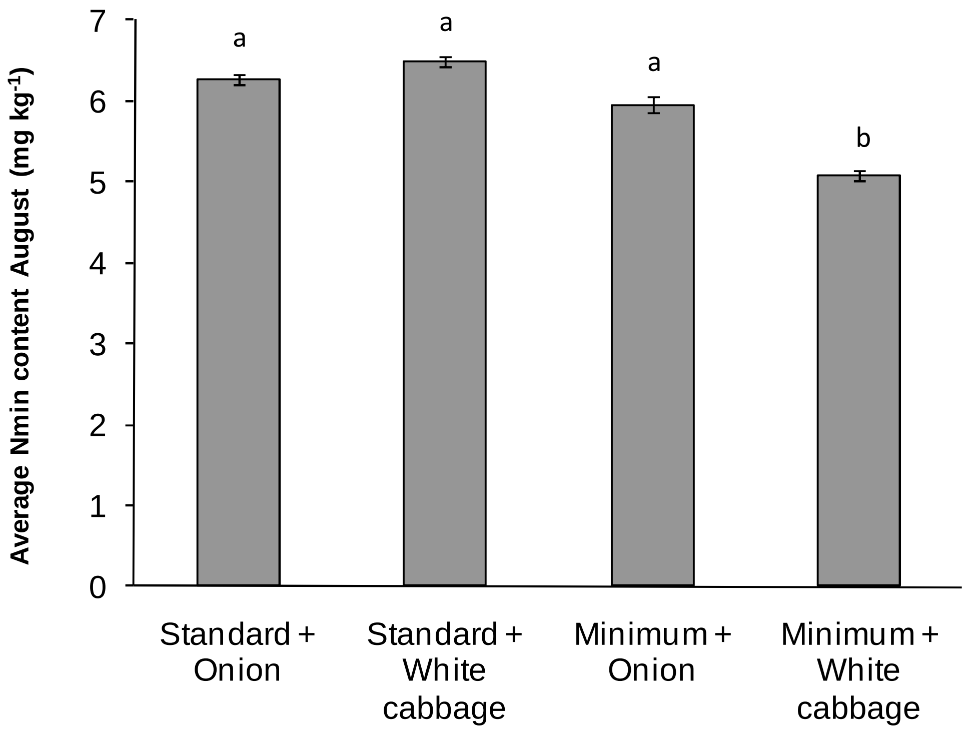

Figure 3: Interactive effect of Pre-crop and Tillage on Nmin in August 2009

the fact that, due to crop nitrogen uptake and drought, the absolute Nmin values were lower in October than in August. This hypothesis is supported by further analysis of the data, revealing a clear effect of month ($P<0.01$) when comparing August and October. As a result, the differences between plots were probably smaller in October than in August.

In none of the months, an effect of white clover could be observed. Nor was there any interaction between white clover and tillage. Since these measurements have only been performed one year after conversion to minimum tillage, this does not come as a surprise. Additionally, the variation in pre-crop might have masked the (interactive) effect of tillage and white clover. Follow-up research in subsequent years is therefore required to investigate the long-term effects of tillage and the increased use of green manures on soil nitrogen status.

Although the effects of tillage show a consistent trend over the months with relatively lower Nmin values under minimum tillage conditions, less consistent trends can be observed for the effect of green manure and pre-crop. In some months, a lower Nmin content is observed in control plots compared to clover plots whereas in other months trends are reversed. The same observation can be made with respect to differences between plots that had onion vs. white cabbage as a preceding crop. Since the differences between treatments are not significant, this is most likely attributable to the inherent variation within the field. However, this could also indicate that there are other factors involved in the regulation of Nmin levels, which have not been included in the experiment. A combination of literature study and field research is required to identify possible candidates for these factors and quantify their effects on nitrogen mineralization.

3.4 Conclusion

Part of the goals of this research was to quantify and compare the interactive effects of tillage and the use of white clover as a green manure on soil organic matter (SOM) and mineral nitrogen (Nmin). With respect to SOM, no significant changes have occurred within the time frame of this experiment and no stratification of SOM could be observed either. However, the initial difference between standard tillage and minimum tillage systems no longer occurred in November. This might indicate an increase in SOM under minimum tillage conditions as well as a decrease in SOM under standard tillage conditions. Therefore, continuation of the soil sampling is required to proof this change in SOM related to tillage practice and green manures and to further investigate the underlying mechanisms. This investigation might be benefitted by focusing on particulate organic matter (POM) fractions in combination with modeling approaches. This might also provide more insight in the long-term effects of tillage and white clover.

With respect to Nmin, pronounced tillage and pre-crop effects could only be observed in August. Moreover, in this case the interaction between these factors was also apparent. Lower Nmin contents in minimum tillage plots that had white cabbage as a pre-crop compared to all standard plots and minimum tillage plots that had onion as a pre-crop are in agreement with the initial hypotheses and with historical data on manure applications. The lack of effects during other months, in particular the (interactive) effects of tillage and white clover, might be explained by the fact that conversion to minimum tillage only took place one year ago. Additionally, the differences between groups are possibly hidden by the enlarged variation due to differences in pre-crop. This variation is likely to decrease during the subsequent years of the experiment, which indicates the need for follow-up research to support this year's findings and to investigate the long-term effects of tillage and white clover on the nitrogen status of the soil.

4 Tillage effects on weed suppression by white clover

4.1 Scientific background

4.1.1 Cover crops and weed suppression

The use of cover crops is part of the cultural control strategy to manage weed populations. During the growing season of the cover crop, positive effects of cover crops on weed suppression have been observed by many authors for different crops and environments (Teasdale et al. 2007). Especially the weed suppressive effects from rye and hairy vetch residue and the underlying mechanisms have been widely documented (Teasdale et al. 1991;Teasdale and Mohler 1993;Mohler and Teasdale 1993;Teasdale and Mohler 1992). The weed suppressiveness of different clover species has been investigated thoroughly by den Hollander *et al* (den Hollander et al. 2007a, 2007b). It was reported that, except for Subterranean clover, all clover species showed an acceptable weed suppression. However, in many cases, an increased weed suppression was also associated with significant yield reduction in leek. Based on this, it was concluded that the use of white clover provided the best compromise between weed suppression and attaining optimal yields. Although in the experiment from den Hollander *et al*, the clover and leek were intercropped, a potential yield reduction may theoretically also occur in a crop following a green manure. In this particular case, the yield reduction could be the result of regrowth of the clover after ploughing and sowing or a reduced Nmin content during the beginning of the growing period of leek, as a result of nutrient uptake by clover.

The weed suppressive effects of cover crops appear to be due to competition for essential resources such as light, nutrients and water (Hoffman and Regnier 2006;Radosevich et al. 1997;Teasdale 1998;Teasdale et al. 2007;Teasdale and Mohler 1993). Additionally, experiments have shown that cover crop residue functions as a physical barrier for weed growth and in some cases produces allelopathic compounds (Teasdale 1998). Moreover, effects on soil organisms, pests and diseases have been reported (Teasdale 1998).

Competition for light affects plant growth directly and indirectly. Increased cover crop biomass was shown to be related to a decrease in light transmittance but does not result in a decreased light quality (Facelli and Pickett 1991b;Teasdale 1998;Teasdale and Mohler 1992, 1993). No significant changes in transmittance could be observed in the red to far red light ratio (Teasdale and Daughtry 1993). As a result of the decreased transmittance, there is less light available for weed plants, resulting in a lower growth rate and plant height. Plant height appears to be a good indicator for this light competition (Violle et al. 2009). Light competition indirectly affects the soil temperature and moisture content, by reducing the heat absorption during daytime which results in a reduced water evaporation (Bristow 1988;Teasdale 1998;Teasdale and Mohler 1993). Together with an increased water infiltration as a result of a cover crop residue layer on the soil surface (McVay et al. 1989), this results in an increased water retention.

Since the decreased transmittance does not affect the quality of light, the phytochrome mediated germination of weed seed is not being affected. However, some indirect effects on germination might be present due to a decrease in soil temperature and increase in soil moisture content. Although the decrease in soil temperature is in most cases not sufficient to prevent weed germination although it might result in a delay of weed seed germination for most species (Teasdale 1998;Teasdale and Mohler 1993). The effect of moisture content on seed germination depends on the environmental conditions. Under dry conditions, an increase in moisture content benefits weed seed germination, whereas in wet conditions it is being prohibited (Mohler and Teasdale 1993;Teasdale 1998).

Additionally, research has confirmed the production of various toxic compounds by residues from several cover crops. These toxic compounds inhibit the establishment of weed seedlings. Allelopathic effects have been observed amongst others for rye residue (Barnes and Putnam 1983, 1986;Putnam and DeFrank 1983), hairy vetch residue (Bradow and Connick Jr. 1990;White et al. 1989), oat residue (Fortin and Pierce 1991) and crimson clover

(Dyck and Liebman 1994;Hoffman and Regnier 2006;Teasdale 1998). A comparison between the suppressive effects of rye and vetch residues showed more weed seedlings emerging with hairy vetch than for rye, which was hypothesized to be due to allelopathic properties (Teasdale and Daughtry 1993). After identification of these allelopathic compounds, breeding programs could be developed to enhance the production of these toxins in cover crop species which is supposed to increase their weed suppressive ability.

There are also indications that cover crop residue alters the soil fauna and increases the amount of pest organisms in the soil (Teasdale 1998). For example, increased populations of disease organisms such as *Pythium* and *Rhizoctonia* have been observed for hairy vetch residue compared to other cover crops (Rothrock et al. 1995;Teasdale 1998). This could benefit the weed suppression during the cover crop period, but it might also increase disease risks in succeeding cash crops. Although there seems to be potential for cover crop residue to provide a beneficial environment for bio-control organisms, the long- term effects on disease development should therefore be investigated further.

4.1.2 Tillage and weed suppression

Most tillage research has been focusing on soil properties that are important to satisfy crop needs, such as soil nutrients, moisture, carbon and structure (Carter 1994;El Titi 2003;Hao et al. 2001;Lal 1976;Tebruegge and Boehrnsen 1997). However currently, the effects of conservation tillage on weed populations have also become apparent (El Titi 2003). The increased weed densities associated with conservation tillage observed in several crops, including grain cereals, pose a barrier to applying minimum tillage techniques (Carter 1994;El Titi 2003;Rickson 1994;Rieck 1981;Tebruegge and Boehrnsen 1997).

Additionally, a change in tillage system has been found to cause a shift in weed population, usually in the second or third year after conversion (Bilalis et al. 2001;Buhler 1995;Coffman and Frank 1992;El Titi 2003). However, the changes observed in the field are highly dependent on the location, environmental conditions and agronomic practices. The varying responses to changes in tillage observed for different weed species can be attributed to differences in the life cycle of the weeds and to differences in seed production (Buhler 1995;El Titi 2003). This is because changes in tillage systems result in changes in the environment giving species with a certain life-cycle a competitive advantage (Buhler 1995).

Specific life-cycle traits may be differentially affected by tillage. Some species require periodic disturbance for their survival, whereas others are being favored by a non-disturbed soil (Buhler 1995). The weed species that require periodic disturbance are being referred to as arable response species, whereas species requiring non-disturbance are referred to as inverse response species. Some species, referred to as intermediate response weed species, fall between both classes and survive in both types of soil tillage systems. In reduced tillage systems, inverse and intermediate response species are being favored (Buhler 1995).

As a result of a decrease in life-cycle break-up and soil disturbance, generally an increase in summer annual grasses can be observed under minimum tillage conditions (Buhler 1995;El Titi 2003). Research by Buhler *et al* reported for example an increase in giant foxtail (*Setaria faberi*) (Buhler and Daniel 1988). However, Amann reported that the increase in certain annual grasses was related to early sowing compared to late sowing in the standard system (Amann 1991;El Titi 2003). In his research, a larger fraction of germinating seedlings of *Alopecurus myosuroidus* was being destroyed when sowing was postponed to a later date. In other studies, an interactive effect of tillage and crop rotation was being reported (El Titi 2003;Knab and Hurle 1988;Schreiber 1992).

The opposite trend can be observed for summer annual broad leave species, which show a decline in density under minimum tillage conditions (Buhler 1995;El Titi 2003;Rieck 1981), However, research results are less consistent for these species than for annual grasses. The most common observation is a decline in large seeded species such as Velvetleaf *(Abutilon theophrasti)* (Buhler 1995;Buhler and Daniel 1988).

Additionally, when reducing the amount of tillage, the establishment of winter annual, bi-annual and perennial species will be favored (Buhler 1995). This is because mechanical disturbance associated with the planting of summer crops is avoided, allowing winter annuals, bi-annuals and perennials to complete their life-cycle. This is illustrated by research from Bruce and Kells (Bruce and Kells 1990), who reported Horseweed (Conyza Canadensis) as one of the most troublesome winter annuals in minimum tillage systems (Buhler 1995). Other examples of winter annuals prevailing under minimum tillage conditions include Downy Brome (*Bromus tectorum*) and Sheperd's purse (*capsella bursa-pastoris*) (Buhler 1995;Triplett Jr 1985a;Wicks et al. 1994). As an example for perennials, increasing numbers of Dandelion (*Taraxacum officinale*), Canada thistle (*Cirsium arvense*)(Triplett Jr and Lytle 1972) and quackgrass (*Elymus repens*) (Pollard and Cussans 1976) have been reported (Buhler 1995).

Additionally, several researchers observed an increase in weed species diversity under minimum tillage conditions. Based on a 6-year field experiment in Ontario, Canada, Murphy *et al* (Murphy et al. 2006) reported a higher weed species diversity under no-tillage conditions compared to fields where a conventional moldboard plow had been used. This is confirmed by results from a 6-year trial in Michigan, USA, in which weed species diversity was found to be higher in no-tillage systems than in conventional systems (Menalled et al. 2001). In the same trial, the weed diversity in low-input and organic systems was found to be even higher than under no-till conditions. Regarding species diversity, the combination of minimum tillage with an organic system is therefore very promising. Similar results were reported in other trials, although in some cases results varied over the years (Menalled et al. 2001) or were found to be also influenced by crop rotation (Stevenson et al. 1997) and manure applications (Miyazawa et al. 2004).

Not only does tillage effect the incidence of certain weed species and species diversity in the weed population, it also has an effect on the distribution of seeds in the soil (Buhler 1995). With conservation tillage, seeds are left close to the soil surface and seeds from lower depths are not being brought to the surface. This leads to a reduced phytochrome-mediated seed germination from deeply buried seeds. Therefore, for soils with a uniform seed distribution, tillage has shown to increase weed density compared to a no tillage control resulting in a faster decline of the soil seed bank (Roberts and Dawkins 1967;Teasdale et al. 1991). This underlines the importance of taking into account specific field conditions when discussing research results.

Additionally, the size of the soil seed bank is also being affected (Buhler 1995;El Titi 2003). A species-specific increase in weed density is usually associated with an increased biomass production. Weed biomass has proven to be a good indicator for seed production and weed reproduction (El Titi 2003). Therefore increased production of weed biomass implies an increase in seed production and an increase in soil seed bank. Dynamics of the soil seed bank seem to play an important role in the long-term effects of tillage on weed species (El Titi 2003).

Because weed populations are affected by the whole farming system, it is hard to isolate the effects of differences in tillage systems specifically (El Titi 2003). Usually changes in tillage system are accompanied by changes in for example fertilizer amendments, crop types, varieties and sowing dates, which might mask the specific tillage effects. Changes in tillage associated measures were found to have a larger influence than changes in tillage system themselves (Bilalis et al. 2001;El Titi 2003). Therefore, it is essential to carefully document these tillage-associated measures when assessing differences between tillage systems and comparing results from different experiments. Furthermore, it points out that site and farming system-specific research is required, before minimum tillage can be optimally implemented on a large-scale.

4.2 Material and methods

4.2.1 Field measurements

The effects of tillage and white clover on weed suppression were assessed for different weed species in four surveys during the growing season of white clover. A baseline survey was carried out in July, after undersowing white clover and before the spring wheat was harvested. This comprised a general qualitative subplot observation with a special focus on crop stand, disease presence and weed diversity. Quantitative measurements were taken in each plot using two sub-subplots of 0.25 m^2 each, for which the results were averaged in order to decrease the effect of the within-subplot variation. Each sub-subplot was placed in a separate diagonal comprising a location for each subsequent survey (location A-D). For each survey, the exact location in this diagonal was determined randomly without allowing the same location to be surveyed twice. The 2 diagonals could be placed in two different layouts (left and right). The layout used for each plot was also determined randomly. This experimental setup is visualized in Figure 4. The resulting setup ensured that there was no disturbance of weed and clover growth in sub-subplots that still had to be surveyed.

In each subsubplot, the plant density (plants m^{-2}), the plant height and the ground cover (%) were determined for wheat, white clover and different weed species. When determining the plant density and ground cover, a 0.25 m^2 frame was used with a grid size of 5 cm, which served to assist in estimating the ground cover visually. The ground cover was rated on a scale from 1-20 in which a value of 1 represents a soil cover of 0-5% and a value of 20 represents a soil cover of 95-100%. Plant height was determined in each subplot by averaging the results of five measurements located in the four corners and the middle of the subplot respectively (Figure 5).

During monthly surveys after the wheat harvest, plant density, soil cover and plant height was determined for white clover and different weed species using the same procedure as described for the baseline survey. However, due to practical limitations caused by the rapid and dense growth of the clover, estimating the clover density became too difficult and unreliable in September and October. Therefore, the white clover density measurements in these months were omitted. Additionally, the sub-subplots were harvested and a composite sample of both plots was brought to the laboratory for the determination of the total fresh and dry matter yield of white clover and total weed populations A summary of the timing of surveys and the parameters measured is given in Table 4.

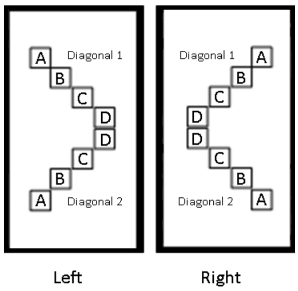

Figure 4: Experimental setup used for surveying weed and clover growth

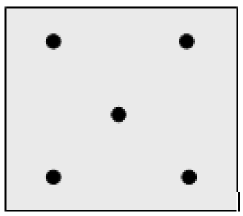

Figure 5: Location of height measurements in a 0.25 m2 subsubplot

4.2.2. Laboratory analysis

The dry matter yield was determined by weighing the fresh plant material after which samples were dried for 48 hours at 70℃ (Sharkey 20 06). After weighing the oven-dried plant material, the dry matter content was determined. The oven-dried white clover shoots were stored at 18℃ before being grinded for the purpose of determining the total N content. Approximately 300 mg of dried and grinded sample was extracted with H_20_2 at room temperature and H_2SO_2 at 330℃ using selenium as a catalyst. After this extraction, salicylic acid was added to minimize nitrate losses. The total N content of the extract was analyzed in

Table 4: Summary of the timing of weed surveys and parameters measured

	Date			
	July 23th, 2009	August 24/25th, 2009	September 21/22th, 2009	October 20-22th, 2009
Measurements				
Qualitative plot observation	x	x	x	x
Wheat density	x	x	x	x
Wheat ground cover	x	x	x	x
White clover density	x	x	x	x
White clover ground cover	x	x	x	x
White clover height	x	x	x	x
Total w eed density	x	x	x	x
Total w eed ground cover	x	x	x	x
Total w hite clover DM		x	x	x
N content w hite clover shoots		x	x	x
Total w eed DM		x	x	x

a segmented-flow analysis system using an auto-analyzer to measure light-absorption at a wavelength of 540 nm (Houba et al. 1999). For this purpose, a calibration curve was constructed by determining the light-absorption for a standard solution containing 0, 2.3, 4.6, and 7 ppm NH_4-N.

4.2.3.Cover crop weed index

To assess the differences between tillage systems with respect to competition between white clover and the weeds, a cover crop weed index (CCWI) was used, as developed by Linares *et al* (Linares et al. 2008). This index expresses the dry weight of the clover relative to the total weed dry weight providing a dry weight ratio (Cover crop dry weight/Weed dry weight). This appears to be an effective measure to determine the weed suppressiveness of a cover crop, because weed biomass was generally found to be inversely related to cover crop biomass (Linares et al. 2008).

4.2.4. Species diversity

To assess the effects of white clover and different tillage systems on species diversity, a distinction was made between annual species and the total of bi-annual and perennial species. In addition, the total species diversity was assessed using several diversity indices. According to Tobham *et al* (Tobham and Lawson 1982) and Beisel *et al* (Beisel et al. 2003), a combination of a species richness index and a species evenness index gives was used to asses overall species diversity. The evenness indices standardize richness indices by correcting them for the number of species present. In this manner, not only the species richness is being evaluated, but also the relative abundance of species. Tobham *et al* suggest the use of Shannon's diversity index in combination with Heip's evenness index or Pilou's evenness index. However, because Beisel *et al* (Beisel et al. 2003*)* found Heip's index to be more sensitive to varying densities of rare species, it was decided to use Heip's evenness index in this analyses. Additionally, the most simple index being the total number of weed species was also evaluated in the analysis.

4.3 Results

4.3.1 Weed density, weed DM and weed cover

The effects of tillage, pre-crop, the interaction between tillage and pre-crop, clover and the interaction between tillage and clover on weed density, weed DM and weed cover are summarized in Table 5. The raw data on which the reported averages are based can be found in Appendix 2. It appears that the weed density was higher in the minimum tillage system compared to the standard tillage system, being 76 and 38 plants m^{-2} respectively (Figure 6). This result is in accordance with the expectations and supported by findings from other researchers (Carter 1994;El Titi 2003;Rickson 1994;Rieck 1981;Tebruegge and Boehrnsen 1997). Therefore it seems reasonable to assume that weed incidence tends to increase when converting to a minimum tillage system. Further research in subsequent years is required to provide further proof for this observation. With respect to weed DM and weed cover, no significant effects of tillage could be detected, although the results do show a higher overall average value for minimum tillage systems. Since weed DM and weed cover are related to weed density, effects may become more pronounced in subsequent years of the experiment.

A higher weed incidence is expected and observed in control plots without clover compared to clover plots, although these effects were only significant for weed DM. The average weed DM in clover plots was 487 kg ha^{-1} while the average weed DM in control plots is 1280 kg ha^{-1} (Figure 7). Nonetheless, the weed cover is significantly larger in control plots compared to clover plots ($P<0.10$). This indicates the need for further research to proof the significance of this difference and if similar trends are observed during subsequent years. Although further measurements are required to statistically proof these findings, the results are in compliance with research from den Hollander *et al* (den Hollander et al. 2007ab). They reported a weed suppressive effect for many clover species including white clover.

