Conservation agriculture with and without use of agrochemicals

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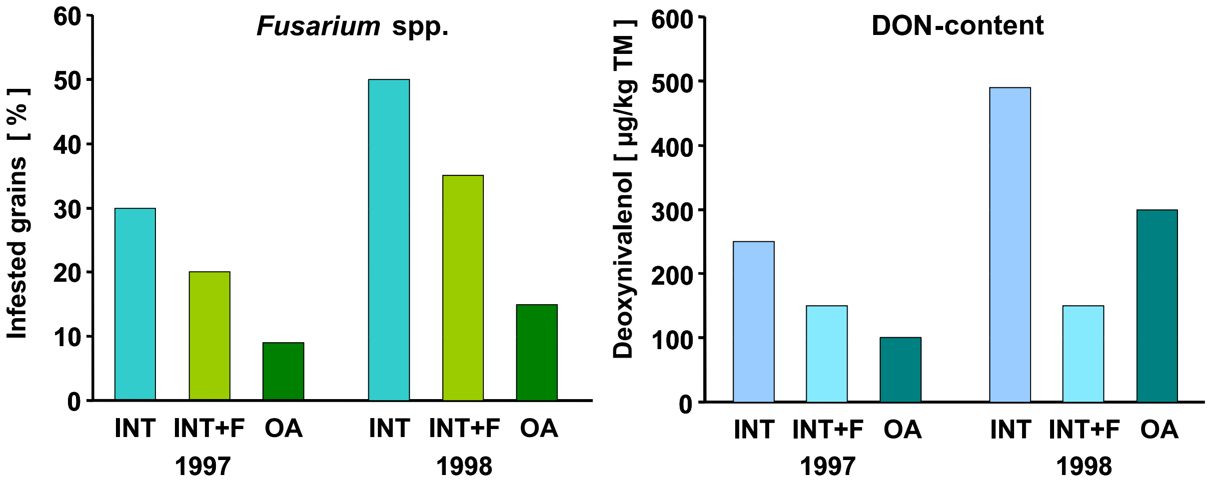
No equivalent for the term conservation agriculture as it is used in this conference exists in Germany or Europe. An important element of conservation agriculture from the Brazilian point of view is the use of conservation tillage with the aim of preventing erosion, soil compaction, improving soil trafficability and saving labour and energy costs. Conservation tillage includes several tillage types, such as no-tillage, reduced tillage, mulch-tillage and strip-tillage (Köller, 2003). Conservation tillage avoids deep turning and loosening of the soil but depends in the majority of cases on non-selective herbicides used prior to sowing to clear the ground of weeds and pioneer plants. If conservation agriculture is viewed and evaluated in a broader sense as including numerous other aspects of nature conservation, we need to consider the approaches and effects of very different competing agricultural systems.

In Central Europe, so-called conventional or mainstream agricultural systems (MAS), have, during the last 30 years, progressively developed to systems of so-called integrated agriculture systems (IAS). One key element of IAS is to maximise farmers' income by reducing the input of fertilisers and pesticides within defined thresholds. If integrated production is defined as “a farming system that produces high quality food and other products by using natural resources and regulating mechanisms to replace polluting inputs and to secure sustainable farming” (El Titi *et al.*, 1993), then the aim of achieving soil conservation by using conservation tillage with standard application of total herbicides conflicts with the objective of using thresholds for herbicide application. Pekrun *et al.* (2003a) proposed that this discrepancy must be resolved on a case by case basis always prioritising conservation of natural resources and regulating mechanisms. However, the pressure of decreasing product prices has led farmers to leave diversified system-stabilising rotations. Meanwhile, after Isoproturone, Glyphosate is the second most used herbicide in Germany. The trend towards simplified cropping systems is obvious. No doubt that this will call the IAS approach into question.

When arable soil is seen as an important and slowly regenerating resource, no-tillage or reduced tillage systems are regarded as the main tools to avoid soil erosion and soil compaction in simplified farming systems, which no longer depend on sophisticated diversified rotations for success. Nevertheless, compared to Southern Brazil or Paraguay, conservation tillage is currently not widely adopted in MAS or IAS in Central Europe. Compared to loose-soil husbandry, conservation tillage systems often appear to be less productive and more risky under the conditions of a temperate climate. Often, a higher nitrogen input is necessary to maintain yields due to reduced net mineralisation in the early growing season, especially in the first years of continuous application of reduced tillage (Baeumer & Köpke, 1989). Non-inverted crop residues of maize or weeds increase the risk for *Fusarium* infestation and, therefore, Deoxynivalenol (DON) mycotoxin in the following winter wheat (Figure 1).



