Renewable Agriculture and Food Systems: 27(1); 7–11 doi:10.1017/S1742170511000470

Development of reduced tillage systems in organic farming in Europe

Paul Mäder* and Alfred Berner

Research Institute of Organic Agriculture, Ackerstrasse, 5070 Frick, Switzerland.
*Corresponding author: paul.maeder@fibl.org

Accepted 11 October 2011; First published online 16 December 2011 **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_2O 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[1–3]. Both organic farming and no-tillage offer many benefits in view of soil fertility and biodiversity[4–6]. 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[7]. 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[8,9]. Both organic farming and no-tillage have been identified as promising options to sequester carbon in European soils[10]. 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[11]. Climate-change mitigation potential of no-tillage systems may also be offset by elevated N_2O emissions, which are fostered under the more anaerobic conditions prevailing in this system[12,13]. Recent research indicates that integrating appropriate conservation agriculture approaches into organic cropping systems may overcome these limitations. For example, N_2O emissions were greater when microbial soil populations were exposed to low C/N ratios by the use of mineral N-fertilizers in conservation agriculture[13,14]. 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[15], 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[16] 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[17]. Carter[18] 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[19]. 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[8,9].

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[17,19,20].

Machinery, Equipment and Research Activities

Organic pioneers, aiming at materializing the ideas of reduced soil tillage, developed special equipment, such as the Kemink system[21], the ridge tillage system of Turiel[22], 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™ (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[23]. 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[24–26] 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[27] 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_2O emission
Gladbacherhof[28,29] 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[30–32] 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[33,34] 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[7,35–38] 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[22,39,40] Lindenbreite 2002 (ongoing)	Germany	Plow (25 cm) Ecomat (7 cm) Ridge till (Turiel)	Soil microbiology Earthworms Soil physics
Borovce[41] 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[42] 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_2O 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.

Acknowledgements. We thank Andreas Fließbach, Andreas Gattinger (FiBL) and Julia Cooper (Newcastle University) for helpful comments on this manuscript.

References

1 Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Christ, S., Shpritz, L., Fitton, L., Saffouri, R., and Blair, R. 1995. Environmental and economic costs of soil erosion and conservation benefits. Science 267:1117–1123.
2 Montgomery, D.R. 2007. Dirt: The Erosion of Civilizations. University of California Press, California, USA.
3 Huggins, D.R. and Reganold, J.P. 2008. No-till: the quiet revolution. Scientific American 299:71–76.
4 Mäder, P., Fließbach, A., Dubois, D., Gunst, L., Fried, P., and Niggli, U. 2002. Soil fertility and biodiversity in organic farming. Science 296:1694–1697.
5 Hole, D.G., Perkins, A.J., Wilson, J.D., Alexander, I.H., Grice, P.V., and Evans, A.D. 2005. Does organic farming benefit biodiversity? Biological Conservation 122:113–130.
6 Triplett, G.B. and Dick, W.A. 2008. No-tillage crop production: a revolution in agriculture! Agronomy Journal 100:153–165.
7 Gadermaier, F., Berner, A., Fließbach, A., Friedel, J., and Mäder, P. 2012. Impact of reduced tillage on soil organic carbon and nutrient budgets under organic farming. Renewable Agriculture and Food Systems 27:68–80.
8 Derpsch, R., Friedrich, T., Kassam, A., and Li, H. 2010. Current status of adoption of no-till farming in the world and some of its main benefits. International Journal of Agricultural and Biological Engineering 3:1–25.
9 Leite, L.F.C., Oliveira, F.C., Araújo, A., Galvão, S.R.S., Lemos, J.O., and Silva, E.F.L. 2010. Soil organic carbon and biological indicators in an Acrisol under tillage systems and organic management in north-eastern Brazil. Australian Journal of Soil Research 48:258–265.
10 Freibauer, A., Rounsevell, M.D.A., Smith, P., and Verhagen, J. 2004. Carbon sequestration in the agricultural soils of Europe. Geoderma 122:1–23.
11 Baker, J.M., Ochsner, T.E., Venterea, R.T., and Griffis, T.J. 2007. Tillage and soil carbon sequestration – What do we really know? Agriculture, Ecosystems and Environment 118:1–5.
12 Steinbach, H.S. and Alvarez, R. 2006. Changes in soil organic carbon contents and nitrous oxide emissions after introduction of no-till in pampean agroecosystems. Journal of Environmental Quality 35:3–13.
13 Khan, S.A., Mulvaney, R.L., Ellsworth, T.R., and Boast, C. W. 2007. The myth of nitrogen fertilization for soil carbon sequestration. Journal of Environmental Quality 36:1821–1832.
14 Davidson, E.A. 2009. The contribution of manure and fertilizer nitrogen to atmospheric nitrous oxide since 1860. Nature Geoscience 2:659–662.
15 Carr, P., Mäder, P., Creamer, N., and Beeby, J.S. 2012. Overview and comparison of conservation tillage practices and organic farming in Europe and North America. Renewable Agriculture and Food Systems 27:2–6.
16 Rusch, H.P. 1968. Bodenfruchtbarkeit. Eine Studie Biologischen Denkens. Haug, Heidelberg, Germany.
17 Peigné, J., Ball, B.C., Roger-Estrade, J., and David, C. 2007. Is conservation tillage suitable for organic farming? A review. Soil Use and Management 23:129–144.
18 Carter, M.R. 1994. A review of conservation tillage strategies for humid temperate regions. Soil and Tillage Research 31:289–301.
19 Hobbs, P.R., Sayre, K., and Gupta, R. 2008. The role of conservation agriculture in sustainable agriculture. Philosophical Transactions of the Royal Society B: Biological Sciences 363:543–555.
20 Köpke, U. and Schulte, H. 2008. Direct seeding of faba beans in organic agriculture. In Cultivating the Future Based on Science: Second Conference of the International Society of Organic Agriculture Research ISOFAR, June 18–20, Modena, Italy. p. 184.