The lack of effects of other factors and interactions was not surprising since this is the first year after conversion to a minimum tillage system and other researchers reported that changes in the weed population were only observed during the 2nd or 3rd year of conversion (Bilalis et al. 2001;Buhler 1995;Coffman and Frank 1992;El Titi 2003). Additionally, the enlarged variation caused by the different pre-crops might have masked the interactive effects of tillage and white clover. For this purpose, a continuation of the monitoring in subsequent years appears to be required.

Not only the time of conversion to minimum tillage, but also the experimental design is thought to affect results. Since standard tillage plots and minimum tillage plots were located close together, weed incidence under standard tillage conditions might be enlarged due to weed infestation by weeds selected for under minimum tillage conditions. This might result in a decreased difference between standard tillage and minimum tillage plots with

Table 5: Effects of tillage, pre-crop, the interaction between tillage and pre-crop, clover and the interaction between tillage and clover on weed density, weed DM and weed cover.

Factor	Weed density (plants m^{-2})	Weed DM (kg ha^{-1})	Weed cover (%)
Pre-crop (PC)			
Onion	50	826	25-30%
White cabbage	64	942	30-35%
Significance	ns	ns	ns
Tillage (T)			
Standard tillage	38 b	823	20-25%
Minimum tillage	76 a	938	35-40%
Significance	x	ns	ns
Green manure (GM)			
Clover	41	487 b	20-25% b
Control	73	1280 a	35-40% a
Significance	ns	*	x
PC*T			
Significance	ns	ns	ns
T*GM			
Significance	ns	ns	ns

The averages include data from all sampling dates resulting in an average value for the whole growing season of white clover. Different letters within a column indicate significant differences. x significance at $P<0.1$ * significance at $p<0.05$ ** significance at $P<0.01$

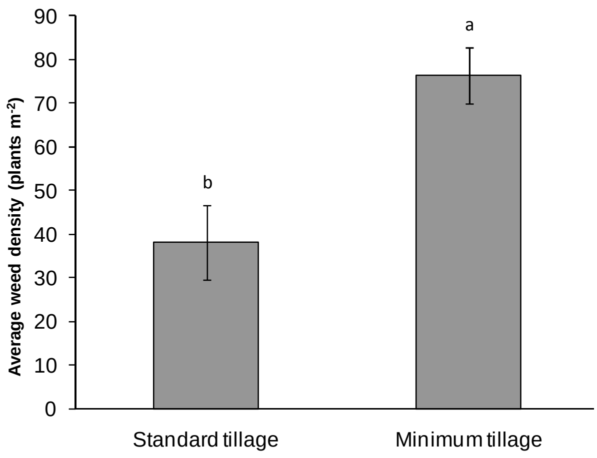

Figure 6: Effect of tillage on weed density

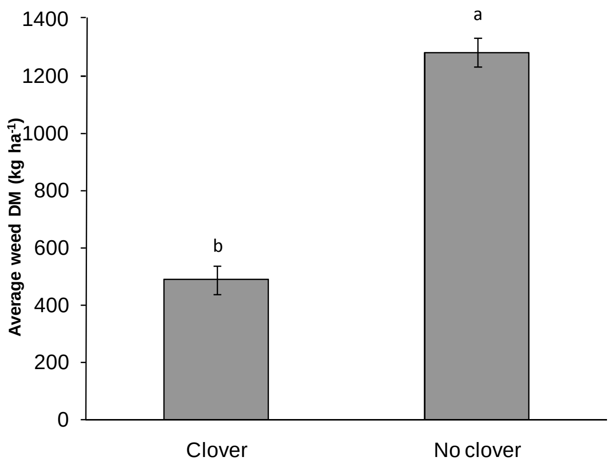

Figure 7: Effect of white clover cover on weed DM

regard to weed density, weed DM and weed cover. Since this is the first year after conversion, only weed species that produce seeds several times a year, such as *Stellaria media,* might be affected by this. However, since *Stellaria media* made up a large proportion of the weed population, as will be presented in section 4.3.4, this aspect of the design should not be neglected. Furthermore, in subsequent years, the weeds species that reproduce once a year might be affected as well.

4.3.2 White clover

Investigating the interactive effects of tillage and white clover also requires the identification of the effects of tillage on clover growth. For this purpose, the density, DM production, soil cover, plant height and N content of white clover was measured. The results are summarized in Table 6. The raw data on which the reported averages are based can be found in Appendix 3. No effects of pre-crop and tillage could be observed. Nor were interaction effect of tillage and pre-crop significant. This indicates it is reasonable to assume that the observed effects of white clover on weed growth have not been caused indirectly by differences between tillage systems and pre-crops and can be directly attributed to white clover itself. However, it should be noted that the density, DM, cover and height of white clover appeared to be larger in plots that had onion as pre-crop than in plots that had white cabbage as pre-crop. Although measurements in subsequent years will probably be less affected by the different pre-crops grown in 2008, it might be interesting to further investigate the underlying mechanisms of the effect of pre-crop on the yield of a green manure.

Table 6: Effects of tillage, pre-crop and the interaction between tillage and pre-crop on.

Factor	Plant density (plants m^{-2})	DM accumulation (kg ha^{-1})	Crop cover (%)	Plant height (cm)	N accumulation (kg ha^{-1})
Pre-crop (PC)					
Onion	221	2108	50-55	13	66
White cabbage	116	1331	30-35	11	43
Significance	ns	ns	ns	ns	ns
Tillage (T)					
Standard tillage	157	2105	45-50	13	67
Minimum tillage	180	1334	35-40	11	42
Significance	ns	ns	ns	ns	ns
PC*T					
Significance	ns	ns	ns	ns	ns

The averages include data from all sampling dates resulting in an average value for the whole growing season of white clover. Different letters within a column indicate significant differences. x significance at P<0.1 * significance at p<0.05 ** significance at P<0.01

Since white clover functions as a green manure in the crop rotation, it is also interesting to know how much DM and nitrogen it has accumulated at the end of the growing season. For this purpose, the average values for October have been summarized in Table *7* 7. It appears that the DM accumulation by white clover ranged from 2191 to 3923 kg ha^{-1}. Furthermore, the nitrogen accumulation by white clover was between 56 and 121 kg ha^{-1}. This is in compliance with previous research from Van Leeuwen and Schröder (Van Leeuwen-Haagsma and Schröder 2003), who report a DM production by white clover of 4 t ha^{-1} and a nitrogen accumulation of 145 kg ha^{-1} under average growing conditions. Although these values are higher than the production achieved in this experiment, this might be attributed to the relatively dry summer in 2009.

Table 7: Accumulation of dry matter (DM) and nitrogen by white clover

Factor	Dry matter accumulation (kg ha^{-1})	N accumulation (kg.ha^{-1})
Pre-crop (PC)		
Onion	3615	113
White cabbage	3020	82
Significance	ns	ns
Tillage (T)		
Standard tillage	3886	116
Minimum tillage	2749	79
Significance	ns	ns
PC*T		
Significance	ns	ns

The averages only include data for the month October. Different letters within a column indicate significant differences. x significance at P<0.1 * significance at p<0.05 ** significance at P<0.01

4.3.3 Cover crop weed index

In order to further investigate the effects of tillage and pre-crop on competition between white clover and weeds, a Cover Crop Weed Index (CCWI) was calculated by dividing the white clover DM by the weed DM. High values can be caused by a low weed DM, a high clover DM or a combination of both. The CCWI is therefore an indicator for competition between white clover and weeds and the weed suppressiveness of white clover. The results of assessing the effects of tillage, pre-crop and the interaction between tillage and pre-crop on the CCWI and therefore weed suppression by white clover are summarized in Table 8. For clear interpretation of the results, this table also repeats the summary of the effects on weed DM and clover DM. The raw data on which reported averages are based can be found in Appendix 2 and 3.

As can be seen, no effect of tillage, pre-crop and their interaction can be observed when focusing on clover DM and weed DM separately. However, when using the CCWI, clear effects can be observed for both factors and their interaction. This implies that the CCWI is a more sensitive indicator for weed suppression than weed DM and clover DM by themselves. The CCWI is higher in onion plots compared to white cabbage plots, being respectively 6.8 and 1.2. Also, a higher CCWI can be observed for standard tillage compared to minimum tillage, being 6.3 and 1.7 respectively. When differences in pre-crop and green manure are not taken into account, the higher weed suppression observed under standard tillage conditions compared to minimum tillage conditions can be explained by the higher weed density observed in minimum tillage plots (P<0.10). This implies that in minimum tillage plots, white clover faces more competition from the beginning. However, the interaction between tillage and pre-crop was also significant and is thus shown in more detail in Figure 8.

The CCWI appears to be larger in standard plots that had onion as a pre-crop compared to plots with another combination of tillage and pre-crop. This indicates that in standard tillage plots with onion as pre-crop, white clover has a significantly larger competitive advantage with respect to weeds, resulting in an increased weed suppression.

Table 8: Effects of tillage, pre-crop and the interaction between tillage and pre-crop on Clover DM, Weed DM and Cover Crop Weed Index (CCWI)

Factor	Clover DM (kg ha^{-1})	Weed DM (kg ha^{-1})	CCWI (Crop DM/Weed DM)
Pre-crop (PC)			
Onion	2108	826	6.8 a
White cabbage	1331	942	1.2 b
Significance	ns	ns	**
Tillage (T)			
Standard tillage	2105	823	6.3 a
Minimum tillage	1334	938	1.7 b
Significance	ns	ns	*
PC*T			
Significance	ns	ns	*

The averages include data from all sampling dates resulting in an average value for the whole growing season of white clover. Different letters within a column indicate significant differences. x significance at P<0.1 * significance at p<0.05 ** significance at P<0.01

Looking at the results for weed DM and clover DM, this seems to be the result of both an increase in Clover DM and a decrease in weed DM, although this trend is not significant.

Within the group of plots that had white cabbage as a pre-crop, no clear effect of tillage can be observed. Significant differences between tillage systems are only apparent in onion plots. When relating this to the nutrient status of the soil, this would not be expected, since the Nmin content was equal or larger in onion plots compared to white cabbage plots. Based on this finding, the opposite trend would be expected since differences between tillage systems could be enlarged under nutrient-limited conditions, giving the leguminous crop white clover an increased competitive advantage. This reasoning is supported by research from Pysek et al (Pysek et al. 2005), who reported that “the decrease of weed cover with increasing crop cover was more pronounced on nutrient-poor than nutrient-rich soils”.

Since focusing on the nutrient status of the soil does not provide us with a possible explanation of the results, it may be possible that the weed suppressive characteristics of the previous crop are more important in this case. Due to a closer canopy and larger leaf area, in practice, white cabbage has proven to suppress weeds better than onion. This might have resulted in a lower seed production and therefore a lower weed incidence in this year.

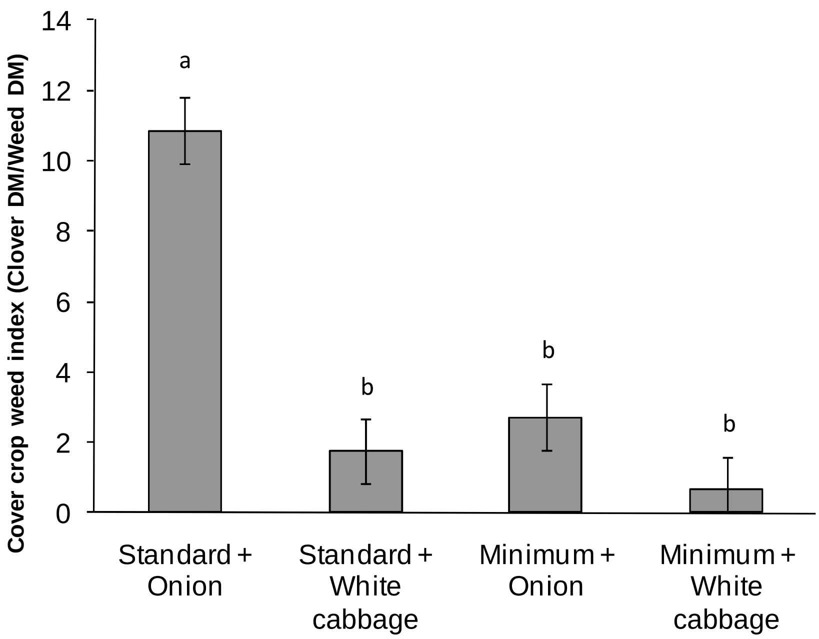

Figure 8: The interactive effect of tillage and pre-crop on CCWI

However, the results of weed density are not consistent with this finding. Although not proven significant, the weed density appears to be higher in white cabbage plots compared to onion plots, being 64 plants m^{-2} and 50 plants m^{-2}, respectively. The inconsistency of these results with possible explanations indicates that other factors not included in the experiment have an important influence. Additional research may be needed to elucidate underlying causal mechanisms. The longer the period after conversion, the smaller the effect of pre-crop will be. This will hopefully reduce the variance between plots and the difficulty of interpretation.

4.3.4 Stellaria media

Since *Stellaria media* made up a large portion of the total weed biomass (Table 9). Therefore, it seemed worthwhile to zoom in on this weed in particular. The effects of tillage, pre-crop, the interaction between tillage and pre-crop, clover and the interaction between tillage and clover on *Stellaria media* density are summarized in Table 9. The raw data on which the reported averages are based can be found in Appendix 4.

Although no clear effects can be observed, there appears to be a higher *Stellaria media* density in the plots that had white cabbage as a pre-crop compared to plots that had onion as a pre-crop, being 42 plants m^{-2} and 30 plants m^{-2} respectively. Also, its density appears to be higher in minimum tillage plots compared to standard tillage plots, respectively being 44 plants m^{-2} and 27 plants m^{-2}. However, the proportion of the total weed biomass appears to be the same for both tillage systems. Therefore, nothing can be said yet about the effects of tillage on *Stellaria media* density. Results from other experiments are also inconsistent with respect to this subject. Some authors report lower densities of Stellaria media under minimum tillage conditions (Froud-Williams et al. 1991;Lindwall et al. 1994;Triplett Jr 1985b) whereas others observed increased densities (Lindwall et al. 1994;Witt 1984).

With this in mind, it should be mentioned that counting *Stellaria media* appeared to be quite hard. With greater densities, it became almost impossible to distinguish separate plants. This resulted in the counting of individual plants if there were less than 10 plants per sub-subplot. For higher densities, a group of 10-20 plants per sub-subplot and a group of more than 20 plants per sub-subplot was defined. The drawback of this approach is that

Table 9: Effects of tillage, pre-crop, the interaction between tillage and pre-crop, clover and the interaction between tillage and clover on Stellaria media

Factor	***Stellaria media* density (plants m^{-2})**	***Stellaria media* prevalence (% of total weed pop.)**	**Stellaria media cover (%)**
Pre-crop (PC)			
Onion	30	49	5-10%
White cabbage	42	62	15-20%
Significance	ns	ns	ns
Tillage (T)			
Standard tillage	27	56	10-15%
Minimum tillage	44	55	15-20%
Significance	ns	ns	ns
Green manure (GM)			
Clover	25	49	10-15%
Control	46	62	20-25%
Significance	ns	ns	ns
PC*T			
Significance	ns	ns	ns
T*GM			
Significance	ns	ns	ns

The averages include data from all sampling dates resulting in an average value for the whole growing season of white clover. Different letters within a column indicate significant differences. x significance at P<0.1 * significance at p<0.05 ** significance at P<0.01

densities might be underestimated. Furthermore, a maximum of 20 plants per sub-subplots was used, which might have resulted in an under-estimation of the differences between plots. Therefore, it is possible that the lack of difference is partly due to the way of measuring. This possibility is avoided when weed density is determined in the seedling stage or when the DM content is determined for each weed species separately. Although this last option requires a substantial amount of extra work, it might be proof a more reliable measure for determining the effect of tillage, clover and pre-crop on specific weed species.

4.3.5 Annual weeds versus bi-annual and perennial weeds

Since focusing on *Stellaria media* does not provide us any information about a shift in weed population, the densities of all annual species were grouped together and compared to the total density of bi-annual and perennial weeds. Also, the relative amount of annual weeds was calculated. The effects of tillage, pre-crop, the interaction between tillage and pre-crop, clover and the interaction between tillage and clover on weed density of both groups and the relative amount of annual weeds are summarized in Table 10. The raw data on which the reported averages are based can be found in Appendix 5.

There appears to be an effect of both tillage and green manure on the density of annual weeds ($P<0.10$). The average annual weed density was 34 plants m^{-2} under standard tillage conditions and 63 plants m^{-2} under minimum tillage conditions. In white clover plots, the annual weed density was 33 plants m^{-2} and in control plots it was 63 plants m^{-2}. However, since the total weed density was also higher under minimum tillage conditions, the average weed density should be viewed relative to the total weed density. Therefore, looking at the percentage of annual weeds appears to be more relevant. Other factors did not have an influence on the average density of annual weed species. Nor could any effect be observed on the average density of bi-annual and perennial weeds.

When the relative annual weed density is being analyzed, there appears to be an effect of pre-crop ($P<0.1$), resulting in a higher percentage of annual weeds in white cabbage plots compared to onion plots, being 91% and 77% respectively. Additionally, an effect of green manure becomes apparent. Although there appears to be no effect of tillage, an

Table 10: The effects of tillage, pre-crop, the interaction between tillage and pre-crop, clover and the interaction between tillage and clover on annual weeds

Factor	Density of annual weeds (plants m^{-2})	Density of bi-annual and perennial weeds (plants m^{-2})	Percentage annual weeds (%)
Pre-crop (PC)			
Onion	39	9	77 b
White cabbage	57	7	91 a
Significance	ns	ns	x
Tillage (T)			
Standard tillage	34 b	4	84
Minimum tillage	63 a	12	84
Significance	x	ns	ns
Green manure (GM)			
Clover	33 b	6	78 b
Control	63 a	10	90 a
Significance	x	ns	*
PC*T			
Significance	ns	ns	ns
T*GM			
Significance	ns	ns	*

The averages include data from all sampling dates resulting in an average value for the whole growing season of white clover. Different letters within a column indicate significant differences. x significance at $P<0.1$ * significance at $p<0.05$ ** significance at $P<0.01$

interaction effect of tillage and green manure can be observed (P<0.05), shown in Figure 9. Under standard tillage conditions, there appears to be an effect of clover on the percentage of annual weeds, whereas under minimal tillage conditions no effect can be detected. Within standard tillage plots, the percentage of annual weeds is higher in control plots compared to clover plots, being 93% and 82%, respectively. In minimum tillage plots, the percentage of annual weeds was 85% for minimum tillage vs. 93% for standard tillage treatments.

It appears, that white clover only had an effect on the relative amount of annual weeds in the standard tillage system. Under minimum tillage conditions, the relative amount of annual weeds was approximately 85% in both the control and the clover plots. The amount of annual weeds appears to be larger under standard tillage conditions than under minimum tillage conditions if no green manure is being used. This seems to be in compliance with the hypothesized decrease in summer annual broad leave weeds under minimal tillage conditions. However, the significance of the effect of green manure can only be evaluated within tillage groups in this case, due to the statistical design with green manure being a repeated measure and tillage being a between plot factor. This design does not allow for the comparison of interaction effects of tillage and green manure between tillage systems.

Due to the grouping of different weed species, it is hard to find a possible explanation for the observed differences. Moreover, due to the large variability between plots partly related to differences in pre-crop and the low densities of several weeds species, focusing on individual weed species is unlikely to result in clear and consistent measurements. This is also acknowledged by Tobham *et al* (Tobham and Lawson 1982). Low densities could be avoided by increasing the amount of sub-subplots used for counting weeds in subsequent years, although this might proof difficult with respect to the available time. Within plot and within group homogeneity is something that can only be affected by consistent management over a longer time period.

Additionally, when reviewing the scientific literature with respect to this subject, the difficulty of interpreting the results with regard to densities of specific weed species also becomes apparent. In general, minimum tillage is found to favor winter annual weeds (Buhler 1995) and summer annual grasses (Buhler 1995;El Titi 2003) whereas summer annual broad leaf species were reported to decline (Buhler 1995;El Titi 2003;Rieck 1981). However, with regard to several weed species, annuals as well as bi-annuals and perennials, the results of different researchers appear to be inconsistent with respect to tillage effects (Lindwall et al. 1994). Probably, the outcomes of this experiment and other experiments are highly dependent on other tillage, management and location related factors as well, as was also recognized by Bilalis *et al*. (Bilalis et al. 2001;El Titi 2003). This implies it would be inappropriate to generalize conclusions.

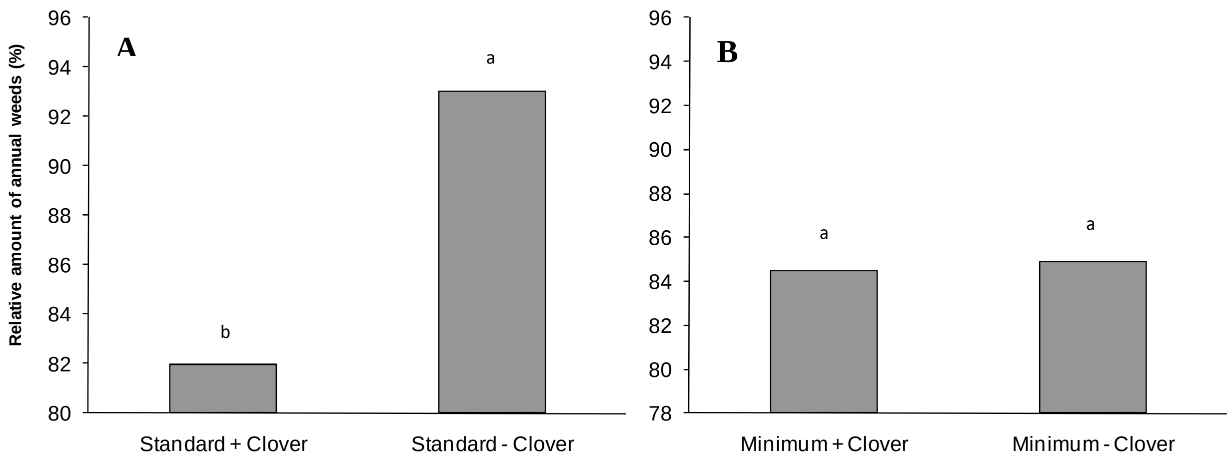

Figure 9: Relative amount of annual weeds in standard tillage (A) and minimum tillage (B)

4.3.6 Weed population diversity

Another approach for assessing the shift in weed population is to focus on weed species diversity. For this purpose, several diversity indices were used, being the total number of weed species, Shannon's diversity index and Heip's evenness index. The results of assessing the effects of tillage, pre-crop and the interaction between tillage and pre-crop on species diversity are summarized in Table 11. The raw data on which the reported averages are based can be found in Appendix 6.