OA= Organic Agriculture Int= Integrated Agric. +F= Fusarium-fungicide applied

Figure 1: *Fusarium infestans* and Deoxynivalenol (DON) mycotoxin content of winter wheat grains derived from organic and integrated cultivation (Birzele *et al.* 2002).

Ideally, organic agriculture systems (OAS) follow a 'whole-farm' approach to manage a (mixed) farm as far as possible as a nearly closed and integrated system (Köpke, 1995). Compared to other types of agriculture, OAS depend more on specific site conditions and are, therefore, forced to combine the best adapted elements in a holistic approach. OAS must always be environmentally sound, locally adapted and individually site-specific. This is also valid for target-oriented soil cultivation. The worldwide diversity of soil and site conditions means that the focus of this contribution must be limited to soil cultivation methods performed in Central Europe and other sites with a similar temperate climate.

The principles relating to soil cultivation in Organic Agriculture have often been linked with the typical layering of forest soils (e.g. Rusch, 1968). In a similar way, proponents of zero-tillage systems compared the soil structure of untilled soil with the stable structure frequently found under permanent pasture (Baeumer and Bakermans, 1973). This contrasts with the more homogenous structure of soil conventionally tilled with the mouldboard-plough. All conservation tillage procedures usually show higher microbial activity or microbial biomass in the upper topsoil than in the lower topsoil (e.g. Grocholl, 1991). Correspondingly, it is often suggested that tillage procedures in Organic Agriculture should avoid disturbance and mixing of the different soil layers and that there is no room for the mouldboard-plough in OAS. Official guidelines of Organic Agriculture recommend deep inversion only for special site conditions or weed problems (Anonymous, 1994). However, a survey of about 100 organic farms in Germany has shown that 95 % owned a plough, which in 90 % of the cases was used for primary tillage of winter wheat, winter rye, oats, potatoes, and faba-beans (Werland, 1990). Currently, mouldboard-ploughing combined with secondary tillage is still common practice and reduced cultivation techniques have not yet been adopted widely. The arguments are convincing: The mouldboard-plough in Organic Agriculture is regarded as an effective and obviously essential tool for nutrient management, for inverting farmyard manure, removing perennial leys, enhancing root growth, nitrogen mineralisation and nutrient uptake as well as for efficient weed control (Köpke, 1993; Pekrun *et al.*, 2003b).

In contrast to IAS, the limited supply of fertilizers and manures in organic farms requires ingenious nutrient management which includes, to a greater extent, the activity of soil organisms. Organic Agriculture has to deal with a lower nutrient supply. Nutrient management has to be considered as the optimisation of nutrient resources which are restricted or which have to be unlocked by improving utilization (Köpke, 1993; Köpke, 1995). Soil cultivation, therefore, has to make nutrients in the system internally available and in the long term ensure efficient use, e.g. via enhanced microbial activity, increased rooting-density, and efficiency of nutrient absorption. Soil cultivation must bring nutrients into close contact with absorbing roots, or at least enable nutrients to reach the root surface. Mutual distribution of roots and nutrients is highly important for an efficient nutrient management. Nutrient management has to focus on the distribution of the capacity to absorb nutrients rather than that of the roots themselves (Tinker, 1981). The ability to absorb nutrients depends upon the available water supply particularly for young and fine roots, root hairs, and mycorrhizal hyphae. Water uptake rates per length of root (specific water uptake rates) were calculated to be the highest near the rooting front (Ehlers *et al*, 1980/1981). The radius of these organs determines the size of the soil volume supplying the nutrients. The lower the radius of roots, root hairs or hyphae, the bigger the depleted soil volume feeding the unit root surface (Figure 2).

