

# Development of reduced tillage systems in organic farming in Europe

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Commentary

## Abstract

No-tillage and reduced tillage are considered sustainable options of conservation tillage. While US organic farming researchers have focused on no-tillage, European organic farming researchers have concentrated on reduced tillage through the reduction of tillage depth or the application of noninversion tillage practices. Combinations of these two approaches have been implemented by the use of the two-layer plow or the layer cultivator. These innovations often came from farmers, aiming at reducing off-farm inputs such as fuel, and saving costs and labor, while at the same time building up soil fertility. Systematic, documented research on reduced tillage systems in Europe started only 1–2 decades ago, with experiments in Germany, Switzerland and France. While most experiments mimic stockless farms, other experiments include fodder crops such as grass–clover ley and applications of manure and slurry as is typical for mixed farms with animals and crops. Soil organic carbon, microbial activity and soil structure are often improved in the upper soil layer under reduced tillage compared with plowed soils. However, these positive findings were confounded by lower yields in some cases and enhanced weed pressure, except for the two-layer plow. Often it was not possible to determine whether and to what extent yield reduction was due to weed competition or to nitrogen shortage, because of retarded nitrogen mineralization in spring in reduced tillage systems. In systems with manure use, also higher soil fertility measures concomitant with increased yields were reported under reduced tillage. Indeed, it is difficult to gain an overview on research activities dealing with reduced tillage in organic farming in Europe due to dispersed experimental infrastructures and the scarcity of peer-reviewed published literature. To close this knowledge gap a European Network is being established aiming at further developing reduced tillage systems in organic farming, addressing the issue of carbon sequestration and N<sub>2</sub>O emissions, as well as weed and nutrient management.

**Key words:** reduced tillage, no-tillage, conservation tillage, organic farming, Europe

## Introduction

The loss of large areas of arable land by erosion calls for more sustainable cropping systems<sup>1–3</sup>. Both organic farming and no-tillage offer many benefits in view of soil fertility and biodiversity<sup>4–6</sup>. No-tillage systems were developed under conventional management aiming at conserving soil moisture, protecting soils from erosion and minimizing soil compaction. The combination of organic farming and no-tillage may provide additional benefits to the environment and further improve the resource use efficiency<sup>7</sup>. However, in no-till systems, weeds are usually controlled by herbicides, and plants fertilized via mineral nitrogen, methods that are not permitted in organic farming systems.

Only relatively small areas are currently under no-tillage in Europe as compared to USA, Brazil, Argentina,

Canada and Australia<sup>8,9</sup>. Both organic farming and no-tillage have been identified as promising options to sequester carbon in European soils<sup>10</sup>. However, only a few studies so far have analyzed carbon pools across the whole soil profile. While organic carbon, in most cases, was elevated under no-tillage in upper soil layers, it may decrease in deeper soil layers, in particular when organic matter input to the systems is low<sup>11</sup>. Climate-change mitigation potential of no-tillage systems may also be offset by elevated N<sub>2</sub>O emissions, which are fostered under the more anaerobic conditions prevailing in this system<sup>12,13</sup>. Recent research indicates that integrating appropriate conservation agriculture approaches into organic cropping systems may overcome these limitations. For example, N<sub>2</sub>O emissions were greater when microbial soil populations were exposed to low C/N ratios by the use of mineral N-fertilizers in conservation

agriculture<sup>13,14</sup>. This may be of lesser importance when using organic fertilizers. Notwithstanding, the introduction of conservation tillage practices such as no-tillage or reduced tillage can further improve organic systems with respect to soil fertility. While no-tillage system development in organic farming is mainly restricted to the USA<sup>15</sup>, farmers and researchers in Europe focus on reduced tillage systems. The current article gives an overview on the development of reduced tillage in organic farming in Europe and identifies relevant research gaps.