When focusing on the total number of weed species, no significant effects of any factor or combination of factors could be observed. However, when focusing on the other diversity indices, a clear effect of tillage became apparent for both factors. Shannon's diversity index and Heip's evenness index were higher in minimum tillage plots than in standard tillage plots, indicating an increase in species richness and evenness of the distribution of species under minimum tillage conditions. This higher species diversity under minimum tillage conditions is in compliance with our expectations and also observed in other experiments as discussed before (Menalled et al. 2001;Miyazawa et al. 2004;Murphy et al. 2006;Stevenson et al. 1997). With respect to species evenness, the use of a green manure also appears to have a direct effect. Heip's evenness index was higher in control plots compared to clover plots. This indicates that there was a more even distribution of species on bare soil. This is logical, since a white clover cover selects for weeds that are most capable in out-competing white clover, resulting in a less even distribution of weed species.

However, both for species diversity and species richness, there appears to be an interaction between tillage and green manure as well as between tillage and pre-crop. This implies caution is required when interpreting the main effects of tillage and green manure. Interaction effects are most pronounced when species evenness is considered. Again, due to the statistical design with green manure being a repeated measure and tillage being a between plot factor, the interaction effect can unfortunately only be evaluated within tillage systems. For species richness and species evenness, the interaction effects of tillage and pre-crop are shown in Figure 10 and 11, respectively, whereas the interactions between tillage and green manure are depicted in Figure 12 and 13 respectively.

From Fig 10, a clear interaction between tillage and pre-crop is apparent. In plots were cabbage was the pre-crop, no distinct effect of tillage could be observed whereas in onion plots a clear difference between tillage systems was visible. In white cabbage plots receiving a standard tillage treatment, species richness was lower than in minimum tillage plots that had onion as a pre-crop. Although species richness in minimum tillage white

Table 11: The effects of tillage, pre-crop, the interaction between tillage and pre-crop, clover and the interaction between tillage and clover on several population diversity indices

Factor	Total number of weed species (#/subplot)	Shannon's diversity index (-)	Heip's evenness index (-)
Pre-crop (PC)			
Onion	12	0.73	0.13
White cabbage	15	0.79	0.11
Significance	ns	ns	ns
Tillage (T)			
Standard tillage	13	0.59 b	0.09 b
Minimum tillage	14	0.93 a	0.15 a
Significance	ns	*	*
Green manure (GM)			
Clover	14	0.73	0.11b
Control	13	0.79	0.13 a
Significance	ns	ns	*
PC*T			
Significance	ns	*	*
T*GM			
Significance	ns	x	**

The averages include data from all sampling dates resulting in an average value for the whole growing season of white clover. Different letters within a column indicate significant differences. x significance at P<0.1 * significance at p<0.05 ** significance at P<0.01

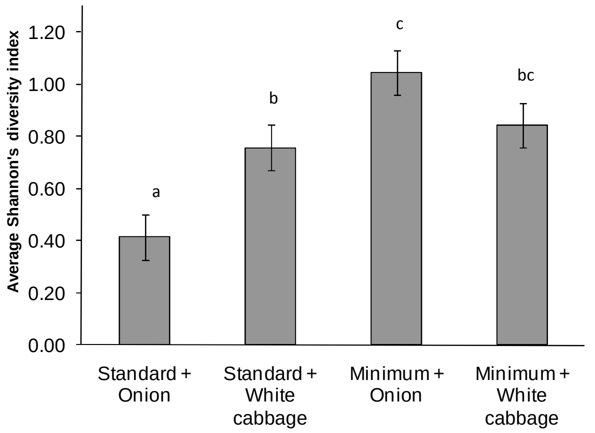

Figure 10: Interaction effect of tillage and pre-crop on species richness

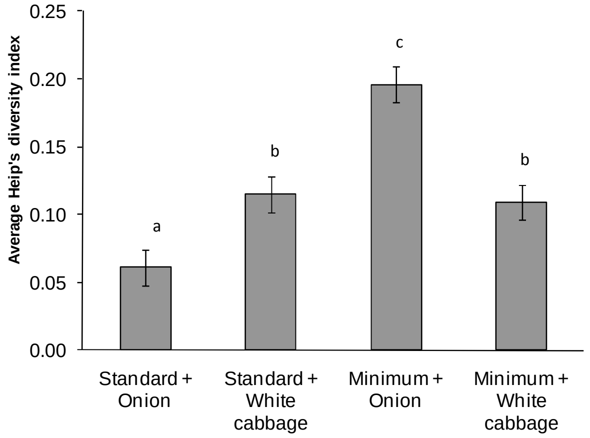

Figure 11: Interaction effect of tillage and pre-crop on species evenness

cabbage plots also appeared to be lower than in minimum tillage onion plots, this difference was not significant. Since this might be due to large within group variances, it would be interesting to repeat the surveys in subsequent years in order to verify this years findings. The species richness in standard tillage plots that received onion as a pre-crop was lower than in plots receiving any other treatment.

With regard to species evenness (Figure 11), the same pattern could be observed as for species richness. Species evenness was the lowest in standard tillage plots that had onion as a pre-crop and the highest in minimum tillage plots that had onion as a pre-crop. No effect of tillage can be observed within the group of plots that had white cabbage as a pre-crop. Species evenness in white cabbage plots appears to be intermediate between onion plots under standard tillage conditions and onion plots under minimum tillage conditions.

For plots receiving onion as a pre-crop, these results confirm the expectation of a higher species diversity under minimum tillage condition. However, this increased population diversity under minimum tillage conditions cannot be observed in plots with white cabbage as a pre-crop. This cannot be explained by a difference in nutrient status. Assuming that white cabbage plots are contain less nutrients, based on the field history and Nmin analysis, the opposite would be expected, since species diversity is known to be larger under nutrient-limited conditions. This increase in species diversity could theoretically result in an enlarged effect of a shift in tillage system. The observation that the increase in weed species diversity appears to be unrelated to the nutrient status of the soil is supported by an experiment from Pysek *et al*, who reported that soil nutrient status had no direct effect on weed species number (Pysek et al. 2005). Since the observed differences related to differences in pre-crop make the interpretation of the results more complicated and the experiment only started one year ago, the effects of tillage are likely to be more pronounced in subsequent years.

In Figure 12 and 13, the interaction between tillage and green manure is shown for species richness and species evenness respectively. Both for species richness and species evenness, the results appear to be similar. In standard tillage and in minimum tillage, species richness and evenness appear to be higher in control plots than in clover plots. As discussed previously, this is expected since a white clover cover selects for weeds that are most capable in out-competing white clover. Although not proven statistically, as explained previously, it also appears that for both green manure treatments, weed species diversity is higher in minimum tillage plots than in standard tillage plots. This statement is supported by tillage effects being significant. Additionally, the difference between clover and control plots appears to be more pronounced under minimum tillage conditions. This would imply the use of a green manure results in an enlarged loss of weed species diversity under minimum tillage conditions. Additional experiments are required to proof these observations and investigate underlying causes.

It should be noted, that the observed differences in weed species diversity might have been affected by experiments performed in previous years. Last year for example, flower

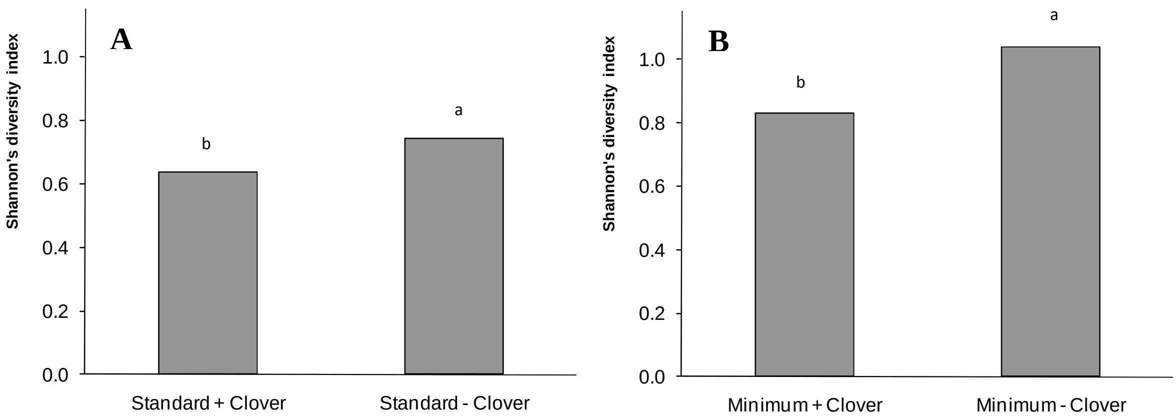

Figure 12: The effect of tillage on species richness in standard tillage (A) and in minimum tillage (B)

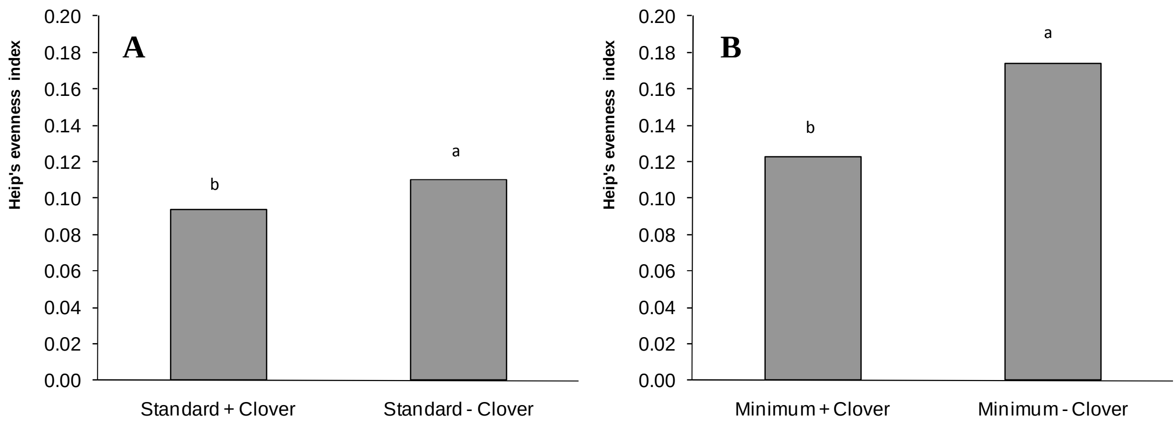

Figure 13: The effect of tillage on species evenness in standard tillage (A) and in minimum tillage (B)

strips were sown in some parts of the field. These flowers might have spread their seeds and spores over the rest of field by insect or wind pollination. Although the location of these strips does not appear to favor a certain group or overlap with the location of the plots used for this experiments, species diversity might still have been enlarged. Additionally, in several plots, crops grown in previous years were found to appear this year as a weed. Examples of these are *Solanum tuberosum* and *Crambe abyssinica*. Their presence increases population diversity in specific plots, resulting in enlarged variances and standard errors within groups.

4.4 Conclusion

Part of the goal of this research was to quantify and compare the interactive effects of tillage and the use of white clover as a green manure on weed suppression. With regard to this aspect, it can be concluded that converting to minimum tillage resulted in an increased total weed density. Under minimum tillage conditions, the total weed density was on average 76 plants m^{-2} whereas under standard tillage conditions the total weed density was 38 plants m^{-2}. Similar trends were observed for total weed DM and total weed cover though differences were not yet significant during the first year of this study. Additionally, total weed DM is found to be significantly higher in control plots compared to white clover plots. In control plots, the total weed DM was 1280 kg ha^{-1} compared to 487 kg ha^{-1} in white clover plots . Again, the same trend can be observed for other measures of total weed incidence, although these are also not yet significant. Since weed density, weed DM and weed cover are different measures of weed incidence, it is expected that in subsequent years, significant effects will become more pronounced for the other measures of weed incidence as well.

During the first year, no significant interaction between tillage and white clover could be observed for any of the measures of weed incidence. Nor was there any effect on the incidence of *Stellaria media*. Although for CCWI, weed species diversity and the percentage of annual weeds an interaction between white clover and tillage did occur, the experimental set up did not allow for the statistical comparison of all different possible combinations. Therefore, further experiments with a completely randomized or a repeated measures experimental design are required to further investigate the interaction between tillage and white clover with respect to a shift in weed population and weed species diversity.

The (interactive) effects of white clover and tillage might very well be masked by the increased variation among plots, caused by differences in pre-crop. However, the effect of pre-crop is very likely to decrease with continuation of the experiment. Furthermore, other experiments have shown significant results since the 2^{nd} and the 3^{rd} year after conversion. Therefore, additional measurements in subsequent years are required to provide further support for this years results and evaluate the long-term effects of tillage in combination with undersowing white clover.

5 Incorporating the effects of tillage and white clover in NDICEA

5.1 Background

5.1.1 Model description

The NDICEA model (Nitrogen Dynamics In Crop rotations in Ecological Agriculture) is a useful tool for capturing on-farm nitrogen flows using a system approach. With regard to nitrogen, this type of approach is essential, since the nitrogen balance is affected by a large number of complex and interactive processes (van der Burgt and Timmermans 2009). Although balance approaches such as the one applied under the MINAS regulations are easier to use, they do not give insight in the underlying processes involved (van der Burgt and Timmermans 2009;Hoffland 2009). This is a major disadvantage, since in-depth knowledge about these processes is required to synchronize nitrogen availability with crop demand which is a prerequisite for optimal nitrogen use efficiency and minimum nitrogen losses. This optimization is not only desirable from an environmental perspective, but also from an economic perspective. Increasing the nitrogen use efficiency has a positive effect on the economic returns and therefore plays an important role when developing sustainable farming systems.

NDICEA can be categorized as a process-based simulation model, calculating the dynamics of several state variables over the course of a crop rotation (van der Burgt et al. 2006). State variables for the soil include: water content, carbon, organic matter (SOM), initial age of organic matter, organic nitrogen and mineral nitrogen (Nmin). For calculations, a one week time interval is being used. Input parameters include planting and harvesting dates of crops and corresponding target yields, manure applications, tillage practices, weather data (or the region in which the farm is being located) and certain soil parameters. Model outputs are visualized in graphs with weekly values or summary tables for both SOM pools and nutrient balances. Additionally, nitrogen losses by denitrification and leaching are also being depicted.

The model consists of three components, addressing the dynamics of soil water, Nmin and SOM, respectively. When calculating the soil water content, the model takes several factors into account, being rainfall, irrigation, evapotranspiration, capillary rise and percolation (van der Burgt et al. 2006). With respect to Nmin dynamics, the calculations include the effects of nitrogen mineralization, atmospheric deposition, irrigation, fertilizers, capillary rise, biological fixation, crop uptake, denitrification and leaching (van der Burgt et al. 2006). For the decomposition of organic matter, a modified one-parameter carbon dissimilation model is used (van der Burgt et al. 2006), based on a model proposed by Janssen (Janssen 1984). This model has been adjusted to enable the calculation of weekly decomposition rates. The exact calculations have been carefully explained in an article from van der Burgt et al (van der Burgt et al. 2006), which I therefore refer to for further information.

5.2 Methodology

5.2.1 Modeling approach

In order to determine the accuracy of NDICEA in modeling the effects of tillage and white clover on the mineralization and availability of nitrogen, the Nmin and SOM data obtained from soil measurements were compared to the results obtained with the NDICEA model. Modeling with NDICEA requires input data for crop rotation, tillage practices, manure applications, soil quality, and climate (rainfall and temperature). In order to calibrate the model, four previous years (2005-2008) have been included in the analysis as well. Additionally, this time-frame has been extend with three years (2010-2012), in order to explore long-term effects of tillage and white clover during the remaining years of the project.

In 2008, the field was split up in half, one half being used for growing onions and the other half being used for growing white cabbage. Therefore, two different crop rotations were being evaluated. A minimum and a standard tillage scenario were created for both crop rotations. Additionally, each tillage scenario was evaluated with and without white clover undersown in spring wheat, resulting in 8 different scenarios. An overview of these scenarios is given in Table 12.

5.2.2 Data input

For the crop rotation and soil parameters during 2005-2009, field historical data were used, as presented in Opticrop, the digital database used at the experimental farm “De Broekemahoeve”. In this database, all cultivated crops, manure applications, soil operations and field measurements are recorded per parcel. Rainfall data were obtained from climate records kept at “De Broekemahoeve” whereas for temperature, the average data for the province of Flevoland were used, obtained from weather station Zeewolde. The temperature and rainfall data used as input in the model are being presented in Appendix 10.

During 2010-2012, soil parameters were kept similar, whereas for data related to crop rotation and manure applications input values were based on the theoretical crop rotation and manure scenarios as developed by PPO Lelystad. With respect to climate, the rainfall and temperature data for an average year in the province of Flevoland were used, as provided in NDICEA 5.4.4 and obtained from weather station Zeewolde (Appendix 10).

For each scenario, data concerning crop rotation and soil characteristics were entered in NDICEA version 5.4.4. These input data have been presented in Appendix 7 and 8, respectively. This was followed by entering the manure applications for each year. With this respect it should be noted that the autumn application of 17 t ha^{-1} of goat manure in 2004 had to be entered in the first week of 2005, since this is the first year of the simulation. The resulting fast increase in Nmin in the beginning of 2004 thus is an artifact although its effect on long-term trends appears to be minimal. In NDICEA, the application of manure is assumed to result in an addition of organic matter with a certain initial age to the initial SOM content. For each scenario, the initial SOM status of the soil and the applications affecting the SOM content were presented in Appendix 9. Except for Activit and Monterra N+, input values for NPK, dry matter content and organic matter content as provided in NDICEA were used. The input values for Activit and Monterra N+ have been summarized in Appendix 13.

After running the model with the environmental data from an average year for the province of Flevoland, the output file was exported to NDICEA 4.59.2 in which the rainfall data for the years 2005-2009 were corrected with the data from “De Broekemahoeve”. The correction of rainfall data was followed by adjusting the texture factor, which is an model parameter to simulate soil texture effects on protecting soil organic matter. The higher the value, the lower the protection and therefore the faster nitrogen mineralization. Since the default value mimics the effects of an average tillage practices, a lower value was used (van der Burgt, personal communication). As a result, all tillage practices could be entered manually, allowing for a comparison between a minimum tillage scenario and a standard tillage scenario. In NDICEA, entering a specific tillage practice results in the decrease of the initial age of a pre-defined quantity of SOM. The input data concerning tillage applications are also shown in Appendix 9.

Table 12: An overview of the scenarios investigated with NDICEA

Scenario	Pre-crop	Tillage	Clover
1	Onion	Standard	Yes
2	Onion	Standard	No
3	Onion	Minimum	Yes
4	Onion	Minimum	No
5	White cabbage	Standard	Yes
6	White cabbage	Standard	No
7	White cabbage	Minimum	Yes
8	White cabbage	Minimum	No

5.2.3 Modeling field history (2005-2009)

In order to calibrate the distribution of SOM over the different fractions, a model run was carried out for the years 2005-2007, after which the run repeat model option was used. As a result, the distribution of organic matter over the different fractions at the end of the first run became the input for the second run. The resulting values have been entered as initial organic matter stock in 2005. However, since the initial age of the old organic matter stock is not expected to change within a time span of three years, the initial value of 24 was maintained. In Appendix 9, the different stocks of organic matter are presented with their calibrated values. The calibration of SOM was followed by entering the average Nmin and SOM contents as determined in the field experiment in 2009 for each scenario. For this purpose, the Nmin concentrations were converted from mg kg^{-1} to kg ha^{-1}, assuming a bulk density of 1450 kg m^{-3} based on field measurements. SOM concentrations were converted from g kg^{-1} to kg ha^{-1} in the same manner. Thereby modeling results can be graphically compared with field data. The converted input values for Nmin and SOM are summarized in Appendix 11. After entering the obtained values from field measurements, the model could be run and results were exported to excel for analysis.

5.2.4 Modeling future scenarios (2010-2012)

In order to explore the course of mineral nitrogen during subsequent years of the experiment (2010-2012), an additional run was performed. For proper calibration of the model, the years 2008 and 2009 were also included, since differences between scenarios started to occur from this point onwards. The input values for the initial organic matter stock were determined by running the calibrated model a second time for the years 2005-2007 using the run repeat mode. In this manner, the distribution of organic matter over the different fractions at the end of 2007 can be used as input for the year 2008. The input values for the initial organic matter stock in 2008 as used in the third run are summarized in Appendix 12. After entering the crop and applications data for the years 2010-2012 and removing the years 2005-2007, the modulation of future scenarios could start.

5.3. Results and discussion

5.3.1 Soil organic matter dynamics during 2005-2009

The modeling results for soil organic matter (SOM) during 2005-2009 are shown in Figure 14. As can be seen, there appears to be a clear dynamic in the SOM content. The SOM content decreases as a result of the decomposition of organic matter and increases after each harvest as a result of the addition of crop residue. The application of organic manure also results in an increase in the total amount of SOM. During 2005-2008, this pattern was the same for each scenario, since management practices were the same. In 2008, differences can be observed between onion and white cabbage scenarios. The corresponding harvest dates were week 36 (week 192 in Figure 14) and week 46 (week 202 in Figure 14) and at both times an increase in SOM occurred. After this increase, the SOM content was approximately 136 t ha^{-1} for both crops. However, due to the application of 25 t ha^{-1} cattle manure, the total amount of SOM in onion scenarios increased. As a result, the organic matter content in 2009 is higher in scenarios in which onion was the preceding crop. There appears to be no differences between tillage systems during the growing season in 2009. Only after incorporation of the clover in week 48 (week 256 in Figure 14), differences started to occur. This was due to an increase in total SOM in standard tillage scenarios with white clover as a green manure.