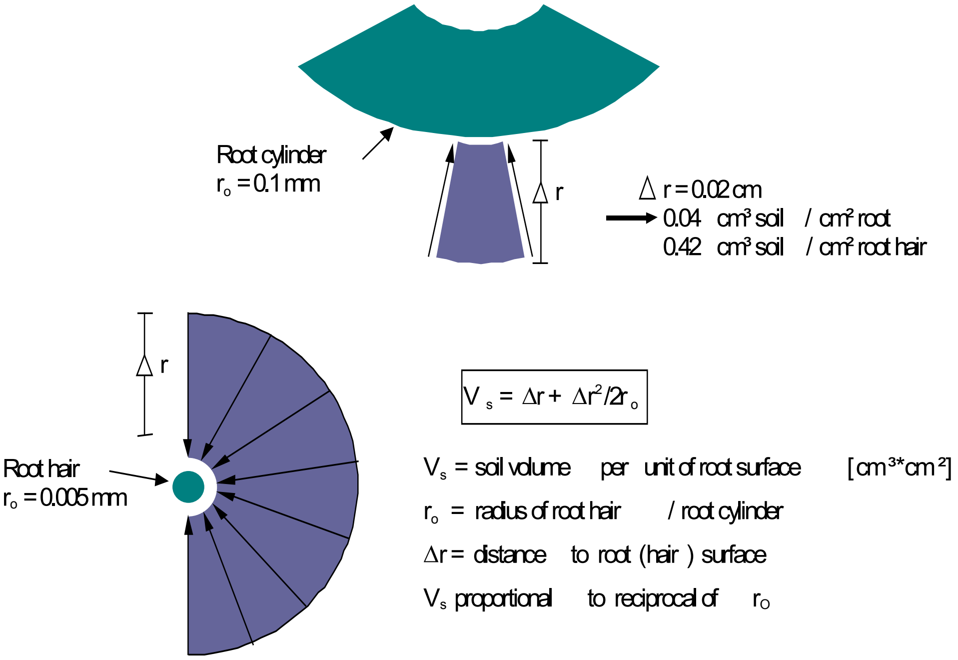


Figure 2: Geometric conditions of diffusion to root or root hair surface (derived from Claassen, 1994).

Rooting density is a function of root branching correlated with an increased number of fine, young growing root tips. Since the use of P and K fertilizers is limited in OAS and the use of mineral N fertilizers forbidden, nutrient uptake by plants has to be enhanced via optimised soil structure due to appropriate tillage procedures, compensating for the lower nutrient concentration of the soil solution. A relative lack of nutrients can be compensated for by improved soil structure and higher rooting density through mixing the tilled layer. Intensive tillage can change the rooting characteristics of crops via improved soil structure by reducing bulk density and soil strength thus promoting root growth in the tilled layer (Figure 3). Consequently, under conditions of a relative lack of nutrients, omission of any soil tillage, and stabilization of the soil structure as realized in untilled soil would be the wrong strategy in Organic Agriculture, where the aim is to unlock nutrients from the bulk soil.

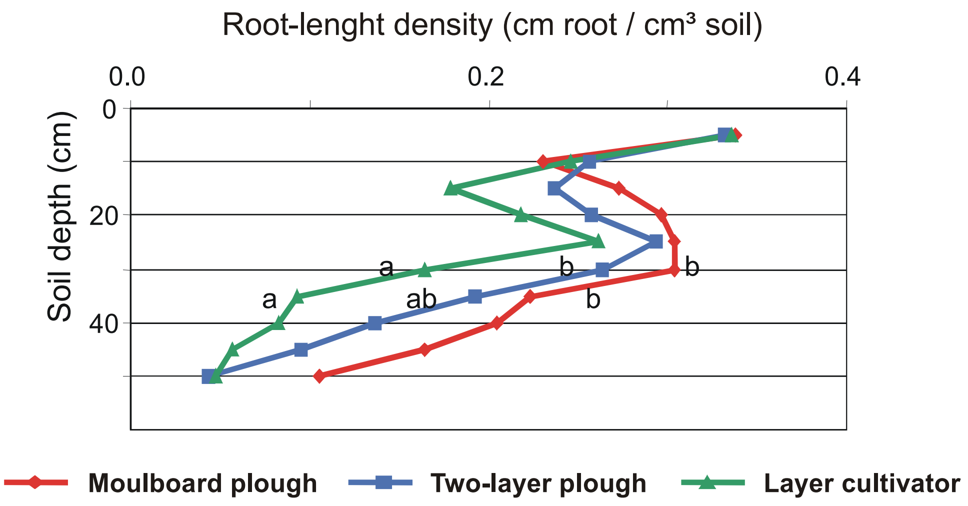


Figure 3: Root-length density of spring barley as affected by tillage intensity (9 weeks after sowing). Site: Long-term experiment Römmersheim, Germany (Vakali *et al.* 2002, Vakali 2003)