## Reduced Tillage Systems in Europe

The idea of noninversion soil preparation in organic farming dates back to the early 1950s, when Rusch<sup>16</sup> developed his ideas of organic farming. His vision was to mimic a stable, natural ecosystem, and pointed out that each soil layer has its adapted biocenosis, which should not be disturbed by deep inversion plowing. In practice, the 'credo' of organic farmers in these times was 'shallow plowing and deep loosening' [Otto Schmid, organic farming advisor at FiBL (the Research Institute of Organic Agriculture), pers. comm.]. Nowadays, reduced tillage practices in organic farming comprise several practices such as the reduction of plowing depth but also noninverting, less-invasive soil loosening, e.g. by the chisel plow<sup>17</sup>. Carter<sup>18</sup> pointed out that conservation tillage practices in humid temperate regions need adaptation to soil and climatic conditions. This applies in particular to organic farming systems, because no synthetic nitrogen fertilizers and herbicides are available.

## Rationale for the Reduced Tillage Approach in Organic Farming in Europe

No-tillage started in the USA triggered by tragic dust storms in the mid-western USA in the 1930s. This served as a wake-up call to how human interventions in excessive soil cultivation led to unsustainable agricultural systems<sup>19</sup>. Later on in the 1980s and 1990s no-till was introduced in Brazil and moved to Argentina. Currently approximately 26 million hectares are under no-till in Brazil and approximately 20 million hectares in Argentina<sup>8,9</sup>.

We interpret the different approaches in Europe (reduced tillage) and USA (no-tillage) in organic farming in the context of the predominant pedo-climatic conditions of the two continents and the type of farms. European farmers in large areas are faced with humid and cold conditions during crop growth, limiting the suitability of no-tillage practices. Mixed farms with animals, fodder and cash crops are considered ideal in view of nutrient recycling, environment protection and specifically the farms' influence on climate change in Europe.

In this context, there are a number of arguments for a better suitability of reduced tillage under humid temperate climate, such as manure incorporation, faster warming up of soil in spring, resulting in faster nitrogen mineralization, better control measures of perennial weeds and removal of grass-clover by shallow undercutting of the whole field. Moreover, in crop rotations comprising maize and wheat, a shallow incorporation of straw residues into the soil may result in faster decay, and thus in a better regulation of pathogens such as *Fusarium* sp. Altogether, reduced tillage may also lead to faster crop establishment able to better compete with weeds compared with no-tillage systems. Nonetheless, newly developed systems such as the 'roller/crimper' system attracted European researchers, who recognize the need for inclusion of more conservation techniques such as the systematic use of cover crops<sup>17,19,20</sup>.

## Machinery, Equipment and Research Activities

Organic pioneers, aiming at materializing the ideas of reduced soil tillage, developed special equipment, such as the Kemink system<sup>21</sup>, the ridge tillage system of Turiel<sup>22</sup>, the two-layer plow and the layer cultivator. The two-layer plow inverts the soil in the upper soil layer and loosens deeper layers. Similarly, the layer cultivator mixes the soil in the upper soil layer and also loosens deeper layers. More recently, machines were created allowing for a shallow cleaning of stubbles or the removal of grass-clover such as the stubble cleaner (German: Stoppelhobel, Zobel—Stahlbau, Germany, a type of skim plow, undercutting the whole field) or the Ecomat<sup>TM</sup> (Kverneland, Germany), which allows for quite shallow plowing.

Despite some early attempts to introduce reduced tillage in organic farm operations, systematic research under organic farming conditions started relatively late. Experiments established since the mid 1990s often included not only two-layer systems such as the layer plow and the layer cultivator, but systems with variable tillage depths were also tested. There is no general agreement on what to call a reduced tillage system. Here, we define all tillage systems as reduced that operate at shallower depths or at lower intensity compared to customary plowing in a given region. To date many research findings are only available in 'grey' literature such as conference proceedings and reports, with restricted availability. A most useful overview on organic farming without deep plowing was recently published in German by Schmidt<sup>23</sup>. Table 1 gives an overview on some key experiments on reduced tillage in organic farming in Europe.