The amount of SOM in the topsoil showed a negative trend over the years. Based on the slope of the trend line, shown in Figure 14, it can be calculated that the total amount of SOM declined with about 5.6 t ha^{-1} within 5 years. Relatively to the total amount of SOM, this is a decline of approximately 4% within 5 years, whereas relatively to the total amount of soil, this is a decline of about 0.1% in 5 years. With an initial SOM content of 3.2%, this does not appear to be unrealistic. However, any decline in SOM is undesirable and points to deterioration of the soil, since SOM is an important indicator for soil quality and has an important function in the supply of nutrients. Therefore, the overall production strategy should

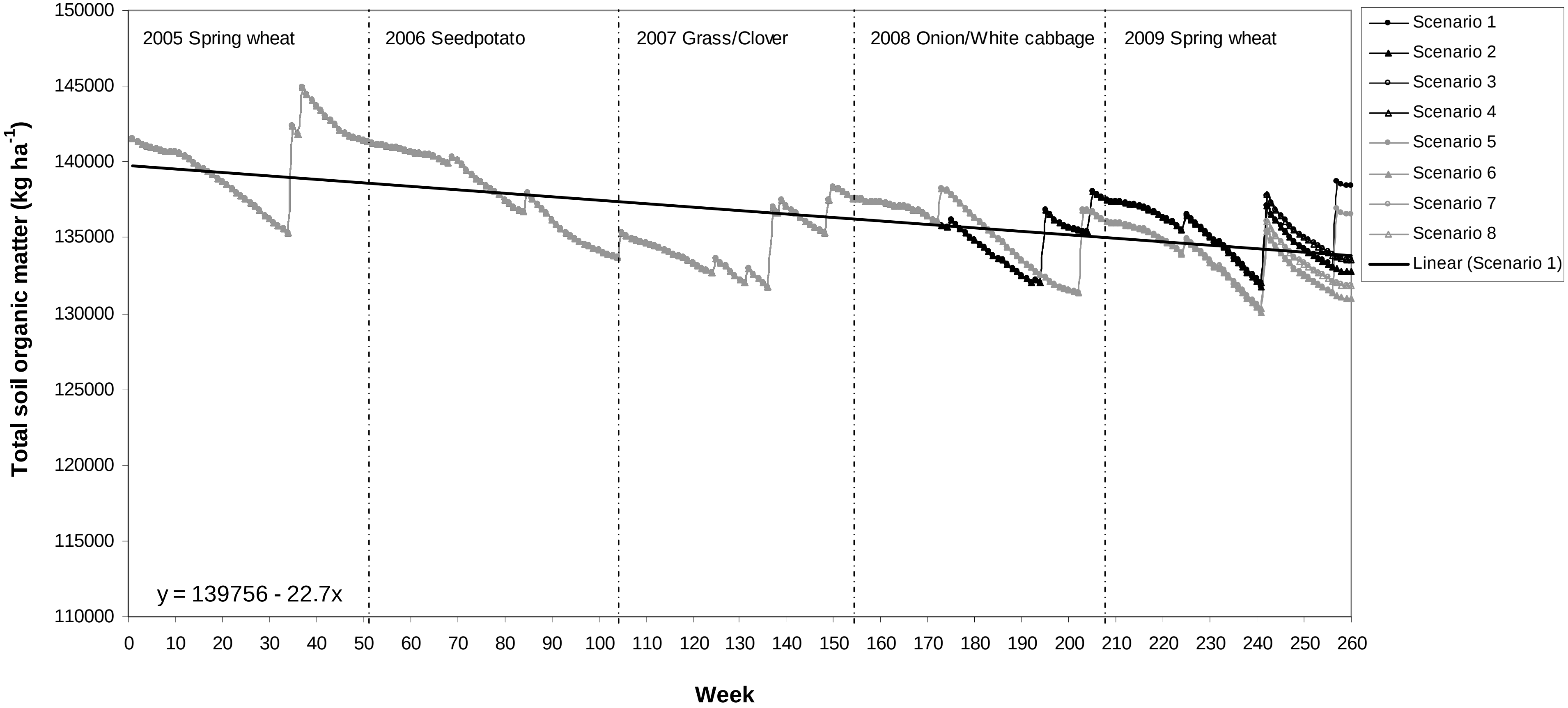

Figure 14: Organic matter content in the topsoil during 2005-2009

The organic matter content in the topsoil (SOM) was modeled in NDICEA for each scenario. Scenarios with onion and white cabbage as a pre-crop are depicted respectively in black and gray. Scenarios with white clover undersown in spring wheat are being marked with dots whereas control scenarios are marked with triangles. Closed markers represent scenarios receiving standard tillage whereas open markers represent scenarios receiving minimum tillage.

be to balance the decomposition of organic matter by supplying sufficient amount of organic amendments.

5.3.2 Comparison of the modeled SOM in 2009 to data obtained from field measurements

In order to determine the accuracy of NDICEA in modeling the amount of SOM, data obtained from field measurements in 2009 have been compared to the modeling results. From this comparison, shown in Figure 15 (field measurements are depicted by markers), it can be concluded that the data obtained from field measurements and the amount of SOM obtained by modeling are approximately within the same range. Therefore, with respect to SOM dynamics, the results of NDICEA appear to be reasonably accurate.

However, some critical remarks should be made with respect to this observation. First of all, November measurements appeared to correspond better with the modeled values than the measurements in July. This might be related to the overestimation of nitrogen mineralization during the growing season of spring wheat in 2009 (which will be elaborated on further in section 5.3.5). Additionally standard deviations from the field measurements were relatively large in some cases, ranging from 0.2% to 7% of the total amount of SOM. This hinders the comparison of field measurements and modeling results, not only with respect to the range of the absolute values, but also with respect to the differences between scenarios. Furthermore, the total amount of SOM as determined by field measurements was influenced by the analytical procedure used for Loss-on-ignition (Heiri et al. 2001). To be more specific, the duration and temperature of combustion and the sample size used can have a substantial effect on the outcomes. Additionally, no clay correction factor was used, correcting for the loss of structural water during combustion. This indicates that the total organic matter content might have been even lower in reality. Although other methods for determining the SOM content have proven to be more accurate, they are also more expensive, which hinders their use in an applied research project.

5.3.3 Soil organic matter dynamics during 2010-2012

Based on the modeling outcomes of NDICEA, for each different scenario, a prediction can be made about the change in SOM content during the subsequent years of the experiment. However, some caution is advised with respect to the interpretation of differences between scenarios. Although the model appears to be accurate in modeling the trend in SOM dynamics, differences between scenarios might have been masked by the overestimation of long-term nitrogen mineralization. The soil organic matter dynamics in 2010-2012 are shown in Figure 16. Again, a clear SOM dynamic can be observed related to the decomposition of SOM and the addition of SOM in the form of crop residue after each harvest and in the form of organic manure. Unfortunately, based on these modulations, the decline in SOM is expected to continue as visualized by the trend line in Figure 16. For all scenarios, the decline appears to be even larger than the decline observed during previous years. It is expected that the SOM content will drop with about 7% of the total amount of SOM. Relatively to the total amount of soil, the SOM content will presumably drop from 3.1% to 2.9% within 3 years. However, in reality, this drop might be less severe due to the overestimation of nitrogen mineralization in NDICEA, which is discussed below. Although the observed decrease in SOM is relatively small, it is an undesirable prospective that should be avoided. Nonetheless, on the other side, to counteract the decline in SOM of about 10 t ha^{-1} in three years about 30-60 t ha^{-1} of fresh organic material may have to be added, depending on the effective organic matter content of the material used. The model results show no clear differences between scenarios. This might related to the overestimation of nitrogen mineralization, but is most likely the result of the increased application of organic manure under standard tillage conditions.

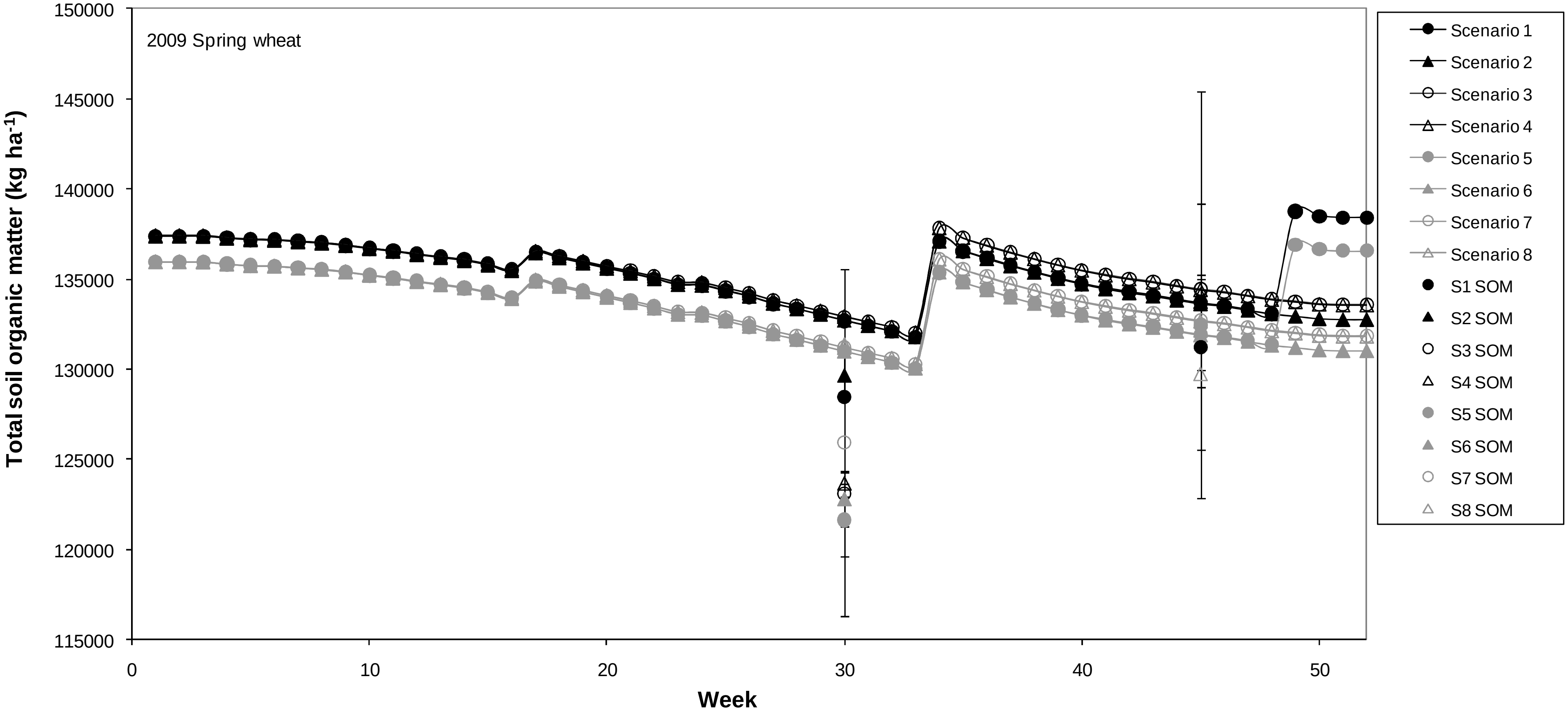

Figure 15: Organic matter content in the topsoil during 2009

The organic matter content in the topsoil (SOM) was modeled in NDICEA for each scenario. Scenarios with onion and white cabbage as a pre-crop are depicted respectively in black and gray. Scenarios with white clover undersown in spring wheat are being marked with dots whereas control scenarios are marked with triangles. Closed markers represent scenarios receiving standard tillage whereas open markers represent scenarios receiving minimum tillage.

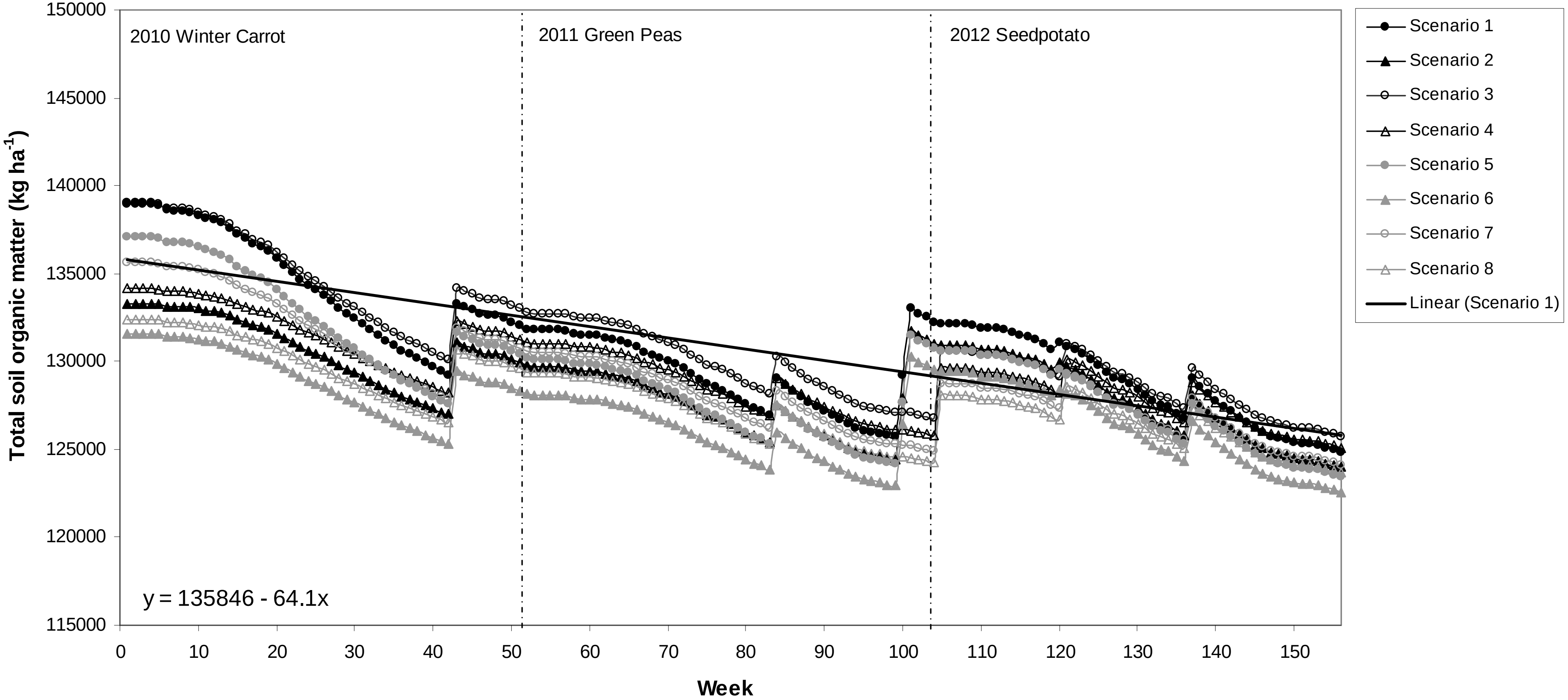

Figure 16: Organic matter content in the topsoil during 2010-2012

The organic matter content in the topsoil (SOM) was modeled in NDICEA for each scenario. Scenarios with onion and white cabbage as a pre-crop are depicted respectively in black and gray. Scenarios with white clover undersown in spring wheat are being marked with dots whereas control scenarios are marked with triangles. Closed markers represent scenarios receiving standard tillage whereas open markers represent scenarios receiving minimum tillage.

5.3.4 Prediction of nitrogen mineralization during 2005-2009

The modeling results for Nmin during 2005–2009 are shown in Figure 17. The nitrogen content in the topsoil follows the same pattern for each scenario during 2005-2007. This is conform expectations, since management was the same during these years. In 2008, when the field was split up in two parts with onion grown on one half and white cabbage grown on the other half, the Nmin dynamics started to differ for the two different crops. For the first four scenarios, in which onion was cultivated in 2008, the Nmin increases at a slower rate than with the last four scenarios, in which white cabbage was cultivated in 2008. Additionally, in onion scenarios, the peak value was reached in week 30 (week 174 in Figure 17) compared to week 18 (week 186 in Figure 17) in white cabbage scenarios. Furthermore, the maximum Nmin content was about 53 kg ha^{-1} lower than in the white cabbage scenarios, being respectively 94 kg ha^{-1} and 147 kg ha^{-1}. At this stage, no differences can be detected between scenarios with the same crop cultivated in 2008, since additional changes in management were only implemented in 2009.

In 2009, all scenarios started to follow a different pattern of fluctuations in Nmin in the topsoil. For the purpose of visualizing these differences more clearly and comparing the results to data obtained from field measurements, Figure 18 zooms in on the Nmin content of the topsoil during 2009. As can be seen, in scenarios in which onion was the preceding crop, the initial amount of nitrogen in the topsoil was larger than in scenarios that had white cabbage as a preceding crop. This can be attributed to the application of 25 t ha^{-1} cattle manure after the harvest of the onion in week 38 (week 194 in Figure 17) during the autumn of 2008. In spring 2009, the Nmin started to increase in all scenarios, as a result of increased mineralization of organic matter related to a rise in temperature. The rate of increase appears to be the same for both pre-crops, although small differences between tillage systems can already be observed. Both in onion and white cabbage scenarios, the Nmin increased with a slightly lower rate under minimum tillage conditions. This is expected, since tillage speeds up the mineralization of organic matter. After sowing the white clover in week 22 (Figure 18), the Nmin content seemed to stabilize for three weeks. Apparently, during this period, the mineralization of nitrogen and the uptake by plants matched. After week 25, all scenarios start to diverge with respect to Nmin.

During the remainder of the year, the predicted nitrogen content in the topsoil was higher in control scenarios compared to white clover scenarios with the same pre-crop and the same tillage treatment. From week 30 onwards (Figure 18), the Nmin content in any control scenario exceeded the Nmin content in any white clover scenario. This is due to a decrease in Nmin as a result of nitrogen uptake by plants in the clover scenarios,. During autumn, the Nmin content appeared to be lower in control scenarios receiving minimum tillage compared to control scenarios receiving standard tillage. This is expected because of the lower mineralization rate under minimum tillage conditions.

Initially, the same observation could also be made for the white clover scenarios. However, from week 30 onwards (Figure 18), the opposite trend was observed in the white cabbage scenarios including white clover as a green manure. Probably, due to nitrogen uptake by white clover and enlarged nitrogen mineralization under standard tillage conditions, the soil was being depleted of nitrogen earlier in the season. As a result, an enlarged decline in Nmin content was observed in standard tillage scenarios. In onion scenarios, this enlarged decline in Nmin under standard tillage conditions did not result in lower Nmin levels compared to minimum tillage conditions. From week 38 onwards, the Nmin contents remained approximately the same in minimum and standard tillage onion plots. Probably, due to the higher nutrient levels as a result of the autumn application of manure in 2008, the soil was not entirely depleted of nitrogen in the standard tillage onion scenarios. In the end of the year, the Nmin levels in all scenarios started to converse again, although the previously discussed trends still remained visible.

5.3.5 Comparison of the modeled Nmin in 2009 to data obtained from field measurements

In order to assess the accuracy of NDICEA in modeling the course of mineral nitrogen (Nmin), data obtained from field measurements in 2009 were compared to the modeling

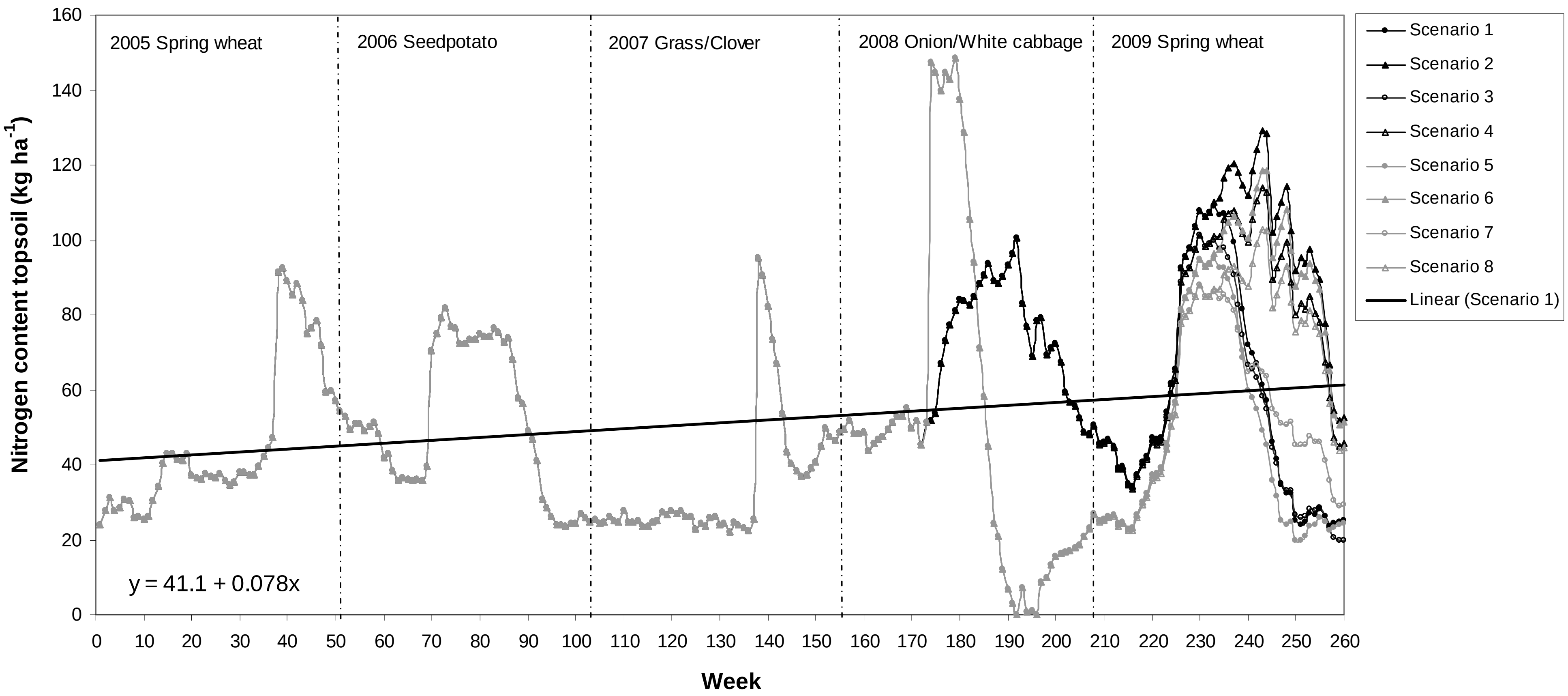

Figure 17: Mineral nitrogen content in the topsoil during 2005-2009

The nitrogen content in the topsoil (Nmin) was modeled in NDICEA for each scenario. Scenarios with onion and white cabbage as a pre-crop are depicted respectively in black and gray. Scenarios with white clover undersown in spring wheat are being marked with dots whereas control scenarios are marked with triangles. Closed markers represent scenarios receiving standard tillage whereas open markers represent scenarios receiving minimum tillage. Differences between scenarios only started to occur in 2008, since management practices were the same in previous years.