Early plant development is strongly enhanced by increased nitrogen availability. Efficient management of nitrogen in OAS is inevitably based on making soil-borne nitrogen available to plants. Lower soil water content and lower bulk density of ploughed soil indicate that diffusion of oxygen into ploughed soil is higher than into unploughed soil. Ploughed or intensively cultivated soils are less compacted, warmer and more aerobic than reduced tilled or untilled soils, especially in early spring. Ap-layers show uniform distribution of soil organic matter and, in the lower parts, a greater activity of aerobic microbial soil life (Doran 1980b), making more nitrate available also from the deeper tilled and mixed soil. Availability of soil-borne nitrogen in OAS, especially in the early vegetation phase, is based on higher amounts of mineralized nitrogen, which in turn is a function of the higher tillage intensity normally achieved by using the mouldboard plough (Vakali *et al.* 2002). This statement is underlined by comparing the use of the mouldboard plough with reduced tillage intensity performed with a two-layer plough and a layer cultivator in a long-term experiment. As a function of higher mineralisation and nitrification and enhanced rooting density (Figure 3), intensive tillage results in higher leaf area index (Figure 4), N-uptake (Figure 5) and plant development (Figure 6) and finally in higher grain yield (Figure 7), compared to reduced primary tillage systems (Vakali *et al.* 2002; Vakali 2003).

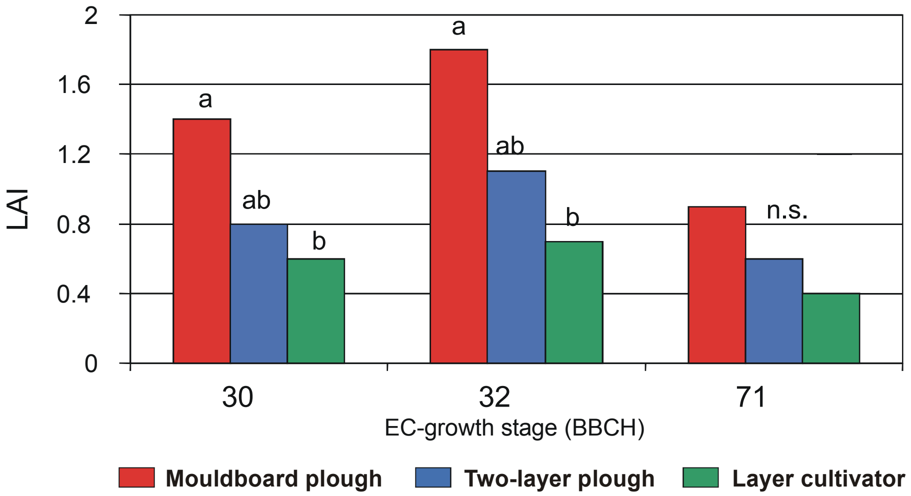


Figure 4: Leaf area index (LAI) of spring barley as affectedv by tillage intensity. Site: Long-term experiment Römmersheim, Germany (Vakali *et al.* 2002, Vakali 2003).

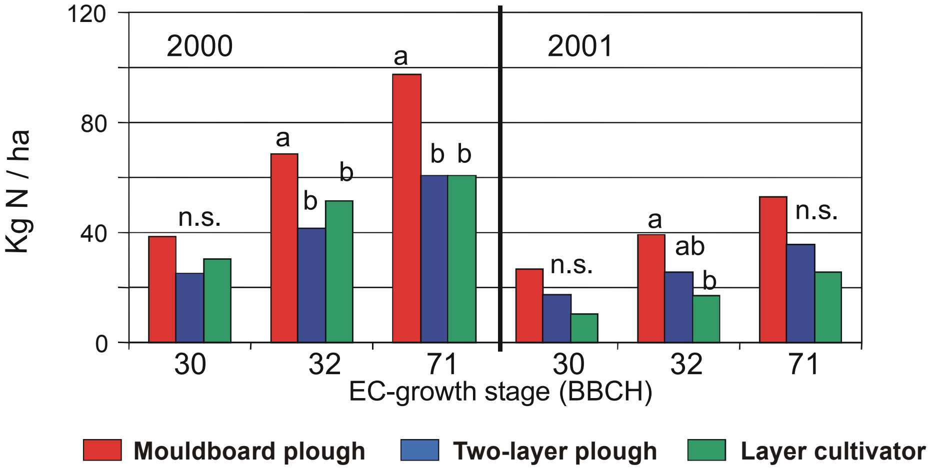


Figure 5: N-uptake of spring barley as affected by tillage intensity.
Site: Long-term experiment Römmersheim, Germany (Vakali *et al.* 2002, Vakali 2003).