In almost all these experiments reduced tillage enhanced soil organic carbon contents, soil microbial activity and soil structure in the upper soil layer. In general, greatest differences were observed when comparing conventional plow treatments (full inversion to 30 cm)

**Table 1.** Research experiments with reduced tillage under organic conditions in Europe (selection).

Experiment start, end year	Country	Tillage systems	Research activities
Rommersheim <sup>24–26</sup> Stiftung Ökologie und Landbau 1995–2004	Germany	Plow (30 cm) Two-layer plow (30 cm) Layer cultivator (30 cm)	Soil organic carbon Soil microbiology Soil fauna Soil physics Yield Root length Weeds
Scheyern <sup>27</sup> organic 1995 (ongoing)	Germany	First factor: farming system Second factor: plow (30 cm approx.) Plow (18 cm) Rotary hoe, cultivator (18 cm max.) Third factor: fertilization	Soil organic carbon Soil microbiology Yield N <sub>2</sub> O emission
Gladbacherhof <sup>28,29</sup> 1998 (ongoing)	Germany	First factor: plow (30 cm) Two-layer plow (30 cm) Plow 15 cm (till 2003) or Cultivator (15 cm) (since 2004) Layer cultivator (30 cm) Second factor: crop rotation	Soil organic carbon Soil microbiology Soil nutrients Soil physics Yield Weeds
Kleinhohenheim <sup>30–32</sup> 1998 (ongoing)	Germany	First factor: plow (25 cm) Two-layer plow (25 cm) Plow (15 cm) Chisel (15 cm) Second factor: stubble tillage	Weeds
Tillage trial Lyon <sup>33,34</sup> 1999 (ongoing)	France	Plow (30 cm) Plow (15 cm) Chisel plow (15 cm) Rotary cultivator (6 cm)	Soil organic carbon Soil microbiology Soil structure Earthworms
Tillage trial Frick <sup>7,35–38</sup> 2002 (ongoing)	Switzerland	Plow (15 cm) Chisel plow (15 cm) plus stubble cleaner (5 cm)	Soil organic carbon Soil microbiology Earthworms Intra-specific diversity mycorrhiza Yield Weeds
Staatsdomäne Frankenhausen <sup>22,39,40</sup> Lindenbreite 2002 (ongoing)	Germany	Plow (25 cm) Ecomat (7 cm) Ridge till (Turiel)	Soil microbiology Earthworms Soil physics
Borovce <sup>41</sup> Started in 2006	Slovak Republic	Plow (20 cm) Chisel plow (15 cm)	Soil organic carbon Soil microbiology Earthworms pH

with layer cultivation. Benefits of two-layer plowing compared with conventional plowing were less pronounced.

Yields were often similar in plow systems and systems using a two-layer plow, but were lower in systems using a two-layer cultivator or chisel. Unexpectedly, the chisel plow combined with a stubble cleaner, in the tillage trial Frick (Table 1), resulted in even higher yields as compared to the plow system in the long term. This was attributed to the relatively high stocking density mimicked in

this experiment, allowing for better timing of available nitrogen to the crops according to their needs, and the inclusion of green manures in the rotation. Moreover, the 2-year grass–clover ley contributed to weed suppression. This experiment clearly demonstrated that tillage systems need the specific adaptation of system components such as tillage timing, the planting of green manures and the use of new equipment to optimize a system.

Weed pressure was generally acceptable in two-layer plow systems, but was increased in two-layer cultivator

systems and systems with a chisel plow. In particular monocotyledonous weeds were enhanced in reduced tillage systems.

## Research Challenges

The results of reduced tillage experiments in organic farming obtained so far clearly demonstrate the superiority of these systems to conventional plow systems with respect to soil biology and soil fertility. However, there are major challenges and research gaps inhibiting more widespread application of reduced tillage in organic systems in Europe. Moreover, the experiments are extremely scattered and often published in national languages only. To close these research gaps, a European Network<sup>42</sup> is currently being established to address the following issues:

- The lack of knowledge on the effect of reduced tillage and no-tillage systems under organic farming on the soil carbon stock across the whole soil profile. This information is urgently needed to assess these systems' potential to mitigate climate change.
- Because N<sub>2</sub>O emissions are strongly dependent on available carbon and nitrogen, as well as on soil temperature and soil oxygen, climate gas-emission studies should be performed in various tillage systems and pedo-climatic zones.
- The higher weed pressure, with perennial weeds in particular, under reduced tillage calls for smart technological and biological solutions for efficient weed control. The acceptability of 'bio-herbicides' such as vinegar and bio-control organisms should be discussed anew.
- The optimum integration of green manure systems shall be investigated to guarantee the crops' nitrogen needs. We expect that this Network will also facilitate the exchange of information between European and American researchers in the field of conservation tillage techniques.

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