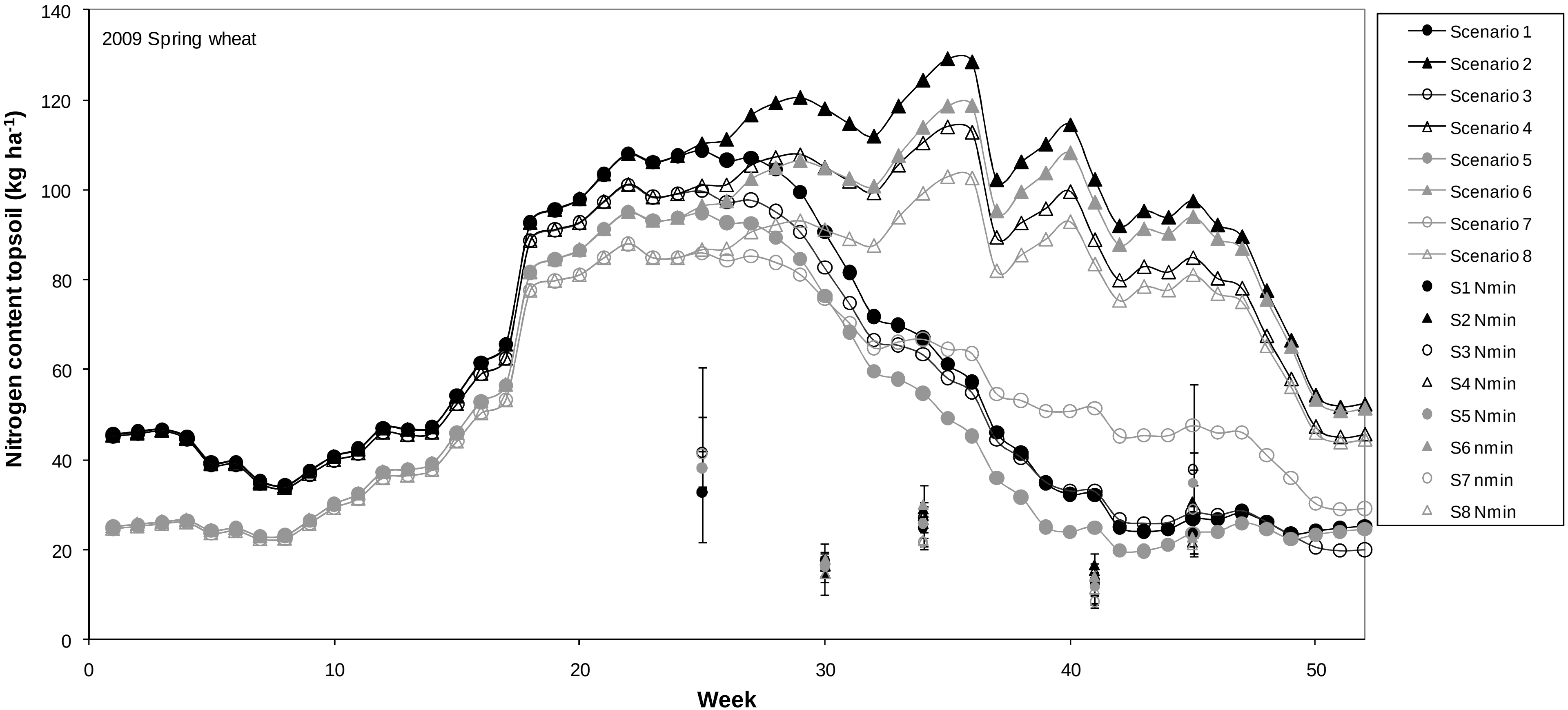

Figure 18: Mineral nitrogen content in the topsoil during 2009

The nitrogen content in the topsoil (Nmin) was modeled in NDICEA for each scenario. Scenarios with onion and white cabbage as a pre-crop are depicted respectively in black and gray. Scenarios with white clover undersown in spring wheat are being marked with dots whereas control scenarios are marked with triangles. Closed markers represent scenarios receiving standard tillage whereas open markers represent scenarios receiving minimum tillage. The lose points represent data obtained from field measurements.

results. From this comparison, shown in Figure 18 (field measurements depicted by markers), it becomes clear that during the growing season of spring wheat in 2009, the measured Nmin contents were at least 2.5 times lower than the values retrieved from the model. This is far more than two standard deviations (indicated by the error bars) and therefore an unacceptable result. Additionally, as a result of the relatively low measured Nmin values obtained by soil sampling, it was hard to observe clear differences between scenarios based on actual field data. This hinders the comparison of NDICEA results to results obtained from field measurements with respect to differences related to effects of tillage and white clover.

The relatively large difference between modeled and measured Nmin values could be the result of converting Nmin values from mg kg^{-1} to kg ha^{-1} using the bulk density of the soil. However, since a bulk density of 1450 kg m^{-3} as obtained from field measurements is already higher than the average bulk density of 1300 kg m^{-3}, this is very unlikely. Other plausible causes are an incomplete extraction of mineral nitrogen from the soil samples or an overestimation of Nmin by the model. However, when comparing the measured Nmin values in this experiment to values obtained from sampling the whole experimental field, these values appear to be approximately in the same range. Hence, it might be assumed that the laboratory analysis was performed correctly. Remains the overestimation of Nmin by the model, which will therefore be the main subject of further investigation.

When observing the course of Nmin as modeled by NDICEA more closely, a positive trend can be detected, indicating an accumulation of Nmin in the system over the years. This accumulation of Nmin (visualized by the trend line and equation in Figure 17) is not realistic, since excessive Nmin levels are supposed to be counteracted by increased leaching and denitrification losses. Based on the slope of the trend line, it can be estimated that the accumulation of Nmin will result in an overestimation of about 20 kg N ha^{-1} after 5 years. Therefore, it is very likely that this accumulation of Nmin points to (part of) the cause of the overestimation in 2009. Identification of the underlying factor(s) responsible for this accumulation is required to gain a better insight in the underlying causes of this overestimation of Nmin by NDICEA. Nevertheless, the critical observation should be made that this accumulation of Nmin still leaves a considerate part of the overestimation to be unaccounted for, especially during the growing season of the second spring wheat crop.

The apparent accumulation of Nmin over time is most likely caused by an accumulation of inputs. Therefore, from the time of application of cattle manure in autumn 2008 until the end of 2009, an overview of the sources of Nmin was made for scenario 1, including nitrogen fixation by leguminous crops and nitrogen mineralization from organic matter, plant residue, cultivations and manure applications. This overview of inputs was combined with an overview of outputs, in this case being uptake by plants and nitrogen leaching, allowing for the construction of a nitrogen balance (Table *13* 13). The nitrogen input from mineralization appears to be approximately in balance with the nitrogen output by plant uptake and leaching. Hence, it can be assumed that the accumulation of Nmin is not a result of a mismatch between those processes and therefore the calculation of mineralization from

Table 13: Nitrogen balance 2009

Nmin input source	Nmin (kg/ha)	Nmin output	Nmin (kg/ha)
Nmin from soil organic matter	122	Nmin uptake plants	379
Nmin from residue	76	Nmin leaching	85
Nmin from applications	155		
Nmin from cultivations	94		
Nmin from fixation	3		
Total Nmin	450		464
Balance (denitrification excluded)	-14		
Available Nmin from mineralization	447		
Available Nmin from mineralization (NDICEA)	469		

The nitrogen balance was constructed including the application of cattle manure in autumn 2008. The total input of Nmin from mineralization has been calculated based on this balance and the result was compared to the available Nmin from mineralization as calculated by NDICEA.

the different sources. However, when comparing the total nitrogen mineralization, calculated by the summation of Nmin available from all sources, with the available Nmin as calculated in NDICEA, there appears to be a difference of approximately 22 kg N ha^{-1}. This difference is approximately in the same range as the calculated nitrogen accumulation based on the trend line and therefore provides additional support for the accumulation Nmin. The nitrogen balance shows that this accumulation cannot be attributed to nitrogen mineralization within a year. Apparently some factor has an additive effect over the years on top of the yearly mineralization.

Since the nitrogen balance and trend line both support the observation of Nmin accumulation in the system, but do not provide us increased insight in the underlying causes, a third approach has to be used to identify them. It seemed worthwhile to further investigate the effects of tillage. Not only is this beside the effects of white clover the main focus of this research, it is also generally known that tillage positively effects the mineralization of nitrogen. This effect is indirect and the result of the tillage effects on soil texture, soil aeration and incorporation of organic matter as explained previously in the introduction. For further investigation, scenario 1 was used to illustrate the effects.

Figure 19 shows the effects of tillage as well as the effects of texture factor on the course of Nmin. As can be seen, a reduction in texture factor from 0.78 to 0.5 lowers the Nmin curve and therefore reduces the overestimation of Nmin in 2009 with a maximum of about 22 kg N ha^{-1}. However, the slope of the trend has not been altered since the texture factor is a multiplication factor. This results in an underestimation of Nmin during the first years of the simulation. When tillage is excluded, the slope of the trend line approximates zero, indicating the accumulation of Nmin over the years became negligible. Moreover, the maximum overestimation in 2009 is reduced with about 20 kg N ha^{-1}. The observed reduction in the overestimation of Nmin in 2009 as a result of the exclusion of tillage and a decrease in texture factor corresponds with the accumulation estimated based on the trend line in Figure 17 and the nitrogen balance in Table 13. Therefore, it is very likely that the observed accumulation of Nmin in NDICEA is a result of the (indirect) effects of tillage applications.

The accumulation of Nmin in NDICEA as a result of tillage applications resulted in an overestimation of Nmin under standard tillage conditions. This affects the differences observed between standard tillage and minimum tillage scenarios. Therefore, with respect to modeling the long-term effects of different tillage systems, a limitation of the model appears to have been encountered and modeling with NDICEA does not appear to be accurate nor realistic. Hence, for further research on minimum tillage, it is required to develop an alternative conceptual modeling approach to capture long-term tillage effects on nitrogen mineralization. Further investigation of the literature regarding the underlying mechanisms of the tillage effects on nitrogen mineralization might proof worthwhile for improving the model calculations and the modeling accuracy.

When linking the observations made previously to the model calculations, some first clues for improving the model can already be ascertained. In NDICEA, the texture factor is a fixed multiplication factor, representing the increase in mineralization as a result of decreased protection of organic matter. Tillage effects the soil structure and decreases the protection of organic matter which should theoretically result in an increased texture factor. However, this link between tillage and texture factor has not been incorporated in the model, which might therefore be a candidate for model improvement. A variable texture factor linked to tillage applications may possibly result in an increased modeling accuracy. This link should be based on a literature study investigating the underlying mechanisms of the effects of tillage on the protection of organic matter.

Additionally, it is observed that a decrease in texture factor, meaning an increase in the protection of organic matter, results in a decreased overestimation of Nmin in 2009. This seems to be in contradiction with the increased Nmin observed as a result of tillage, demonstrated previously. Based on this, tillage would increase the texture factor. From this observation, it can be deduced that the required decrease in this multiplication factor over the years has no relation to the protection effect of texture. Probably, another (multiplication) factor is required counteracting the effects of tillage on the protection of soil organic matter.

Some support for this last statement has already been supplied in the scientific background section of the field experiment, regarding tillage effects on soil organic matter

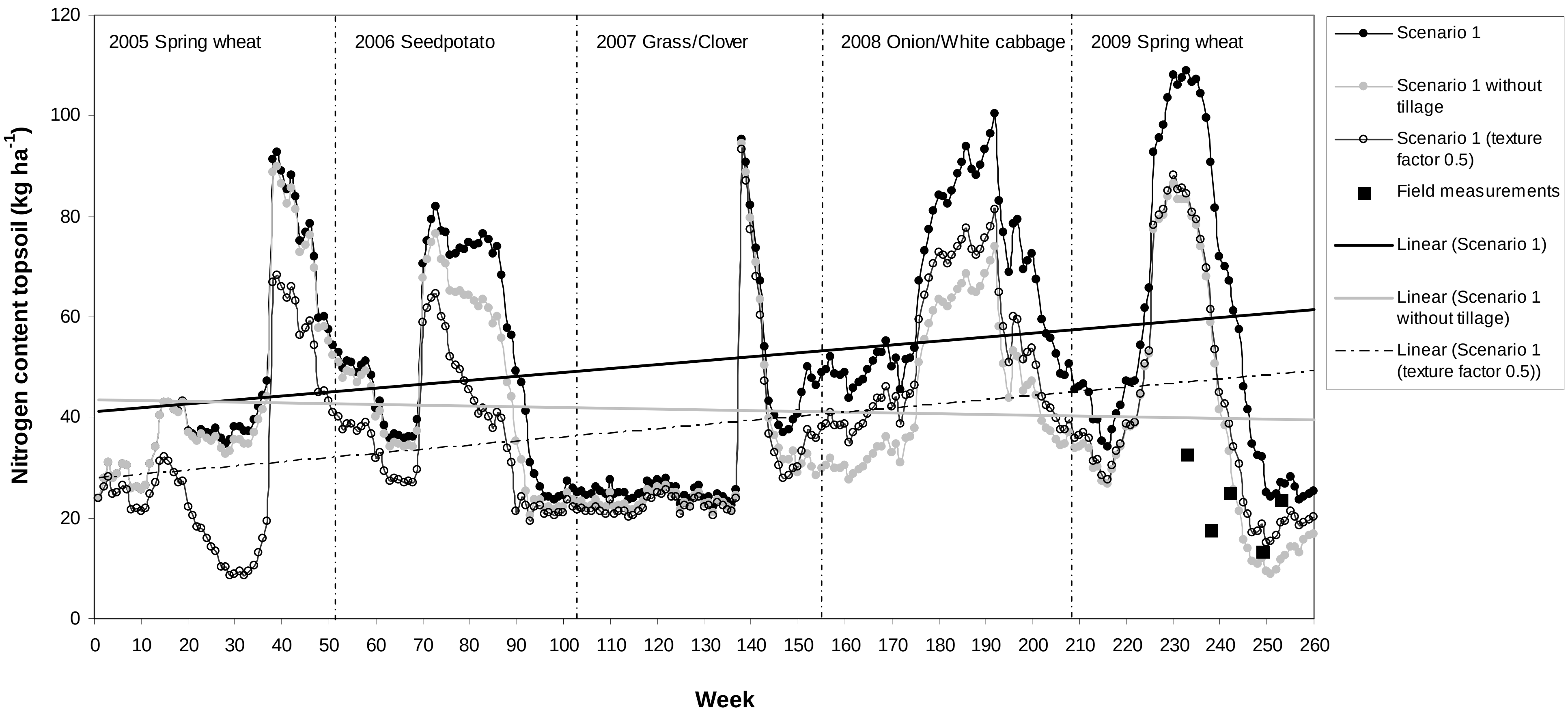

Figure 19: Mineral nitrogen as effected by tillage and texture factor during 2005-2009

The nitrogen content in the topsoil was modeled by NDICEA for scenario 1. The closed black dots represent the Nmin content for each week in scenario 1 as modeled previously. The gray dots represent the Nmin content for each week in scenario 1 when tillage is excluded from the modeling whereas the open dots represent the Nmin content for each week in scenario 1 when the texture factor has been lowered to 0.5. The black, gray and dashed trend line respectively correspond to the normal scenario 1, scenario 1 without tillage and scenario 1 with a reduced texture factor.

dynamics (section 3.1.2). To recall, although tillage initially speeds up the mineralization of organic matter, a steady state is reached after a certain period of time in which the production and mineralization of organic matter are again in balance (Janzen et al. 1997;Pekrun et al. 2003). This steady state is the result of a negative feedback loop caused by the decrease in organic matter associated with increased mineralization. In NDICEA, the effects of tillage are assumed to be infinite, which contradicts the theory predicting that steady state is occurring over time as a result of a negative feedback loop. Although it is assumed that tillage effects the initial age of a certain quantity of SOM speeding up the decomposition process, apparently the effect of this decrease on nitrogen mineralization is small, especially in soils with a high organic matter content or just after the application of organic matter. Further research is therefore required to further investigate and find more support for this proposed steady state and feedback loop. The knowledge gained by this research might proof valuable in improving the linkage between the tillage induced increase in Nmin to the associated decrease in soil organic matter in NDICEA.

5.3.6 Prediction of nitrogen mineralization during 2010-2012

The results of exploring the course of Nmin in the subsequent years of the experiment (2010-2012), are shown in Figure 20. Since it was demonstrated previously that NDICEA does not appear to be very accurate in modeling the long-term effects of tillage on Nmin, the discussion of the results was confined to the main issues and trends.

The model predicts that in 2010, the initial Nmin content is higher in all control scenarios than in all scenarios with white clover. However, during spring, this trend will probably reverse as a result of the release of nitrogen accumulated in white clover tissue. Additionally, the effects of pre-crop are expected to become negligible. In all scenarios a peak value will probably be reached around week 22, although the maximum Nmin level is higher in clover scenarios compared to control scenarios. This indicates that the use of white clover as a green manure has a beneficial effect on the availability of nitrogen for the subsequent crop. Additionally, the Nmin content is predicted to be lower in minimum tillage scenarios than in standard tillage scenarios. Both trends remain visible during the rest of the year.

In 2011, when green peas are being cultivated, the differences between scenarios are predicted to be less pronounced. This might be due to the fact that green pea is a leguminous crop fixing its own nitrogen and thereby buffering the differences associated with tillage practices. The trends observed in the end of 2010 will probably continue to exist until the Nmin levels drop in may 2011, related to the ripening of the peas. From this point until the application of 25 t ha^{-1} cattle manure in week 48 (week 100 in Figure 20), no clear differences between scenarios is expected to occur.

In 2012, as a result of the autumn application of cattle manure in 2011, the Nmin content is expected to be higher in standard tillage scenarios than for the minimum tillage scenarios during most of the year. Due to the application of 15 t ha^{-1} of cattle manure with the minimum tillage scenarios, this difference will probably disappear for a short period in spring, when all scenarios show a peak in Nmin levels. Differences between white clover scenarios and control scenarios are expected to dissipate in this year.

Also for the future scenarios, the model simulation shows a positive trend indicating an accumulation of Nmin over time. This supports the observation made during 2005-2009 and hinders the formation of clear hypothesis for the subsequent years of the experiment.

5.4 Conclusion

In order to determine the accuracy of NDICEA in modeling the effects of tillage and white clover on nitrogen mineralization and availability the Nmin and SOM data obtained by soil analysis were compared to results obtained with the NDICEA model. With respect to SOM, the total amount of soil organic matter was found to have declined with 0.1% within a period of five years. Although this is a relatively small decrease, the loss of organic matter is still undesirable, because of its essential function in sustaining inherent soil fertility and buffering crop nutrient supply. With respect to Nmin, modeling results with NDICEA show a clear effect

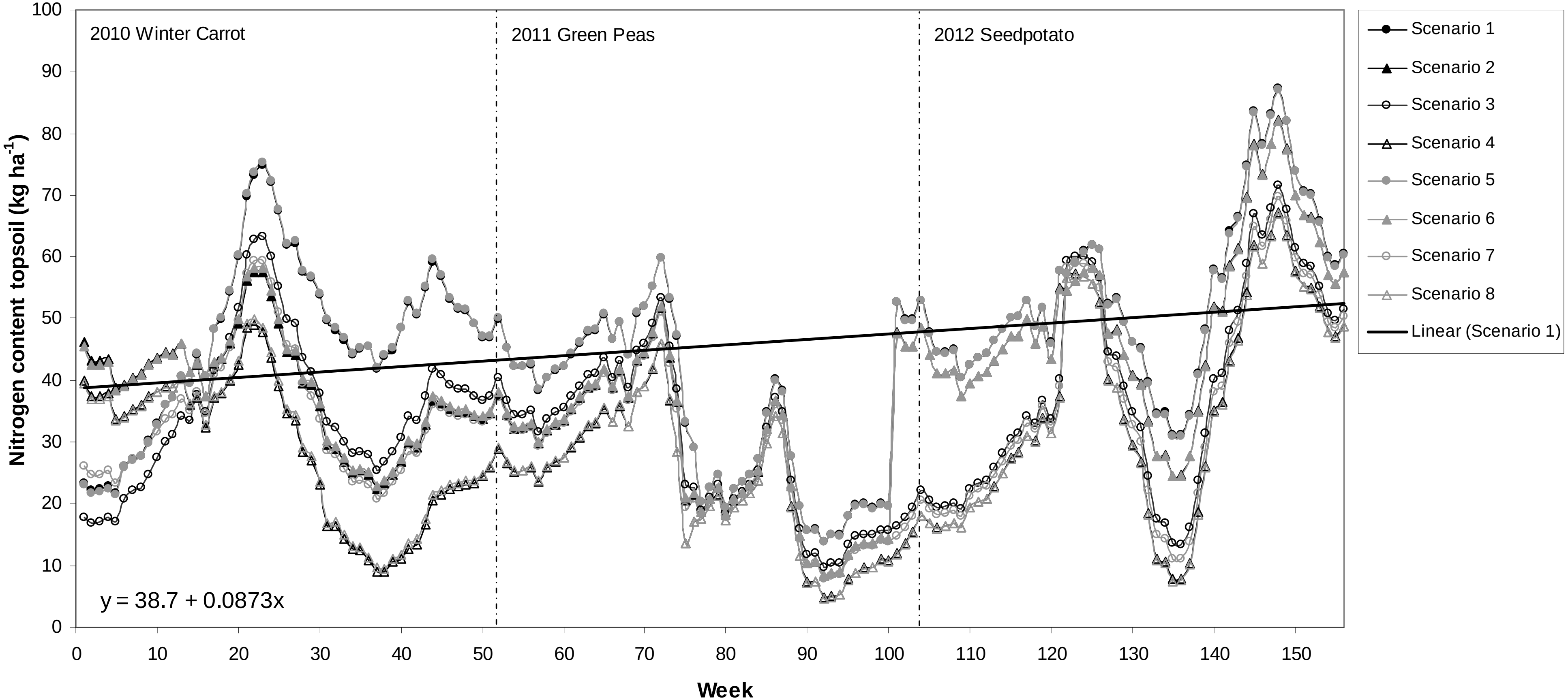

Figure 20: Mineral nitrogen content in the topsoil during 2010-2012

The nitrogen content in the topsoil was modeled by NDICEA for each scenario. Scenarios with onion and white cabbage as a pre-crop are depicted respectively in black and gray. Scenarios with white clover undersown in spring wheat are being marked with dots whereas control scenarios are marked with triangles. Closed markers represent scenarios receiving standard tillage whereas open markers represent scenarios receiving minimum tillage.

of tillage and white clover during its growing season in autumn 2009 and during winter 2009-2010. The Nmin content appears to be higher in control plots than in white clover plots. This is expected since part of the nitrogen is accumulated by white clover. Additionally, in control plots, the Nmin content was observed to be higher under standard tillage conditions than under minimum tillage conditions. This is also in agreement with our expectations, since tillage enhances the mineralization of organic matter. Therefore, on first sight, NDICEA appears to be accurate in modeling the course of Nmin.

However, when comparing the modeling results with field measurements during the growing season of spring wheat in 2009, the values obtained in field research appear to be at least 2.5 times lower. This is a substantial difference, which can most definitely be attributed to an overestimation of Nmin by the model, since the field measurements are in range with other measurements obtained from the same field. Further investigation of the results revealed that this overestimation of Nmin is most likely caused by a tillage related accumulation of Nmin over time. This would bias the results when comparing different tillage systems, making the NDICEA model unsuitable for assessing long-term tillage effects in its current form. The same statement holds for the comparison of modeled SOM to measured SOM, since Nmin is linked to SOM by the process of mineralization.