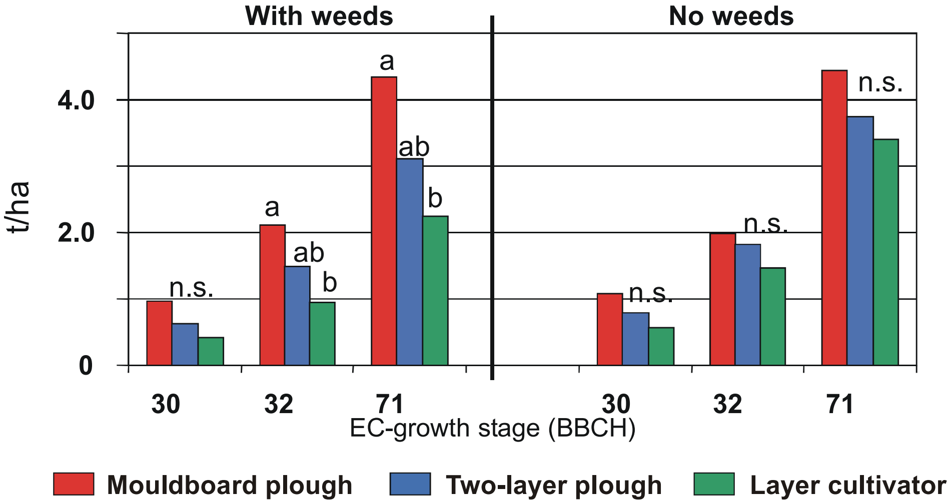


Figure 6: Shoot mass of spring barley as affected by tillage intensity and competition of weeds.
Site: Long-term experiment Römmersheim, Germany (Vakali *et al.* 2002, Vakali 2003).

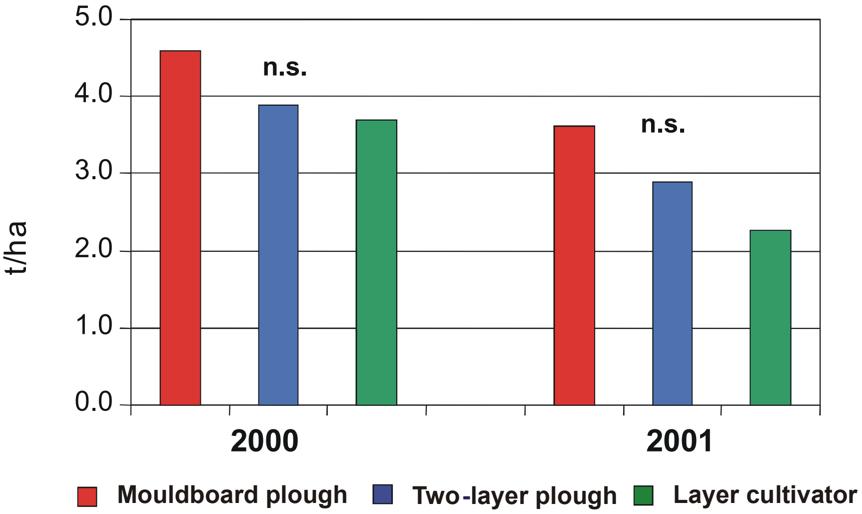


Figure 7: Grain yield of spring barley as affected by tillage intensity.
Site: Long-term experiment Römmersheim, Germany (Vakali *et al.* 2002, Vakali 2003).

As shown in Figure 6, use of the mouldboard-plough resulted in a significantly higher shoot mass in barley compared to reduced tillage intensity. When weeds were destroyed through herbicide application, this effect decreased and the differences were not significant. Weed control is one of the top concerns of OAS. Whilst yields in OAS are quite lower and weed thresholds higher compared to IAS, weeds are regarded as having positive effects, such as:

● Reduction of monoculture effects, ● Soil cover and shading, ● Increased diversity of fauna,
● Alternative nutrition for pests, ● Source of organic matter, ● Crop improvement through allelopathy (Schenke 1994)

Additionally, the weed flora in OAS is generally more diverse, often consisting of legal protected species (Frieben and Köpke 1995) and may be valued for aesthetic reasons (Conservation Agriculture!).

In contrast to IAS with its use of quite efficient herbicides, OAS has to combine different elements of indirect and direct methods of weed control within a more or less efficient site-specific weed management strategy. General preventive tools are, besides tillage hygiene, rotation, choice of cultivars, seeding date, seeding density, spacing and manuring, which all result in enhanced crop competitiveness. Direct mechanical methods are based on reducing the amount of light, water and nutrients available to weeds as well as on weakening the amount of assimilates in storage organs, roots and bulbs.

Unfortunately, no equivalent tool such as the use of the allelopathic effects of *Avena strigosa* in Southern Brazil is available here yet. Research on the allelopathic effects of sunflower and buckwheat is in progress (Gawronski *et al.*, 2002). If these approaches are successful, the chapter on reduced tillage in OAS should be opened and written again.