21 Henriksen, C.B., Rasmussen, J., and Søgaard, C. 2005. Kemink subsoiling before and after planting. Soil and Tillage Research 80:59–68.
22 Müller, E., Wildhagen, H., Quintern, M., Heß, J., Wichern, F., and Joergensen, R.G. 2009. Spatial patterns of soil biological and physical properties in a ridge tilled and a ploughed luvisol. Soil and Tillage Research 105:88–95.
23 Schmidt, H. 2010. Öko-Ackerbau ohne tiefes Pflügen. Praxisbeispiele und Forschungsergebnisse. Köster, Berlin, Germany.
24 Hampl, U. 1996. Soil tillage systems in Eco-Farming. In 11th IFOAM International Scientific Conference 'Down to Earth—and Further Afield', August 11–15, Copenhagen, Denmark. p. 65.
25 Emmerling, C. 2001. Response of earthworm communities to different types of soil tillage. Applied Soil Ecology 17:91–96.
26 Vakali, C., Zaller, J.G., and Köpke, U. 2011. Reduced tillage effects on soil properties and growth of cereals and associated weeds under organic farming. Soil and Tillage Research 111:133–141.
27 Kainz, M., Gerl, G., Lemnitzer, B., Bauchenss, J., and Hülsbergen, K.-J. 2005. Effects of different tillage systems in the long-term field experiment Scheyern. In J. Heß and G. Rahmann (eds), 8. Wissenschaftstagung Ökologischer Landbau, Kassel, Germany. p. 1–4.
28 Schmidt, H., Schulz, F., and Leithold, G. 2006. Organic farming trial Gladbacherhof. Effects of different crop rotations and tillage systems. In J. Raupp, C. Pekrun, M. Oltmans, and U. Köpke (eds). Long-Term Field Experiments in Organic Farming. Köster, Berlin. p. 165–182.
29 Schulz, F., Brock, C., and Leithold, G. 2008. Effects of farm type and different intensities of soil tillage on cash crop yields and soil organic matter. In: Cultivating the Future Based on Science. Proceedings of the Second Scientific Conference of the International Society of Organic Agriculture Research (ISOFAR), June 18–20, Modena, Italy, p. 580–583.
30 Pekrun, C. and Claupein, W. 2004. The effect of stubble tillage and primary tillage on population dynamics of Canada thistle (*Cirsium arvense*) in organic farming. Journal of Plant Diseases and Protection – Special Issue 19:483–490.
31 Pekrun, C. and Claupein, W. 2006. The implication of stubble tillage for weed population dynamics in organic farming. Weed Research 46:414–423.
32 Gruber, S. and Claupein, W. 2009. Effect of tillage intensity on weed infestation in organic farming. Soil and Tillage Research 105:104–111.
33 Vian, J.F., Peigné, J., Chaussod, R., and Roger-Estrade, J. 2009. Effects of four tillage systems on soil structure and soil microbial biomass in organic farming. Soil Use and Management 25:1–10.
34 Peigné, J., Cannavaciuolo, M., Gautronneau, Y., Aveline, A., Giteau, J.L., and Cluzeau, D. 2009. Earthworm populations under different tillage systems in organic farming. Soil and Tillage Research 104: 207–214.
35 Berner, A., Hildermann, I., Fließbach, A., Pfiffner, L., Niggli, U., and Mäder, P. 2008. Crop yield and soil quality response to reduced tillage under organic management. Soil and Tillage Research 101:89–96.
36 Krauss, M., Berner, A., Burger, D., Wiemken, A., Niggli, U., and Mäder, P. 2010. Reduced tillage in temperate organic farming: implications for crop management and forage production. Soil Use and Management 26:12–20.
37 Börstler, B., Thiéry, O., Sykorová, Z., Berner, A., and Redecker, D. 2010. Diversity of mitochondrial large subunit rDNA haplotypes of *Glomus intraradices* in two agricultural field experiments and two semi-natural grasslands. Molecular Ecology 19:1497–1511.
38 Sans, F.X., Berner, A., Armengot, L., and Mäder, P. 2011. Tillage effects on weed communities in an organic winter wheat–sunflower–spelt cropping sequence. Weed Research 51:413–421.
39 Metzke, M., Potthoff, M., Quintern, M., Heß, J., and Joergensen, R.G. 2007. Effect of reduced tillage systems on earthworm communities in a 6-year organic rotation. European Journal of Soil Biology 43:209–215.
40 Müller, E., Wildhagen, H., Quintern, M., Heß, J., Wichern, F., and Joergensen, R.G. 2009. CO_2 evolution from a ridge tilled and a mouldboard ploughed luvisol in the field. Applied Soil Ecology 43:89–94.
41 Lehocká, Z., Klimeková, M., Bieliková, M., and Mendel, L. 2009. The effect of different tillage systems under organic management on soil quality indicators. Agronomy Research 7:369–373.
42 Reduced tillage and green manures for sustainable organic cropping systems. A CORE Organic II project. Available at Web site www.tilman-org.net (accessed November 22, 2011).