Further literature research is therefore required to identify the underlying mechanisms regarding the regulation of tillage induced mineralization. In this research, special attention should be given to the effects of tillage on soil structure and the relation between tillage-induced mineralization and the (total) accumulation of SOM over time. The acquired knowledge might be used to improve the model calculations, which hopefully improves the accuracy of NDICEA in modeling differences between tillage systems. Only then could NDICEA effectively be used for exploring the long-term effects of minimum tillage on soil organic matter and nitrogen dynamics.

Due to model limitations in correctly predicting Nmin, the relevance of predicted results of the course of Nmin during subsequent years of the experiment (2010-2012), may be limited. But in its current parameterization NDICEA predicts that effects of white clover remain present in the subsequent crop. The nitrogen accumulated in white clover is released during the growing season of carrot, resulting in higher Nmin levels in white clover scenarios. This effect of white clover is expected to last until May 2011. The reduced Nmin levels, associated with minimum tillage might be observed in all years, but differences are probably less pronounced when green beans are cultivated in 2011. The SOM content is expected to decline with 0.2% in three years, indicating a deterioration of the soil. Therefore, special attention should be given to the addition of crop residue and application of organic manure, in order to counteract this predicted decline in SOM. Although caution is required in interpreting the results of modeling future scenarios, the observed effects of tillage and white clover on Nmin and SOM as modeled with NDICEA could function as hypothesis that can be tested with field research in subsequent years of the experiment.

6 Discussion of results on a system-level

6.1.1 System approach

After focusing on the different components in separate chapters, in the last chapter, an effort was made to integrate the results on a system-level. By combining the knowledge obtained from the system analysis with NDICEA with knowledge obtained from both the soil and the weed analysis, all results can be discussed from a systems point of view. This will result in recommendations for improvement of current research and relevant topics for further research. However, a short summary of the system description in the introduction will first be provided, in order to outline basic system aspects and dynamics to provide a base for the subsequent discussion.

As stated in the introduction, tillage affects the decomposition of organic matter by incorporating crop residue into the soil. This increases the aeration and soil-residue contact and buffers the temperature and water level at which decomposition takes place, thereby positively affecting the mineralization rate. Minimum tillage, on the other hand, is considered to hold promise for preserving soil structure and SOM. However, minimizing tillage might also increase weed pressure and the associated labor for weed management, while reducing the efficacy of mechanical control. Additionally, the reduced nitrogen mineralization associated with minimum tillage requires the increased use of organic manure, crop residue or green manures to retain nutrients in the system and keep nutrient supply to the crop at a sufficient level. Whereas green manures and crop residue have also proven to suppress weeds, the downside of this approach might be competition with other uses for crop residue and, in case of cereals, the slow release of nutrients due to the high C/N ratios of straw. Nitrogen fixation by a leguminous green manure might prevent the potential risk of N-immobilization.. Taken the above aspects into consideration, it seemed pertinent to investigate the interactive effects of minimum tillage and a leguminous green manure on weed suppression and SOM dynamics.

6.1.2 Discussion of results with regard to SOM preservation

With respect to the comparison of the different combinations of tillage and white clover, the results regarding the preservation of SOM appeared to be inconclusive. Field research shows no significant effect of tillage, attributable to a confounding effect of differences in pre-crop. Continuation of the soil sampling and SOM analysis during subsequent years of the experiment therefore seems worthwhile. However, the NDICEA results also show that differences between pre-crops will remain present, due to the application of 25 t ha^{-1} of cattle manure in onion plots. Furthermore, from NDICEA simulations it appears that the beneficial effects of minimum tillage on SOM will not persist, as a result of the application of larger amounts of organic manure in the standard tillage system. With this respect, it should be noted that the NDICEA results are biased as a result of the tillage induced accumulation of Nmin and enlarged mineralization of SOM in the model.

In order to proof the beneficial (interactive) effects of minimum tillage and the associated increased application of green manures in field research, the same amount of organic matter from manure applications should be applied for all tillage systems. However, the timing of these manure applications might vary, as a result of the absence of ploughing in autumn under minimum tillage conditions. The same holds for an investigation with NDICEA, which in addition would require the improvement of model calculations regarding tillage induced mineralization for the model to be less biased. With this respect, it might also proof worthwhile to investigate the possibility for incorporating particulate organic matter (POM) fractions into the model.

6.1.3 Discussion of results with regard to Nmin

With respect to the comparison of the effects of different combinations of tillage and white clover on Nmin, differences in pre-crop proved to hinder the interpretation of results from soil analysis. These effects of pre-crop are expected to decrease over time, which is supported by NDICEA predictions. Therefore, continuation of the experiment might very well provide better insight on tillage effects on actual system processes.

Simulation results also show that on average the Nmin levels are higher in control plots and under standard tillage conditions, which is in agreement with the expectations and initial hypothesis. However, the results from NDICEA seemed to be inaccurate due to inherent model limitations. Especially during the growing season of spring wheat in 2009, the Nmin was highly overestimated. This could be partly attributed to a tillage induced accumulation of Nmin over time in combination with a fixed texture factor. As a result, the differences between tillage systems become biased, by overestimating the Nmin in the standard tillage system. Therefore, for NDICEA to be used in scientific research concerning the effects of minimum tillage, it is essential to improve the model with respect to the calculation of long-term effects of tillage induced mineralization.

Provided that the inherent model limitations of NDICEA are solved, it would be interesting to investigate the interactive effects of tillage and white clover on nitrogen leaching during the winter. Current NDICEA results indicate that, for both tillage systems in combination with white clover, the Nmin levels in autumn and associated nitrogen leaching in winter might even be higher under minimum tillage conditions than under standard tillage conditions. This would be an undesirable side effect. However, measuring nitrogen leaching in the field has proven to be very difficult. Moreover, in order to improve the accuracy of NDICEA in modeling the Nmin levels during the growing season of the crop, it would be worthwhile to determine the nitrogen content of the product, the crop residue and the roots. By combining this with frequent measurements of Nmin during the growing season of the crop, the nitrogen balance could be improved.

It is also apparent that more research is needed to investigate the tillage effects on the addition of organic matter accumulated by white clover to different SOM fractions. Related to this, it would be relevant to determine tillage effects on the rate and timing of the decomposition of white clover in future monitoring studies.. These factors determine how much of the nitrogen released by the decomposition of white clover becomes available for the subsequent crop and how much nitrogen is being lost due to leaching. Since with the standard tillage system, white clover is ploughed under in November, whereas for the minimum tillage system it is left over winter, the timing and rate of the decomposition of white clover might be very different. The delay in incorporation of white clover with minimum tillage systems is expected to cause differences in temperature and water levels at time of incorporation, and these effects should therefore also be taken into consideration.

Due to the later start of mineralization and the lower tillage induced mineralization, the Nmin levels under minimum tillage conditions will very likely be lower during the beginning of the growing season. This poses a risk of nitrogen shortages for a subsequent crop, especially if this is a crop with high N requirements. This indicates that an optimal crop rotation under minimum tillage conditions may be quite different from the optimal crop rotation under standard tillage conditions. In case of the experiment at the Broekemahoeve, in which winter carrot is the subsequent crop, the lower Nmin levels under minimum tillage conditions might proof to be beneficial for the product quality, especially when carrot is cultivated after a leguminous green manure. It would therefore be interesting to investigate the differences between tillage systems combined with the use of white clover as a green manure with respect to the performance of the subsequent crop.

6.1.4 Discussion of results with regard to weed management

With respect to the effects of tillage and white clover on weed suppression, no interaction effect could be proven for weed incidence. Also in this case, the variation as a result of differences in pre-crop might have masked potential differences. Additionally, it was found that the current experimental set-up did not allow for the comparison of interactive effects between tillage systems, which should therefore be reconsidered before starting the measurements in subsequent years. However, since separate effects of tillage and white clover can be detected on respectively weed density and weed DM and other experiments only report results after the 2nd or 3rd year, the future prospects are promising. Continuation of the experiment is therefore highly recommended to support and confirm this year's findings.

Moreover, some inconsistency between results from soil analysis and weed analysis occurred. Differences in cover crop weed index and population diversity could not be related to differences associated with differences in pre-crop, such as the nutrient status of the soil and weed suppression in the previous year. Apparently, other factors not included in the current measurements and treatments also affected these processes. Future research focus should be geared towards elucidating which underlying mechanisms may be involved using a literature review and/or simple studies under controlled conditions.. This knowledge can be used to evaluate the experimental setup and if necessary adapt it in order to minimize the effects of the disturbing factors and increase the homogeneity within and between plots.

A possible strategy for optimizing the experimental design may be to modify the size and shape of the tillage plots. Plots receiving a different tillage treatment are less than 13 m wide and only in some cases separated by a service strip of 3.15 m. This distance is too small to avoid the spread of seed-producing weeds between tillage systems, which reduces the chance of significant results. Since new fields are to be incorporated into the experiment in next year, reconsideration and adaption of this design in the new fields might proof worthwhile. This would allow for the comparison of results with a different design associated with different limitations.

This year's research did not only point to a limitation of the design, it also revealed an interesting topic for further research. The use of a green manure to increase SOM and suppress weeds poses the risk of re-growth after incorporation. Additionally, the green manure might compete for nutrients with a subsequent crop, not only during the growing season, but also by reducing the nutrient levels in the beginning of the season. This may result in substantial financial losses, especially in case of a cash crop such as winter carrot. Therefore, quantification of potential yield reduction and the associated financial losses is of major importance for the successful on-farm implementation of white clover as a green manure. This research should not only incorporate on-farm measurements, but also a thorough literature review and small scale studies in order to allow for generalization of the results for different subsequent crops and different soil types.

References

Amann, A., 1991. Einfluss von Saattermin und Grundbodenbearbeitung auf die Verunkrautung in verschiedene Kulturen. Thesis, Universitat Hohenheim, Stuttgard, 148 pp.

Arrouays, D. and Pelissier, P., 1994. Changes in carbon storage in temporate humic loamy soils after forest clearing and continuous corn cropping in France. Plant Soil 160: 215-223.

Askegaard, M. and Eriksen, J., 2007. Growth of legume and nonlegume catch crops and residual-N effects inspring barley on coarse sand. J. Plant Nutr. Soil Sci. 170:773-780.

Barnes, J.P. and Putnam, A.R., 1983. Rye residues contribute weed suppression in no-tillage cropping systems. J. Chem. Ecol. 9:1045-1057.

Barnes, J.P. and Putnam, A.R., 1986. Evidence for allelopathy by residues and aquaeous extracts of rye (*Secale cereale*). Weed Sci. 34:384-390.

Bauer, A. and Black, A. L., 1981. Soil carbon, nitrogen and bulk density comparisons in two cropland tillage systems after 25 years and in virgin grasslands. Soil Sci. Soc. Am. J. 45:1166-1170.

Beisel, J.N., Usseglio-Polatera, P., Bachman, V. and Moreteau, J.C., 2003. A comparative analysis of evenness index sensitivity. Internat. Rev. Hydrobiol. 8:3-15.

Bilalis, D., Efthimiadis, P. and Sidiras, M., 2001. Effect of three tillage systems on weed flora in a 3-year rotation with four crops. J. Agron. Crop Sci. 186:135-141.

Bradow, J.M. and Connick , WJ., Jr., 1990. Volatile seed germination inhibitors from plant residues. J. Chem. Ecol. 16:645-666.

Bristow, K.L., 1988. The role of mulch and its architecture in modifying soil temperature. Aust. J. Soil Res. 26:269-280.

Brown, P.L. and Dickey, D.D., 1970. Losses of wheat straw residue under stimulated field conditions. Soil Sci. Soc. Am. J. 34:118-121.

Bruce, J.A. and Kells, J.J., 1990. Horseweed (*Conyza canadensis*) control in no-tillage soybean with pre-plant and pre-emergence herbicides. Weed technol. 4:642-647.

Buhler, D.D., 1995. Influence of Tillage Systems on Weed Population Dynamics and Management in Corn and Soybean in the Central USA. Crop Sci. 35:1247-1258.

Buhler, D.D. and Daniel T.C., 1988. Influence of tillage systems on giant foxtail (*Setaria faberi*) and velvetleaf (*Abutilon theophrasti*) population and control in corn (*Zea mays*). Weed Sci. 36:642-647.

van der Burgt, G.J.H.M., Oomen, G.J.M., Habets, A.S.J. and Rossing, W.A.H., 2006. The NDICEA model, a tool to improve nitrogen use efficiency in cropping systems. Nutr. Cycl. Agroecosyst. 74:275-294.

van der Burgt, G.J.H.M. and Timmermans, B.G.H., 2009. The NDICEA model: a supporting tool for nitrogen management in arable farming. Bioacademy 2009 Lednice na Morave, Czech Republic, 24-26 Juni 2009. In: Sarapatka, B., (ed.): Bioacademy 2009 – proceedings, 4-8 pp.

Cambardella, C.A. and Elliott, E.T., 1992. Particulate soil organic matter changes across a grassland cultivation sequence. Soil Sci. Soc. Am. J. 56:777-783.

Carter, M. R., 1994. Conservation tillage in temperate agroecosystems. CRC Press, Boca Raton, Florida, USA, 390 pp.

Cherr, C.M., Scholberg, J.M.S. and Mc Sorley. R., 2006. green manure approaches to crop production: a synthesis. Agron. J. 98:302-319.

Christensen, B.T., 1992. Physical fractionation of soil and organic matter in primary particle size and density separates. Adv. Soil Sci. 20:1-89.

Coffman, C.B. and Frank, J.R., 1992. Corn-weed interactions with long-term conservation tillage management. Agron. J. 84:17-21.

Cogle, A.L., Strong, W.M., Saffigna, P.G., Ladd, J.N., Amato, M. 1987. Wheat straw decomposition in subtropical Australia II. Effect of straw placement on decomposition and recovery of added 15N-urea. Aust. J. Soil Res. 25:473-479.

den Hollander, N.G., Bastiaans, L., Kropff, M.J., 2007a. Clover as a cover crop for weed suppression in an intercropping design I. Characteristics of several clover species. Europ. J. Agron. 26:92-103.
den Hollander, N.G., Bastiaans, L., Kropff, M.J., 2007b, Clover as a cover crop for weed suppression in an intercropping design II. Competitive ability of several clover species. Europ. J. Agron. 26:104-112.
Douglas C.L., Jr, Allmaras, R.R., Rasmussen, P.E., Ramig, R.E. and Roager, N.C., Jr., 1980. Wheat straw composition and placement effects on decomposition in dryland agriculture of the Pacific Northwest. Soil Sci. Soc. Am. J. 44:833-837.
Dyck, E. and Liebman, M., 1994. Soil fertility management as a factor in weed control: the effect of crimson clover residue, synthetic nitrogen fertilizer, and their interaction on emergence and early growth of lambsquarters and sweet corn. Plant Soil 167: 227-237.
El Titi, A., 2003. Implications of soil tillage for weed communities. In: El Titi, A., (ed.): Soil tillage in agroecosystems. CRC Press, Boca Raton, Florida, USA, 384 pp.
Facelli, J.M. and Pickett, S.T.A., 1991b. Plant litter: Light interception and effects on an old-field plant community. Ecol. 72:1024-1031.
Fortin, M.C. and Pierce, F.J., 1991. Timing and nature of mulch retardation of corn vegetative development. Agron. J. 83:258-263.
Francis, G.S., Haynes, R.J. and Williams, P.H., 1995. Effects of the timing of ploughing-in temporary leguminous pastures and two winter cover crops on nitrogen mineralization, nitrate leaching and spring wheat growth. J. Agric. Sci. 124:1-9.
Froud-Williams, R.J., Chancellor, R.J. and Drennan, D.S.H., 1991. Potential changes in weed floras associated with reduced cultivation systems for cereal production in temperate regions. Weed Res. 21:99-109.
Giller, K.E., Witter, E., Corbeels, M. and Tittonel, P., 2009. Conservation agriculture and smallholder farming in Africa: The heretics' view. Field Crop Res. 114:23-34.
Hao, X., Chang, C., and Lindwall, C.W., 2001. Tillage and crop sequence effects on organic carbon and total nitrogen content in an irrigated Alberta soil. Soil Till. Res. 62:167-169.
Hargrove, W.L., Ford, P.B. and Somda, Z.C., 1991. Crop residue decomposition under controlled and field conditions. In: 12th Conference international soil tillage research organization. Ohio state university press, Columbus, Ohio, USA, 99 pp.
Hargrove, W.L., Reid, J.T., Touchton, J.T. and Gallaher, R.N., 1982. Influence of tillage practises on the fertility status of an acid soil double-cropped to wheat and soybean. Agron. J. 74:684-687.
Harrison, K.G., Broecker, W.S. and Bonani, G., 1993. The effect of changing land use on soil radiocarbon. Science 262:725-729.
Hassink, J., 1995. Decomposition rate constants of size and density fractions of soil organic matter. Soil Sci. Soc. Am. J. 59:1631-1635.
Havlin, J.L., Kissel, D.E., Maddux, L.D., Claassen, M.M. and Long, J.H., 1990. Crop rotation and tillage effects on soil organic carbon and nitrogen. Soil Sci. Soc. Am. J. 54: 448-452.
Heiri, O., Lotter, A.F. and Lemcke, G., 2001. Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. J. Paleolim. 25:101-110.
Hoffland, E. 2009. Nutrient Balances, Budgets and Flows. In: Hoffland, E., van Groeningen, J.W. and Oenema, O., (eds.): Nutrient management. Wageningen UR, Wageningen, The Netherlands, 238 pp.
Hoffman, M.L. and Regnier, E.E., 2006. Contributions to weed suppression from cover crops. In: Singh, H.P., Batish, D.R. and Kohli, R.K., (eds.): Handbook of sustainable weed management. Food Products Press, New York, USA, 882 pp.
Houba, V.J.G., Temminghoff, E.J.M., Gaikhorst, G.A. and van Vark, W., 1999. Soil analysis procedures, extraction with 0.01M $CaCL_2$. Wageningen Agricultural University, Wageningen, The Netherlands, 113 pp.
Howard, P.J.A. and Howard, D.M., 1990. Use of organic carbon and loss-on-ignition to estimate soil organic matter in different soil types and horizons. Biol. Fertil. Soils 9:306-310.

Janssen, B.H., 1984. A simple method for calculation of decomposition and accumulation of 'young' soil organic matter. Plant Soil 76:297-304.
Janzen, H.H., Campbell, C.A., Ellert, B.H. and Bremer, E., 1997. Soil organic matter dynamics and their relationship to soil quality. In: Gregorich, E.G. and Carter, M.R., (eds.): Soil quality for crop production. Elsevier, Amsterdam, 277-292.
Kasozi, G.N., Nkedi-Kizza, P. and Harris, W.G., 2009. Varied carbon content of organic matter in histosols, spodosols, and carbonatic soils. Soil Sci. Soc. Am. J. 73: 1313-1318.
Knab, W. and Hurle, K., 1988. Einfluss der Grundbodenbearbeitung auf Ackerfuchsschwanz (*Alopecurus myosuroides* Huds.). Zeitschr. Pfl. Krankh. Pfl. Schutz, Sonderheft XI: 97-108.
Kristiansen, P., Taji, A. and Reganold, P., 2006. Organic agriculture, a global perspective (1st ed). CSIRO publishing, Collingwood, Victoria, Australia.
Lal, R., 1976. No-tillage effects on soil properties under different crops in Western Nigeria. Soil Sci. Soc. Am. J. 40:762-768.
Linares, J., Scholberg, J.M.S., Boote, K., Chase, C.A., Ferguson, J.J. and Mc Sorley, R., 2008. Use of the cover crop weed index to evaluate weed suppression by cover crops in organic citrus orchards. Hort. Sci. 43:27-38.
Lindwall, C.W., Larney, F.J., Johnston, A.M. and Moyer, J.R., 1994. Crop management in conservation tillage systems. In: Unger, P.W, (ed.): Managing agricultural residues. CRC Press, Boca Raton, Florida, USA, 432 pp.
McVay, K.A., Radcliffe, D.E. and Hargrove W.L., 1989. Winter legume effects on soil quality and nitrogen fertilizer requirements. Soil Sci. Soc. Am. J. 53:1856-1862.
Menalled, F.D., Gross, K.L. and Hammond, M., 2001. Weed aboveground and seedbank community responses to agricultural management systems. Ecol. Appl. 11:1586-1601.
Miller, R.W. and Gardiner, D.W., 2001. Soils in our environment (9th ed). Prentice Hall inc., Upper Saddle river, New Jersey, USA 642 pp.
Minderman, G., 1968. Addition, decomposition and accumulation of organic matter in forests. J. Ecol. 56: 355-362.
Miyazawa, K., Tsuji, H., Yamagata, M., Nakano, H. and Nakamoto, T., 2004. Response of weed flora to combinations of reduced tillage, biocide application and fertilization practices in a 3-year crop rotation. Weed Biol. Manag. 4:24-34.
Mohler, C.L. and Teasdale. J.R., 1993. Response of weed emergence to rate of *Vicia villosa* Roth and *Secale cereale L*. residue. Weed Res. 33:487-499.
Murphy, S.D., Clements, D.R., Belaoussoff, S., Kevan, P.G. and Swanton C.J., 2006. Promotion of weed species diversity and reduction of weed seedbanks with conservation tillage and crop rotation. Weed Sci 54:69-77.
Peigné, J., Ball, B.C., Roger-Estrade, J. and David. C., 2007. Is conservation tillage suitable for organic farming? A review. Soil Use Manag 23:129-144.
Pekrun, C., Kaul, H.P. and Claupein, W., 2003. Soil tillage for sustainable nutrient management. In: El Titi, A., (ed.): Soil tillage in agroecosystems. CRC Press, Boca Raton, Florida, USA, 384 pp.
Pollard, F. and Cussans., G.W., 1976. The influence of tillage on the weed flora of four sites sown to successive crops of spring barley. In: Proc. 13th Brithish Weed control conference. 13: 1019-1028.
Prasad, R. and Power, J.F., 1997. Soil fertility management for sustainable agriculture. CRC Press, Boca Raton, Florida, USA, 356 pp.
Putnam, A. R. and DeFrank. J., 1983. Use of phytotoxic plant residues for selective weed control. Crop Prot. 2:173-181.
Pysek, P., Jarosik, V., Kropac, Z., Chytry, Z., Wild, J. and Tichy, L., 2005. Effects of abiotic factors on species richness and cover in Central European weed communities. Agr. Ecos. Env. 109:1-8.
Radosevich, S., Holt, J. and Ghersa, C., 1997. Weed ecology: implications for management. John Wilet & Sons, Inc., New York, USA, 589 pp.
Reddy, K., Zablotowitcz, R.M., Locke, M.A. and Koger, C.A., 2003. Cover crop, tillage and herbicide effects on weeds, soil properties, microbial populations and soybean yields. Weed Sci 51:987-994.