Problem weeds, especially perennials (e.g. creeping thistle, *Cirsium arvense,* couch-grass, *Agropyron repens*) are less well controlled by heavy cultivators or other non-inverting primary tillage tools than by mouldboard-ploughing. Therefore, in OAS mouldboard-ploughing should continue to be used in order to control rhizomatous weeds, but the unanswered question is how deep does the ploughing have to be? Consequently, a combination of "shallow soil inversion" and "deep soil loosening" performed with so-called two-layer ploughs seems to be a good compromise for controlling weeds, enhancing mineralisation and nitrification, root growth and nutrient uptake, while reducing fuel consumption and physical disruption by deep inversion (Vakali, 2003).

Tillage operations that bury most of the crop residue might benefit weed and disease control but can cause serious soil erosion problems. Mulch layers of dead plant residues can seldom be used in OAS. One example is the use of residues of white mustard as a catch- and cover-crop, which acts as a living mulch until winter and as dead mulch after frost kill. Living mulches in the form of perennial grass/legume-mixtures, underseeds, catch crops and green manures are used in Organic Agriculture to fill the gap of uncovered soil between main crops (which are generally harvested earlier in OAS compared to IAS). Consequently, the C-factor of Wischmeyer and Smith's (1978) Universal Soil Loss Equation (USLE) is often calculated to be lower in OAS compared to IAS. Auerswald (1997) calculated a C-factor of only 0.06 for the 6-field rotation of our experimental farm for Organic Agriculture Wiesengut/Hennef-Sieg, which integrates many of the elements for optimising soil cultivation in OAS as outlined above. This C-factor equals the C-factor calculated for a maize-smallgrain-meadow-rotation by Stewart *et al* (1976) and is clearly lower than that calculated for conventional arable farms in Bavaria, Germany (0.16), varying between 0.20 (leafy crops > 50%) and 0.12 (cereal crops only) (Auerswald and Schmidt 1986).

Generally, the risk of soil and nutrient losses through erosion and surface run-off is significantly lower in OAS compared with IAS when the mouldboard-plough is used in both systems. Soil conservation has been an issue in Organic Agriculture right from the beginning. This is realised by fertility building, which increases soil organic matter content leaving the soil undisturbed as long as possible, using undersown perennial grass/clover ley, farmyard manure and cover crops, all resulting in higher microbial activity and aggregate stability (Mäder *et al*., 2002). Long-term organic farming using diversified rotations with longer periods of rest for the soil achieved with grass/legume-leys, and application of farmyard manure, can result in a soil organic matter (SOM) content up to 20% higher than in intensive conventional farming (Haider 1992; Mäder *et al.* 1995). Soil structure improved by SOM can provide an integrative expression of soil biological, physical and chemical processes, but the debate about the most appropriate parameters for characterising soil structure is still ongoing (Hamblin, 1991). Schwertmann (1991) presented results from the diploma-thesis of Heindl (1991) showing that aggregate stability was higher in organic loess soil, showing about 1.5 times higher water percolation through soil columns. Siegrist (1995) also found higher percolation stability for biodynamic and organic treatments compared to conventional treatment in the long term DOC-trial near Therwil, Switzerland, on a Luvisol from loess. The author of this contribution was able to differentiate these (encoded) treatments in all 4 replications under conditions of bare soil in November 1995 when visiting the experiment for the first time. Surface soil of the biodynamic and organic plots appeared to be darker brown and capped to a lesser extent due to larger amounts of earthworm casts. Earthworm biomass and density of the DOC-trial were found to be significantly higher in the organic than in the conventional plots (Pfiffner *et al.* 1995, Mäder *et al.* 2002).

However, under conditions of high soil erodibility, intensive use of living mulch established as perennial leguminous forage crops undersown in cereals and cover crops, which increase Ct-content, biomass and abundance of earthworms, is considered as not sufficient to control erosion (Auerswald and Kainz 2003). Consequently, bi-cropping or strip-cultivation systems have to be developed further alongside erosion control oriented on preserving the baking quality of wheat together with biodiversity and other aspects of nature conservation.