Rickson, R.J., 1994. Conserving soil resources, European perspectives. CAB international, Wallingford, UK, 425 pp.
Rieck, C.E., 1981. Herbicide effectiveness and weed populations in no-tillage corn. In: Proc. Symp. Int. Congr. Plant Prot. 9:65-67.
Roberts, H.A. and Dawkins, P.A., 1967. Effect of cultivation on the numbers of viable weed seeds in the soil. Weed Res. 7:290-301.
Rothrock, C.S., Kirkpatrick, R.E. and Scott. H.D., 1995. The influence of winter annual legume cover crops on soilborne plant pathogens and cotton seedling diseases. Plant Dis. 79:167-171.
Schlesinger, W. H., 1991. Biogeochemistry: an analysis of global change. Academic press, Inc., San Diego, California, USA, 588 pp.
Schomberg, H.H., Ford, P.B. and Hargrove, W.L., 1994. Influence of crop residues on nutrient cycling and soil chemical properties. In: Unger, P.W, (ed.): Managing agricultural residues. CRC Press, Boca Raton, Florida, USA, 432 pp.
Schreiber, M. M., 1992. Influence of tillage, crop rotation, and weed management on Giant foxtail (*Setaria faberi*) population dynamics and corn yield. Weed Sci 40:645-653.
Sharkey, M.J., 2006. Errors in measuring nitrogen and dry matter content of plant and faeces material. Grass Forage Sci. 25:289-294.
Smit, A.,. van Beek, C.L. and Hoogland, T., 2007. Risicogebieden voor organische stof. Alterra, Wageningen, The Netherlands, 51 pp.
Sohi, S.P., Mahieu, N., Arah, J.R.M., Powlson, D.S., Madari, B. and Gaunt, J.L., 2001. A procedure for isolating soil organic matter fractions suitable for modeling. Soil Sci. Soc. Am. J. 65:1121-1128.
Stanley, J., Hunter, H.M., Thomas, G. A., Blight, G.W. and Web, A.A., 1990. Tillage and crop residue management affect vertisoil properties and grain sorghum growth over seven years in the semi-arid subtropics. II. Changes in soil properties. Soil Till. Res. 18:367-388.
Stevenson, F.C., Legere, A., Simard, R.R. and Lafond, D.P.J., 1997. Weed species diversity in spring barley varies with crop rotation and tillage, but not with nutrient source. Weed Sci. 45:798-806.
Stockfisch, N., Forstreuter, T. and Ehlers, W., 1999. Ploughing effects on soil organic matter after twenty years of conservation tillage in Lower Saxony, Germany. Soil Till. Res. 52:91-101.
Teasdale, J.R., 1998. Cover crops, Smother Plants, and weed management. In: Hatfield, J.L., Buhler D.D. and Steward, B.A., (eds.): Integrated weed and soil management. Sleeping Bear press, Chelsea, Michigan, USA, 373 pp.
Teasdale, J.R., Beste, C.E. and Potts, W.E., 1991, Response of weeds to tillage and cover crop residue. Weed Sci 39:195-199.
Teasdale, J.R., Brandsaeter, L.O., Calegari, A. and Skora Neto, F., 2007. Cover crops and weed management. In: Upadhyaya M.K. and Blackshaw, R.E., (eds.): Non chemical weed management. CAB international, Wallingford, UK, 239 pp.
Teasdale, J.R. and Daughtry, C.S.T., 1993. Weed suppression by live and dessicated hairy vetch. Weed Sci. 41:207-212.
Teasdale, J.R. and Mohler, C.L., 1992. Weed suppression by residue from hairy vetch and rye cover crops. Proc. First Internat. Weed Control Congr. 2:516-518.
Teasdale, J.R. and Mohler, C.L., 1993. Light transmittance, soil temperature and soil moisture under residue of hairy vetch and rye. Agron. J. 85:673-680.
Tebruegge, F. and Boehrnsen. A., 1997. Experience with the applicability of no-tillage crop production in the West-European countries. Proc. EC workshop VI, Boigneville, 12-14 May, 1997, 25-43.
Tobham, P.B. and Lawson. H.M., 1982. Measurement of weed species diversity in crop/weed competition studies. Weed Res. 22:285-293.
Triplett, G.B., Jr, 1985a. Principles of weed control for reduced tillage corn production. In*:* Wiese, A.F., (ed.): Weed control in limited tillage systems. Weed Sci. Soc. Am., Champaign, Illinois, USA, 26-40.

Triplett, G.B., Jr, 1985b. Principles of weed control for reduced tillage corn production. In: Wiese, A.F., (ed.): Weed control in limited tillage systems. Weed Sci. Soc. Am., Champaign, Illinois, USA, 40-53.
Triplett, G.B., Jr and Lytle, G.D., 1972. Control and ecology of weeds in continuous corn without tillage. Weed Sci. 20: 453-457.
Unger, P.W., 1968. Soil organic matter and nitrogen changes during 24 years of dryland wheat tillage and cropping practises. Soil Sci. Soc. Am. J. 32:427-429.
Unger, P. W. and Parker, J.J., Jr., 1975. Residue placement effects on decomposition, evaporation and soil moisture distribution. Agron. J. 60:469-472.
Utomo, M., Frye, W.W. and Blevins, R.L., 1990. Sustaining soil nitrogen for corn using hairy vetch cover crop. Agron. J. 82:879-883.
Van Leeuwen-Haagsma, W.K. and Schröder, J.J., 2003. Groenbemesters en rustgewassen. In: Wijnands F.G. and Holwerda, J., (eds.). Op weg naar goede biologische praktijk, resultaten en ervaringen uit BIOM. Praktijkonderzoek Plant en Omgeving, Lelystad, The Netherlands, 168 pp.
Violle, C., Garnier, E., Lecoeur, J., Roumet, C., Podeur, C., Blanchard, A. and Navas, M.L., 2009. Competition, traits and resource depletion in plant communities. Oecologia 160:747-755.
White, R.H., Worsham, A.D. and Blum. U., 1989. Allelopathic potential of legume debris and aqueous extracts. Weed Sci. 37:674-679.
Wicks, G.A., Burnside, O.C. and Felton, W.L., 1994. Weed control in conservation tillage. In: Unger, P.W, (ed.): Managing agricultural residues. CRC Press, Boca Raton, Florida, USA, 432 pp.
Witt, W.W., 1984. Response of weeds and herbicides under no-tillage conditions. In: Phillips R.E. and Phillips, S.H., (eds.): No-tillage agriculture: Principles and Practises. Van Nostrand Reinhold, New York, USA, 152 pp.
Yadav, V., Malanson, G.P., Bekele, E., and Lant. C., 2009. Modeling watershed-scale sequestration of soil organic carbon for carbon credit programs. Appl. Geogr. 29: 488-500.

Appendix 1: Raw data – Nmin and SOM analysis

				NMIN (0-30cm) (mg kg^{-1})					SOM (%)					
Plot nr	Precrop	Tillage	Green manure	June	July	August	October	November	July (0-15 cm)	July (15-30 cm)	July (30-60 cm)	November (0-15 cm)	November (15-30 cm)	November (30-60 cm)
36MA	Onion	minimum	Clover	8.40	3.69	5.93	3.64	5.64	2.91	2.63	2.61	3.07	3.06	2.11
36MB	Onion	minimum	Control		3.81	6.41	3.57	5.04	2.82	2.89	2.74	2.90	2.44	2.90
35STA	Onion	Standard	Clover	8.60	4.11	5.81	3.54	5.58	3.01	2.83	2.60	3.04	3.00	2.54
35STB	Onion	Standard	Control		3.71	7.02	4.29	5.92	2.93	3.03	2.84	3.17	2.98	2.99
32STA	White cabbage	Standard	Clover	9.50	3.36	5.83	3.03	9.21	2.97	2.75	2.87	3.09	2.92	3.01
32STB	White cabbage	Standard	Control		4.74	7.69	3.09	5.90	3.09	3.00	2.48	3.18	3.00	2.58
31MA	White cabbage	minimum	Clover	6.40	3.40	5.21	1.78	5.87	2.93	2.97	2.32	3.08	2.79	2.51
31MB	White cabbage	minimum	Control		2.67	5.42	3.19	4.58	2.82	2.74	2.56	2.94	2.94	2.52
72STA	Onion	Standard	Clover	6.60	4.13	5.78	2.67	5.43	3.02	2.96	3.06	2.94	3.09	2.82
70MA	Onion	minimum	Clover	11.00	4.04	6.71	2.22	11.94	2.88	2.90	2.64	3.16	3.08	2.86
70MB	Onion	minimum	Control		3.10	6.48	3.36	8.30	2.83	2.83	2.65	3.14	3.39	3.11
68MA	White cabbage	minimum	Clover	12.80	4.33	4.89	2.18	7.62	2.71	2.57	2.66	3.18	3.13	2.76
68MB	White cabbage	minimum	Control		4.13	4.79	2.03	5.18	2.86	2.87	2.92	3.10	2.94	2.50
67STA	White cabbage	Standard	Clover	8.20	4.19	6.15	2.46	7.01	3.02	2.83	2.83	3.20	2.97	2.51
67STB	White cabbage	Standard	Control		3.55	6.32	3.42	4.69	3.05	2.94	2.83	3.10	2.87	2.81

Summary of the raw data regarding Nmin and SOM as obtained from field measurements and soil analysis has been presented. These data served as input for statistical analysis. Plot 72STB has been omitted from the experiment because of a progressive infestation of white clover from neighboring plots.

Appendix 2: Raw data – Weed density, weed dry matter and weed cover

				Weed density (plants m^{-2})				Weed dry matter (DM)			Weed cover (rank 1-20)			
Plot nr	**Precrop**	**Tillage**	**Green manure**	**July**	**August**	**September**	**October**	**August**	**September**	**October**	**July**	**August**	**September**	**October**
36MA	Onion	minimum	Clover	11	13.5	4.5	4	126	182	468	3.5	6.5	3	2
36MB	Onion	minimum	Control	5.5	20	28	22	504	1198	1962	2.5	8	17	11.5
35STA	Onion	Standard	Clover	1.5	2	4	4	86	80	250	1	2.5	3	1
35STB	Onion	Standard	Control	1.5	5	22	24.5	204	1494	2912	1.5	2.5	12.5	11
32STA	White cabbage	Standard	Clover	6	9.5	7.5	8	480	464	604	3	4	3.5	2
32STB	White cabbage	Standard	Control	3	2.5	21	22.5	138	1290	2866	2	2	10	13.5
31MA	White cabbage	minimum	Clover	24	22	21	21	1086	1118	1152	4	13.5	11.5	10
31MB	White cabbage	minimum	Control	18	11.5	37	33.5	442	798	2568	6	3.5	12.5	17
72STA	Onion	Standard	Clover	2.5	2	4.5	6	8	162	748	2	2	2.5	4.5
70MA	Onion	minimum	Clover	18	20	14.5	17.5	674	350	826	5	9.5	5	6
70MB	Onion	minimum	Control	9.5	10	24	40.5	294	1692	2116	3	4.5	16	14
68MA	White cabbage	minimum	Clover	13.5	24	16	6.5	680	662	592	4	9	6	2.5
68MB	White cabbage	minimum	Control	20	26	25	29	322	1138	1564	3	7	15.5	10.5
67STA	White cabbage	Standard	Clover	6.5	4	5.5	7.5	98	202	1226	3	4	2	8
67STB	White cabbage	Standard	Control	4.5	5.5	24.5	29.5	144	828	2144	3	3	10	12.5

Summary of the raw data regarding weed density, weed dry matter (DM) and weed cover as obtained from field measurements has been presented. These data served as input for statistical analysis. Plot 72STB has been omitted from the experiment because of a progressive infestation of white clover from neighboring plots.

Appendix 3: Raw data – White clover density, dry matter, cover, height and N content

				White clover density (plants m^{-2})				White clover dry matter (DM) ($kg\ ha^{-1}$)			White clover cover (rank 1-20)			
Plot nr	**Precrop**	**Tillage**	**Green manure**	**July**	**August**	**September**	**October**	**August**	**September**	**October**	**July**	**August**	**September**	**October**
36MA	Onion	minimum	Clover	69.5	97.5	-	-	584	2250	4290	2	9.5	17	19
35STA	Onion	Standard	Clover	39	64.5	-	-	734	3178	4578	1.5	9.5	19	18.5
32STA	White cabbage	Standard	Clover	33.5	23	-	-	154	1592	3582	1	3	14	19
31MA	White cabbage	minimum	Clover	4.5	18	-	-	26	76	944	1	3	2	6
72STA	Onion	Standard	Clover	32	60.5	-	-	360	2322	3268	1	6.5	19	16
70MA	Onion	minimum	Clover	52.5	26.5	-	-	210	1202	2324	1	3	15	14
68MA	White cabbage	minimum	Clover	66	26	-	-	144	520	3438	1.5	3.5	13	16
67STA	White cabbage	Standard	Clover	31	30	-	-	234	1140	4116	1	4	19	11

				White clover height (cm)				White clover N%		
Plot nr	**Precrop**	**Tillage**	**Green manure**	**July**	**August**	**September**	**October**	**August**	**September**	**October**
36MA	Onion	minimum	Clover	5	10	20	19	2.97	3.33	3.46
35STA	Onion	Standard	Clover	6	10	23	20	2.93	3.32	2.86
32STA	White cabbage	Standard	Clover	8	8	16	21	3.16	3.55	3.23
31MA	White cabbage	minimum	Clover	1	9	9	13	3.55	3.84	2.45
72STA	Onion	Standard	Clover	6	11	17	19	2.86	3.21	3.29
70MA	Onion	minimum	Clover	7	12	12	15	3.06	3.44	2.89
68MA	White cabbage	minimum	Clover	5	13	13	19	2.78	3.77	2.67
67STA	White cabbage	Standard	Clover	4	8	15	16	3.07	4.10	2.58

Summary of the raw data regarding weed white clover density, white clover dry matter, white clover cover, white clover height and white clover nitrogen content as obtained from field measurements has been presented. These data served as input for statistical analysis. Plot 72STB has been omitted from the experiment because of a progressive infestation of white clover from neighboring plots. No data regarding white clover density could be obtained in September and October due to difficulties with counting as a result of high densities.

Appendix 4: Raw data – Stellaria media density

				Stellaria media density (plants m^{-2})			
Plot nr	**Precrop**	**Tillage**	**Green manure**	**July**	**August**	**September**	**October**
36MA	Onion	minimum	Clover	7	8	3	4
36MB	Onion	minimum	Control	5	15	18	17
35STA	Onion	Standard	Clover	1	2	3	0
35STB	Onion	Standard	Control	2	5	22	22
32STA	White cabbage	Standard	Clover	6	9	8	8
32STB	White cabbage	Standard	Control	3	3	20	19
31MA	White cabbage	minimum	Clover	22	22	20	20
31MB	White cabbage	minimum	Control	16	10	25	26
72STA	Onion	Standard	Clover	3	2	5	4
70MA	Onion	minimum	Clover	4	18	11	14
70MB	Onion	minimum	Control	9	10	23	29
68MA	White cabbage	minimum	Clover	13	23	15	6
68MB	White cabbage	minimum	Control	20	26	24	27
67STA	White cabbage	Standard	Clover	6	3	6	7
67STB	White cabbage	Standard	Control	5	5	20	25

Summary of the raw data regarding *Stellaria media* density as obtained from field measurements has been presented. These data served as input for statistical analysis. Plot 72STB has been omitted from the experiment because of a progressive infestation of white clover from neighboring plots.

Appendix 5: Raw data – Annual weed density

				Annual weed density (plants m-2)			
Plot nr	**Precrop**	**Tillage**	**Green manure**	**July**	**August**	**September**	**October**
36MA	Onion	minimum	Clover	5	4	2	1
36MB	Onion	minimum	Control	2	6	5	12
35STA	Onion	Standard	Clover	0	1	2	0
35STB	Onion	Standard	Control	1	3	20	20
32STA	White cabbage	Standard	Clover	5	6	6	4
32STB	White cabbage	Standard	Control	2	2	15	15
31MA	White cabbage	minimum	Clover	20	20	15	15
31MB	White cabbage	minimum	Control	7	4	15	13
72STA	Onion	Standard	Clover	0	0	0	0
70MA	Onion	minimum	Clover	9	14	9	10
70MB	Onion	minimum	Control	4	6	20	20
68MA	White cabbage	minimum	Clover	9	20	13	2
68MB	White cabbage	minimum	Control	17	20	20	20
67STA	White cabbage	Standard	Clover	3	1	4	3
67STB	White cabbage	Standard	Control	3	1	4	3

Summary of the raw data regarding Annual weed density as obtained from field measurements has been presented. These data served as input for statistical analysis. Plot 72STB has been omitted from the experiment because of a progressive infestation of white clover from neighboring plots.

Appendix 6: Raw data – Species diversity indices

				Total nr weed species (nr subplot^{-1})				Shannons diversity index (-)				Heip's evenness index (-)			
Plot nr	**Precrop**	**Tillage**	**Green manure**	**July**	**August**	**September**	**October**	**July**	**August**	**September**	**October**	**July**	**August**	**September**	**October**
36MA	Onion	minimum	Clover	13	15	14	14	1.17	1.71	0.99	0.37	0.19	0.38	0.14	0.04
36MB	Onion	minimum	Control	10	10	13	12	0.49	1.46	1.71	1.30	0.09	0.37	0.38	0.24
35STA	Onion	Standard	Clover	10	12	14	13	0.32	0.35	0.79	0.33	0.05	0.06	0.11	0.04
35STB	Onion	Standard	Control	11	7	15	11	0.35	0.80	0.27	0.62	0.05	0.12	0.03	0.06
32STA	White cabbage	Standard	Clover	10	13	18	16	0.43	0.84	0.48	0.62	0.08	0.15	0.05	0.05
32STB	White cabbage	Standard	Control	6	12	14	18	0.52	0.66	0.92	1.10	0.18	0.19	0.12	0.16
31MA	White cabbage	minimum	Clover	15	16	18	17	0.40	0.34	0.82	0.76	0.04	0.03	0.07	0.07
31MB	White cabbage	minimum	Control	15	14	19	19	1.37	1.05	1.43	1.49	0.21	0.16	0.18	0.21
72STA	Onion	Standard	Clover	10	12	11	15	0.66	0.55	0.85	0.74	0.10	0.11	0.14	0.11
70MA	Onion	minimum	Clover	11	14	15	13	1.20	0.95	1.11	0.84	0.24	0.16	0.15	0.10
70MB	Onion	minimum	Control	10	10	15	15	1.20	0.95	1.11	0.84	0.24	0.16	0.15	0.10
68MA	White cabbage	minimum	Clover	11	14	15	12	0.79	0.55	0.63	0.64	0.12	0.07	0.07	0.09
68MB	White cabbage	minimum	Control	10	11	13	13	0.47	0.75	0.71	0.98	0.07	0.13	0.09	0.14
67STA	White cabbage	Standard	Clover	12	17	18	16	0.94	1.19	0.58	0.56	0.16	0.21	0.05	0.04
67STB	White cabbage	Standard	Control	17	14	16	20	0.94	1.19	0.58	0.56	0.08	0.10	0.13	0.09

Summary of the raw data regarding weed density, weed dry matter (DM) and weed cover as obtained from field measurements has been presented. These data served as input for statistical analysis. Plot 72STB has been omitted from the experiment because of a progressive infestation of white clover from neighboring plots.

Appendix 7: NDICEA - Inputs crop rotation

					Yield (kg/ha)							
Year	**Crop**	**Function**	**Week of sowing**	**Week of harvesting**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**	**Scenario 7**	**Scenario 8**
2005	Spring wheat	Crop	13	34	6322	6322	6322	6322	6322	6322	6322	6322
2006	Seedpotato	Crop	17	32	20000	20000	20000	20000	20000	20000	20000	20000
2006	Grass Clover	Green manure	34	-	3000	3000	3000	3000	3000	3000	3000	3000
2007	Grass Clover	Green manure	-	45	8000	8000	8000	8000	8000	8000	8000	8000
2008	Onion	Crop	16	36	27000	27000	27000	27000	-	-	-	-
2008	Yellow Mustard	Green manure	36	46	2200	2200	2200	2200	-	-	-	-
2008	White cabbage	Crop	25	46	-	-	-	-	90000	90000	90000	90000
2009	Spring wheat	Crop	14	33	4930	4930	5319	5319	4930	4930	5319	5319
2009	White clover	Green manure	23	48	3923	-	-	-	3849	-	-	-
2009	White clover	Green manure	23	52	-	-	3307	-			2191	-
2010	Winter carrot	Crop	20	42	80000	80000	80000	80000	80000	80000	80000	80000
2010	Winter rye	Green manure	43	-	-	-	-	-	-	-	-	-
2011	Winter rye	Green manure	-	15	-	-	500	500	-	-	500	500
2011	Pea (green)	Crop	19	31	5000	5000	5000	5000	5000	5000	5000	5000
2011	Yellow Mustard	Green manure	33	48	3100	3100	-	-	3100	3100	-	-
2011	Yellow Mustard	Green manure	33	52	-	-	3100	3100	-	-	3100	3100
2012	Seedpotato	Crop	16	32	35000	35000	35000	35000	35000	35000	35000	35000

For each scenario investigated, an overview is given of the inputs regarding crop rotation. For each crop, the date of sowing, date of harvesting and the yields are being presented. Yield values are based on data supplied by experimental farm “De Broekemahoeve”.

Appendix 8: NDICEA - Inputs soil

Soil parameter	Amount	unit
Soil type	Clay loam	
Clay fraction (0-2µm)	18	%
Thickness topsoil	30	cm
Texture factor top soil	0.78	
Texture factor subsoil	0.82	
pH Topsoil	7.5	
SOM content	3.2	%

The soil parameters used as modeling input. Soil parameters were the same in all scenarios.