Although conservation tillage systems using total herbicides can be considered as more efficient in reducing erosion and fuel consumption in soil cultivation, Organic Agriculture is currently regarded as being the more sustainable agricultural approach, at least under the conditions of a temperate climate due to several other positive environmental impacts. Organic Agriculture, having a tradition of more than 80 years, is steadily increasing, currently covering more than 3 % of the agricultural area in Europe – a function of its delivered high product and process quality. For more than 20 years, the environmental impacts of MAS have been listed hierarchically (Haber & Salzwedel 1992): 1. Impacts on biotopes, 2. Contamination of ground water, 3. Impacts on soil, 4. Impacts on surface water, 5. Impacts on food quality, 6. Contamination of air. A seventh important category is given with the global warming potential.

In the industrialised countries, emission of CO_2 is caused mainly by fossil energy consumption. The fuels used by farmers comprise direct (diesel, heating oil, etc.) and indirect (operating materials) forms of energy supply. Since the early studies of Lockeretz *et al.* (1976), Organic Agriculture has been recognised as a farming system that uses less fossil energy resources than conventional farming. The average amount of total energy input per hectare saved by OAS in Germany was calculated at about 65% of the fossil energy required for conventional farming, which means a reduction in climate-relevant CO_2 of about 60 % (Figure 8).

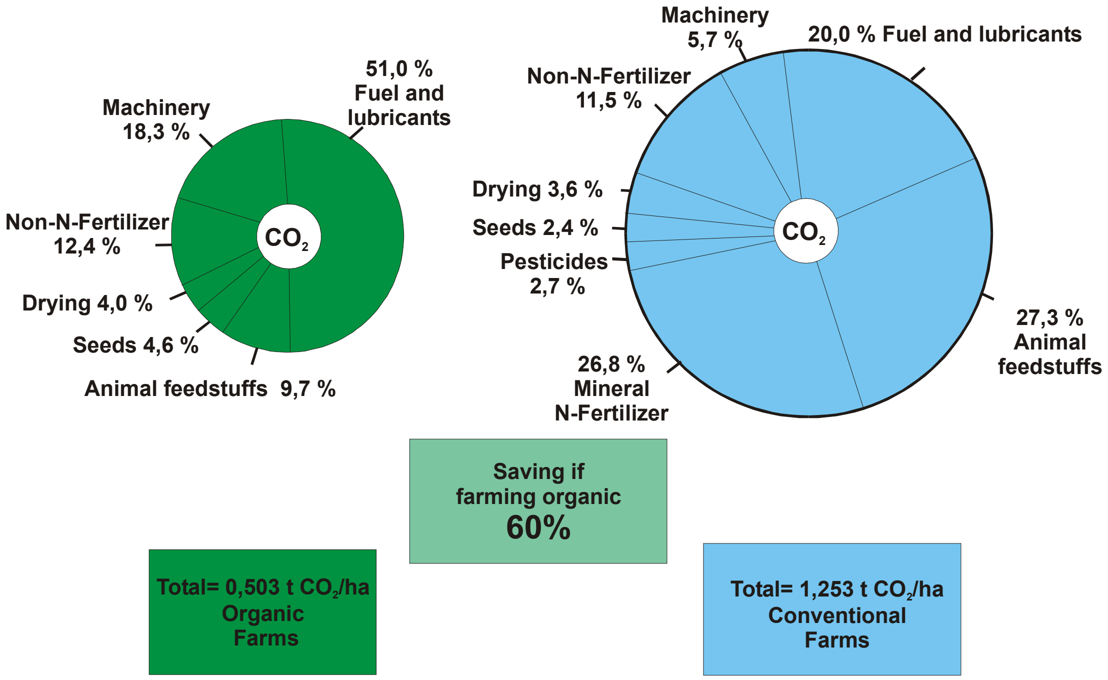


Figure 8: CO_2-emission (%) of organic and conventional farms in Germany. Analysis based on data for 1990/91, area of former FRG (Haas *et al.* 1995).

In terms of CO_2 input (emissions), the CO_2 binding in OAS at 42.8 units per input unit CO_2 is double the 21.6 units per input unit CO_2 found for conventional farms (Haas & Köpke 1994, Köpke & Haas 1995). In general, due to the high proportions of forage plants and longer periods of rest for the soil, together with the addition of farmyard manure, more CO_2 is bound in OAS than in conventional farming. Long-term trials have revealed that when conducted over a period of years, Organic Farming apparently leads to changes in the composition of the soil microflora resulting in a detectably increased proportional assimilation of CO_2 through the higher microbial biomass in the soil. In contrast, the amount of exhaled CO_2, referred to biomass has been found to be greater in conventionally cultivated soils (Haider 1992, Mäder *et al.* 1993).