Appendix 9: NDICEA - Inputs SOM, manure applications and soil tillage

Year	Week	Application	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5		Scenario 6		Scenario 7		Scenario 8	
			OM (kg/ha)	Initial age	OM (kg/ha)	Initial age	OM (kg/ha)	Initial age	OM (kg/ha)	Initial age	OM (kg/ha)	Initial age	OM (kg/ha)	Initial age	OM (kg/ha)	Initial age	OM (kg/ha)	Initial age
2005	1	Old organic matter	120167	24.00	120167	24.00	120167	24.00	120167	24.00	120167	24.00	120167	24.00	120167	24.00	120167	24.00
2005	1	Young organic matter	13150	3.38	13150	3.38	13150	3.38	13150	3.38	13150	3.38	13150	3.38	13150	3.38	13150	3.38
2005	1	Fresh organic matter	5102	1.48	5102	1.48	5102	1.48	5102	1.48	5102	1.48	5102	1.48	5102	1.48	5102	1.48
2005	1	Goat manure solid	17000	2.50	17000	2.50	17000	2.50	17000	2.50	17000	2.50	17000	2.50	17000	2.50	17000	2.50
2005	13	planting	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45
2005	18	Scuffling	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45
2005	19	Harrowing	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45
2005	20	Scuffling	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45
2005	23	Scuffling	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45
2005	37	Goat manure solid	20000	2.50	20000	2.5	20000	2.5	20000	2.5	20000	2.5	20000	2.5	20000	2.5	20000	2.5
2005	47	Harrowing	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45
2005	47	Ploughing	450	2.45	450	2.45	450	2.45	450	2.45	450	2.45	450	2.45	450	2.45	450	2.45
2006	16	Rotary cultivating	400	2.45	400	2.45	400	2.45	400	2.45	400	2.45	400	2.45	400	2.45	400	2.45
2006	17	Drilling	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45
2006	19	Milling and Ridging	400	2.45	400	2.45	400	2.45	400	2.45	400	2.45	400	2.45	400	2.45	400	2.45
2006	23	Vinasse-kali liquid	1500	1.30	1500	1.3	1500	1.3	1500	1.3	1500	1.3	1500	1.3	1500	1.3	1500	1.3
2006	24	Ridging	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45
2006	29	Dig-up	300	2.45	300	2.45	300	2.45	300	2.45	300	2.45	300	2.45	300	2.45	300	2.45
2006	31	Ploughing	350	2.45	350	2.45	350	2.45	350	2.45	350	2.45	350	2.45	350	2.45	350	2.45
2006	31	Grubbing	200	2.45	200	2.45	200	2.45	200	2.45	200	2.45	200	2.45	200	2.45	200	2.45
2006	34	Planting	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45
2007	20	Shake harrowing	300	2.45	300	2.45	300	2.45	300	2.45	300	2.45	300	2.45	300	2.45	300	2.45
2007	33	Goat manure solid	30000	2.50	30000	2.5	30000	2.5	30000	2.5	30000	2.5	30000	2.5	30000	2.5	30000	2.5
2007	37	Disk harrowing	200	2.45	200	2.45	200	2.45	200	2.45	200	2.45	200	2.45	200	2.45	200	2.45
2007	41	Ploughing	450	2.45	450	2.45	450	2.45	450	2.45	450	2.45	450	2.45	450	2.45	450	2.45

For each scenario, the callibrated initial SOM content, manure applications and tillage applications have been presented. Manure and tillage applications are assumed to change the initial age of a certain amount of organic matter (OM).

Appendix 9: NDICEA - Inputs SOM, manure applications and soil tillage

(continued)

Year	Week	Application	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5		Scenario 6		Scenario 7		Scenario 8	
			OM (kg/ha)	Initial age	OM (kg/ha)	Initial age	OM (kg/ha)	Initial age	OM (kg/ha)	Initial age	OM (kg/ha)	Initial age	OM (kg/ha)	Initial age	OM (kg/ha)	Initial age	OM (kg/ha)	Initial age
2007	45	Biomass	400	0.40	400	0.4	400	0.4	400	0.4	400	0.4	400	0.4	400	0.4	400	0.4
2007	45	Rootmass	2300	1.57	2300	1.57	2300	1.57	2300	1.57	2300	1.57	2300	1.57	2300	1.57	2300	1.57
2008	17	Cattle slurry	-	-	-	-	-	-	-	-	40000	2	40000	2	40000	2	40000	2
2008	17	Cultivatoring	-	-	-	-	-	-	-	-	250	2.45	250	2.45	250	2.45	250	2.45
2008	22	Harrowing	-	-	-	-	-	-	-	-	400	2.45	400	2.45	400	2.45	400	2.45
2008	24	Cultivatoring	-	-	-	-	-	-	-	-	250	2.45	250	2.45	250	2.45	250	2.45
2008	25	Planting									100	2.45	100	2.45	100	2.45	100	2.45
2008	25	Harrowing	-	-	-	-	-	-	-	-	400	2.45	400	2.45	400	2.45	400	2.45
2008	27	Harrowing	-	-	-	-	-	-	-	-	100	2.45	100	2.45	100	2.45	100	2.45
2008	27	Scuffling	-	-	-	-	-	-	-	-	100	2.45	100	2.45	100	2.45	100	2.45
2008	29	Scuffling	-	-	-	-	-	-	-	-	100	2.45	100	2.45	100	2.45	100	2.45
2008	29	Scuffling	-	-	-	-	-	-	-	-	100	2.45	100	2.45	100	2.45	100	2.45
2008	16	Planting	100	2.45	100	2.45	100	2.45	100	2.45	-	-	-	-	-	-	-	-
2008	19	Activit	1200	1.50	1200	1.50	1200	1.50	1200	1.50	-	-	-	-	-	-	-	-
2008	23	Scuffling	100	2.45	100	2.45	100	2.45	100	2.45	-	-	-	-	-	-	-	-
2008	27	Scuffling	100	2.45	100	2.45	100	2.45	100	2.45	-	-	-	-	-	-	-	-
2008	34	Dig-up	300	2.45	300	2.45	300	2.45	300	2.45	-	-	-	-	-	-	-	-
2008	35	Cultivatoring	250	2.45	250	2.45	250	2.45	250	2.45	-	-	-	-	-	-	-	-
2008	35	Cultivatoring	250	2.45	250	2.45	250	2.45	250	2.45	-	-	-	-	-	-	-	-
2008	36	Planting	100	2.45	100	2.45	100	2.45	100	2.45	-	-	-	-	-	-	-	-
2008	39	Cattle manure	25000	1.95	25000	1.95	25000	1.95	25000	1.95	-	-	-	-	-	-	-	-
2008	50	Ploughing	450	2.45	450	2.45	-	-	-	-	450	2.45	450	2.45	-	-	-	-
2008	52	Grubbing	200	2.45	200	2.45	-	-	-	-	200	2.45	200	2.45	-	-	-	-
2009	14	Rotary cultivating	400	2.45	400	2.45	-	-	-	-	400	2.45	400	2.45	-	-	-	-

For each scenario, manure applications and tillage applications have been presented. Manure and tillage applications are assumed to change the initial age of a certain amount of organic matter (OM).

Appendix 9: NDICEA - Inputs SOM, manure applications and soil tillage

(continued)

Year	Week	Application	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5		Scenario 6		Scenario 7		Scenario 8	
			OM (kg/ha)	Initial age	OM (kg/ha)	Initial age	OM (kg/ha)	Initial age	OM (kg/ha)	Initial age	OM (kg/ha)	Initial age	OM (kg/ha)	Initial age	OM (kg/ha)	Initial age	OM (kg/ha)	Initial age
2009	14	Planting	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45
2009	15	Harrowing	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45
2009	16	Harrowing	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45
2009	17	Harrowing	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45
2009	17	Activit	2300	1.50	2300	1.5	2300	1.5	2300	1.5	2300	1.5	2300	1.5	2300	1.5	2300	1.5
2009	18	Scuffling	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45
2009	20	Harrowing	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45
2009	20	Scuffling	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45
2009	22	Harrowing	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45
2009	23	Harrowing	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45
2009	23	Planting	100	2.45	-	-	100	2.45	-	-	100	2.45	-	-	100	2.45	-	-
2009	24	Monterra N+	200	0.50	200	0.5	200	0.5	200	0.5	200	0.5	200	0.5	200	0.5	200	0.5
2009	33	Cultivatoring	250	2.45	250	2.45	-	-	-	-	250	2.45	250	2.45	-	-	-	-
2009	33	Rotary cultivating	400	2.45	400	2.45	-	-	-	-	400	2.45	400	2.45	-	-	-	-
2009	35	Cultivatoring	250	2.45	250	2.45	-	-	-	-	250	2.45	250	2.45	-	-	-	-
2009	47	Ploughing	450	2.45	450	2.45	-	-	-	-	450	2.45	450	2.45	-	-	-	-
2010	17	Milling and Ridging	400	2.45	400	2.45	400	2.45	400	2.45	400	2.45	400	2.45	400	2.45	400	2.45
2010	17	Rotary cultivating	400	2.45	400	2.45	-	-	-	-	400	2.45	400	2.45	-	-	-	-
2010	20	Planting	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45
2010	24	Ridging	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45
2010	26	Ridging	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45
2010	28	Ridging	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45
2010	30	Ridging	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45
2010	42	Dig-up	300	2.45	300	2.45	300	2.45	300	2.45	300	2.45	300	2.45	300	2.45	300	2.45

For each scenario, manure applications and tillage applications have been presented. Manure and tillage applications are assumed to change the initial age of a certain amount of organic matter (OM).

Appendix 9: NDICEA - Inputs SOM, manure applications and soil tillage

(continued)

Year	Week	Application	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5		Scenario 6		Scenario 7		Scenario 8	
			OM (kg/ha)	Initial age	OM (kg/ha)	Initial age	OM (kg/ha)	Initial age	OM (kg/ha)	Initial age	OM (kg/ha)	Initial age	OM (kg/ha)	Initial age	OM (kg/ha)	Initial age	OM (kg/ha)	Initial age
2010	42	Grubbing	200	2.45	200	2.45	200	2.45	200	2.45	200	2.45	200	2.45	200	2.45	200	2.45
2010	43	Planting	-	-	-	-	100	2.45	100	2.45	-	-	-	-	100	2.45	100	2.45
2010	44	Ploughing	450	2.45	450	2.45	-	-	-	-	450	2.45	450	2.45	-	-	-	-
2011	16	Harrowing	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45
2011	17	Harrowing	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45
2011	19	Planting	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45
2011	19	Harrowing	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45
2011	19	Scuffling	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45
2011	30	Grubbing	200	2.45	200	2.45	200	2.45	200	2.45	200	2.45	200	2.45	200	2.45	200	2.45
2011	30	Disk harrowing	200	2.45	200	2.45	200	2.45	200	2.45	200	2.45	200	2.45	200	2.45	200	2.45
2011	33	Planting	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45
2011	48	Cattle manure	25000	2.50	25000	2.50	-	-	-	-	25000	2.50	25000	2.50	-	-	-	-
2011	50	Ploughing	450	2.45	450	2.45	-	-	-	-	450	2.45	450	2.45	-	-	-	-
2012	16	Chicken manure	1600	1.40	1600	1.40	-	-	-	-	1600	1.40	1600	1.40	-	-	-	-
2012	16	Drilling	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45
2012	17	Cattle manure	-	-	-	-	15000	2.5	15000	2.5	-	-	-	-	15000	2.5	15000	2.5
2012	18	Milling and Ridging	400	2.45	400	2.45	400	2.45	400	2.45	400	2.45	400	2.45	400	2.45	400	2.45
2012	20	Harrowing	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45
2012	20	Ridging	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45	100	2.45
2012	31	Dig-up	300	2.45	300	2.45	300	2.45	300	2.45	300	2.45	300	2.45	300	2.45	300	2.45
2012	32	Dig-up	300	2.45	300	2.45	300	2.45	300	2.45	300	2.45	300	2.45	300	2.45	300	2.45
2012	32	Cultivatoring	250	2.45	250	2.45	-	-	-	-	250	2.45	250	2.45	-	-	-	-

For each scenario, manure applications and tillage applications have been presented. Manure and tillage applications are assumed to change the initial age of a certain amount of organic matter (OM).

Appendix 10: NDICEA - Inputs Climate

	2005		2006		2007		2008	
Week	**Temperature (℃)**	**Rainfall (mm)**	**Temperature (℃)**	**Ra infall (mm)**	**Temperature (℃)**	**Rainfall (mm)**	**Temperature (℃)**	**Rainfall (mm)**
1	7.5	9.2	1.5	3.5	7.4	21.7	-1.3	11.1
2	7.5	3.1	1.6	4.4	9.8	43.2	-1.9	15.8
3	4.5	26.1	3.5	9	8.4	39.5	-0.9	34
4	0.9	5.7	1.5	2.5	1	14.8	1.3	21
5	5	7.6	0.4	0	6.6	5.9	6	12.5
6	3	7.6	3.8	19.2	1.9	5	0	6.4
7	2.5	32.9	4.4	16.6	6.7	33.7	-1.7	0.8
8	0.7	10.7	1.8	7.9	7.8	7.8	1.7	1.4
9	-2.2	18.2	0.2	11	7.1	37.6	3.7	13.6
10	2	6.5	2.8	35.6	7.4	40.7	4.4	9.1
11	7.8	10.9	-0.4	0.9	7.3	4.1	2.2	35.3
12	10.4	9.7	4	0	6	19.9	4.5	30
13	11.1	19.3	11.5	40.8	10.6	3.2	8.1	24.3
14	10.2	21.2	6.4	13.5	8.2	0.8	11.8	12.9
15	9.1	17	6.9	12.7	14.6	0.4	7.3	2.3
16	9	26.1	10.4	8.9	10.4	0.1	9.3	1.4
17	12.1	21.1	10.2	1.2	17.5	0	5	10.3
18	13.5	0.7	14.3	11.4	14	0	8	9.6
19	8.5	20.4	17.7	0	13	14.8	13.4	0
20	11.2	16.6	14.1	12.5	12.9	20.7	14.8	11.8
21	16.3	9.7	12	35.3	15.9	22.6	15.3	0.2
22	14.4	13.2	10.9	15	15.1	18.4	15.5	11.5
23	12.3	13.7	14.7	0	19.3	0.9	13.9	2.4
24	14.5	16.3	18.7	6.2	17.7	40.1	10.8	30.3
25	21.7	0	17.7	1.6	17	18.6	14.2	1.4
26	17.6	35.3	17.5	11.2	15.3	39.5	14.5	7.9
27	16.2	30.6	22.9	6.8	15.6	74.8	17.2	3.6
28	19.7	2.5	19.5	8	17.4	12	18.4	53.7
29	16.8	14.6	24.8	0	18.2	6.9	15.7	32.1
30	17.9	25.2	23.3	49.6	16.5	56.4	18.2	15.7
31	15.1	76.1	17.9	87.1	16.7	21.3	15	43.9
32	14.3	35	15.6	31.4	17.1	0.5	16	13.9
33	17.1	33.5	17.3	32.9	17	21.3	16.4	19.9
34	15.9	11	16	20.7	17.5	6.1	15.5	15.7
35	18.5	4.2	14.6	48.6	14.8	0.8	16.6	0
36	19.6	0	17	4.9	14	20.5	13.1	17.3
37	16.1	33.1	20.1	0.2	13.1	6.9	13.6	22.5
38	12	1.1	17.4	0.5	13.6	12.3	15.8	0
39	13.6	9.1	17	0.9	12.1	16.2	14.1	3.3
40	12.4	937	14	41.1	11.5	20.6	16.3	87.6
41	14.8	1.4	13.6	12.7	11.5	0.5	11.5	1.2
42	10.8	5.5	12.8	0.3	9.3	13.4	10.7	13.1
43	13.8	41.7	13.8	35.1	7.4	0.6	6.4	23.4
44	14.6	6	8.3	11.9	10	4.6	3.9	6.9
45	10.1	7.3	8.6	3.4	8.1	14.8	7.4	8
46	5.5	26.9	10.9	33.3	2.9	29.8	2.3	42.2
47	3.3	17.5	8.6	23.5	6	1.7	-0.3	37.1
48	2.1	7.5	9.2	3	6.4	6.3	3	7.3
49	5.3	10.9	9.1	36.1	8.3	48.4	8.8	11.2
50	4.9	5.8	7.1	18.2	2.1	19.5	5.5	7.5
51	4.3	13.9	3	6.1	-2.4	0	7.4	7.1
52	1	2.8	5.1	0	4.4	2.1	1.9	0.5

For the years 2005-2008, the temperature (Temp.) and rainfall (Rain) have been presented on a weekly scale. Rainfall data have been supplied by experimental farm “De Broekemahoeve” whereas temperature data were taken from the weather station in Zeewolde.

Appendix 10: NDICEA - Inputs Climate

(continued)

	2009		2010		2011		2012	
Week	**Temperature (℃)**	**Rainfall (mm)**	**Temperature (℃)**	**Ra infall (mm)**	**Temperature (℃)**	**Rainfall (mm)**	**Temperature (℃)**	**Rainfall (mm)**
1	-1	8.1	-1.3	11.4	-1.3	11.4	-1.3	11.4
2	0.7	4.1	-1.9	2.1	-1.9	2.1	-1.9	2.1
3	3.5	11	-0.9	0.5	-0.9	0.5	-0.9	0.5
4	2.5	24.6	1.3	21.7	1.3	21.7	1.3	21.7
5	0.2	3.4	6	10.8	6	10.8	6	10.8
6	2.7	26.5	0	0.1	0	0.1	0	0.1
7	2.3	3	-1.7	0	-1.7	0	-1.7	0
8	4.8	6.4	1.7	0.8	1.7	0.8	1.7	0.8
9	6.5	2.8	3.7	5.3	3.7	5.3	3.7	5.3
10	5.8	1	4.4	6.5	4.4	6.5	4.4	6.5
11	7.5	0	2.2	8.2	2.2	8.2	2.2	8.2
12	6.3	5.9	4.5	4.6	4.5	4.6	4.5	4.6
13	7	0	8.1	30.1	8.1	30.1	8.1	30.1
14	11.1	4.3	11.8	17.8	11.8	17.8	11.8	17.8
15	14.3	0.2	7.3	33.8	7.3	33.8	7.3	33.8
16	12.7	0	9.3	1.2	9.3	1.2	9.3	1.2
17	12.2	0	5	11.5	5	11.5	5	11.5
18	12.7	0	8	8.7	8	8.7	8	8.7
19	13.3	0.8	13.4	13.9	13.4	13.9	13.4	13.9
20	14.3	0	14.8	5.6	14.8	5.6	14.8	5.6
21	15.5	1.6	15.3	12.6	15.3	12.6	15.3	12.6
22	15.7	1.1	15.5	0	15.5	0	15.5	0
23	12.2	22.7	13.9	27.4	13.9	27.4	13.9	27.4
24	14.4	0.3	10.8	35.6	10.8	35.6	10.8	35.6
25	15	0	14.2	23.1	14.2	23.1	14.2	23.1
26	19.6	0	14.5	11.1	14.5	11.1	14.5	11.1
27	18.9	11.6	17.2	3.6	17.2	3.6	17.2	3.6
28	16.7	6.5	18.4	0.4	18.4	0.4	18.4	0.4
29	17.8	19.8	15.7	27.6	15.7	27.6	15.7	27.6
30	17.2	3.3	18.2	33.3	18.2	33.3	18.2	33.3
31	17.5	0	15	40.2	15	40.2	15	40.2
32	19.2	0.3	16	14.9	16	14.9	16	14.9
33	18.8	1.8	16.4	41.3	16.4	41.3	16.4	41.3
34	18.8	0	15.5	12.9	15.5	12.9	15.5	12.9
35	16.5	2.2	16.6	6.5	16.6	6.5	16.6	6.5
36	15.8	2.4	13.1	27	13.1	27	13.1	27
37	14.9	0	13.6	4.3	13.6	4.3	13.6	4.3
38	14.8	1.5	15.8	18.1	15.8	18.1	15.8	18.1
39	13.4	18.7	14.1	0	14.1	0	14.1	0
40	12.6	33.9	16.3	2.9	16.3	2.9	16.3	2.9
41	9.8	1.9	11.5	21.9	11.5	21.9	11.5	21.9
42	8.3	13.7	10.7	2.8	10.7	2.8	10.7	2.8
43	10.5	0.2	6.4	0.2	6.4	0.2	6.4	0.2
44	9.8	14	3.9	14	3.9	14	3.9	14
45	6.7	45.9	7.4	45.9	7.4	45.9	7.4	45.9
46	10	11.3	2.3	11.3	2.3	11.3	2.3	11.3
47	10.7	3.2	-0.3	3.2	-0.3	3.2	-0.3	3.2
48	5.9	14.4	3	14.4	3	14.4	3	14.4
49	6.6	25.5	8.8	25.5	8.8	25.5	8.8	25.5
50	1.1	13.3	5.5	13.3	5.5	13.3	5.5	13.3
51	-2.9	7.4	7.4	7.4	7.4	7.4	7.4	7.4
52	1.9	40.7	1.9	40.7	1.9	40.7	1.9	40.7

For the years 2009-2012, the temperature (Temp.) and rainfall (Rain) have been presented on a weekly scale. Rainfall data have been supplied by experimental farm “De Broekemahoeve” whereas temperature data were taken from the weather station in Zeewolde.

Appendix 11: NDICEA – Inputs Nmin and SOM as obtained in field measurements

	Nmin (kg/ha)					Soil organic matter kg/ha)	
Scenario	**June**	**July**	**August**	**October**	**November**	**July**	**November**
scenario 1	32.68	17.72	24.91	13.35	23.68	128485	131217
scenario 2		14.64	29.02	16.46	30.58	129631	133773
scenario 3	41.71	16.62	27.18	12.59	37.80	123099	134464
scenario 4		16.38	27.55	15.35	21.66	123660	134152
scenario 5	38.06	16.23	25.77	11.80	34.86	121653	132489
scenario 6		17.82	30.13	14.00	22.78	122783	132131
scenario 7	41.28	16.62	21.71	8.51	29.02	125940	132401
scenario 8		14.62	21.96	11.22	20.98	131383	129744

For each scenario, Nmin and SOM contents as determined by soil sampling and chemical analysis have been presented for the year 2009.

Appendix 12: NDICEA – Initial organic matter inputs for modeling Future scenarios (2008-2012)

Year	Week	Application	OM (kg/ha)	N%	Initial age
2008	1	Old organic matter	111469	5.77	26.36
2008	1	Young organic matter	20825	4.63	4.19
2008	1	Fresh organic matter	5102	2.9	1.48

The initial soil organic matter in 2008 after callibration. Since no differentiation in management practices has taken place before 2008, the values are the same for each scenario.

Appendix 13: NDICEA – Inputs fertilizers

Fertilizer	DM(%)	OM (%)	Ntot (%)	P (%)	K (%)	Nmin	Initial age
Activit	88	62	3.17	2.46	1.94	1.00	1.5
Monterra N+	90	85	11.70	0.00	0.45	0	0.5

For the fertilizers Activit and Monterra N+, the adjusted inputs for dry matter content (DM), organic matter content (OM) and NPK have been presented.