The amount of energy consumed by organic crop production in 1991/92 was 6,828 MJ/ha^{-1} compared to 19,408 MJ/ha^{-1} in conventional full-time farming, primarily due to the non-use of mineral nitrogen fertilisers, synthetic chemical pesticides and to lower amounts of phosphorus and potash fertilisers. The absolute input of fuel and lubricants is almost equal in both organic and conventional farming systems when mouldboard ploughing is used, but can be reduced to about 30% in the conventional system when reduced tillage is performed in winter wheat. On the other hand, the overall energy input per hectare in conventional farming is only marginally reduced when reduced tillage is applied instead of mouldboard ploughing, and energy input per ton of grain produced is higher compared to that in organic wheat production. Nevertheless, the fact that about 50 % of the total energy used in OAS is bound in fuel and lubricants indicates a need for action to reduce this relatively high energy input.

Several comparative studies have shown that compared to IAS, in most cases OAS also resulted in enhanced biodiversity of crops and wild flora and fauna (Frieben & Köpke 1996, Frieben 1998). The multifunctionality and high process quality of Organic Agriculture can be determined by life cycle assessment (LCA) (Geier and Köpke, 1998).

Table 1: Ecobalance of agriculture: Comparison of organic and mainstream agriculture in Hamburg (Geier & Köpke 1998, Geier *et al.* 1998).

Impact categories	Indicators
Biodiversity ⊕	Arable land: clear improvement Grassland: improvement Structures (ditches and margins): improvement
Landscape image ⊜	No difference
Soil protection ⊜	No difference
Drinking water protection ⊕	N-surplus without ammonia emission: Reduction of 77 % (from 311 t to 77 t) Pesticide use: Reduction of 100% (from 22.7 t). No risk of contaminating surface and ground water.
Eutrophication ⊕	Ammonia emission: Reduction of 31 % (from 238 t to 165 t)
Acidification ⊕	SO_2 - equivalents: Reduction of 31 % (from 474 t to 328 t)
Global warming effect ⊕	CO_2 - equivalents: Reduction of 37 % (from 22,024 t to 13,882 t)
Abiotic ressource depletion ⊕	Energy use: Reduction of 54 % (from 83,000 GJ to 38,500 GJ) P-fertilizer: Reduction of 100 % (from 81.1 t)
Human toxicity ⊕	Organic farmers: No risk of contamination by pesticides

⊕ = Advantage for organic farming

Table 1 shows the result of an LCA performed in the Vier- und Marschlande of Hamburg, Germany, an agricultural area of 5,674 hectares. In 7 out of 9 impact categories indicators gave clear advantages for Organic Agriculture when compared to IAS. A life cycle assessment of intensive, extensified and organic pasture farms in Southern Germany (Bavaria) also resulted in a clear hierarchy of external effects. Table 2 shows the inventory (schematic) of selected impact categories and indicators of life cycle assessment for the best and the least best farm in each group, also enabling a weak point analysis for the single farm. Overall analysis of the impact categories biodiversity, landscape image and animal husbandry indicated that organic farming has clear advantages in the indicators: number of grassland species, grazing cattle, layout of farmstead and herd management. However, the indices in these categories showed a wide range and were partly independent of the farming system (Haas *et al.* 2001). In contrast to intensive farms, extensified and organic farms could reduce the negative effects in the abiotic impact categories of energy use, global warming potential and groundwater mainly by renouncing the use of mineral N-fertilizer. Energy consumption of intensive farms was 19.1 GJ ha^{-1} and 2.7 GJ t^{-1} milk, of extensified and organic farms 8.7 and 5.9 GJ ha^{-1} along with 1.3 and 1.2 GJ t^{-1} milk, respectively. The global warming potential was 9.4, 7.0 and 6.3 CO_2 equivalents ha^{-1} and 1.3, 1.0 and 1.3 CO_2 equivalents per ton of milk for the intensive, extensified and organic farms, respectively. Acidification, calculated in SO_2 equivalents was high, but emission was lower in extensified (119 kg SO_2 ha^{-1}) and organic farms (107 kg SO_2 ha^{-1}) compared to intensive farms (136 kg SO_2 ha^{-1}). The eutrophication potential computed in PO_4-equivalents was higher for intensive (54.2 kg PO_4 ha^{-1}) compared with extensified (31.2 kg PO_4 ha^{-1}) and organic farms (13.5 kg PO_4 ha^{-1}). Different impacts on ground and surface water quality were indicated by farm gate balances for N (80.1, 31.4 and 31.1 kg ha^{-1}) and P (5.3, 4.5 and –2.3 kg ha^{-1}) for intensive, extensified and organic farms, respectively.

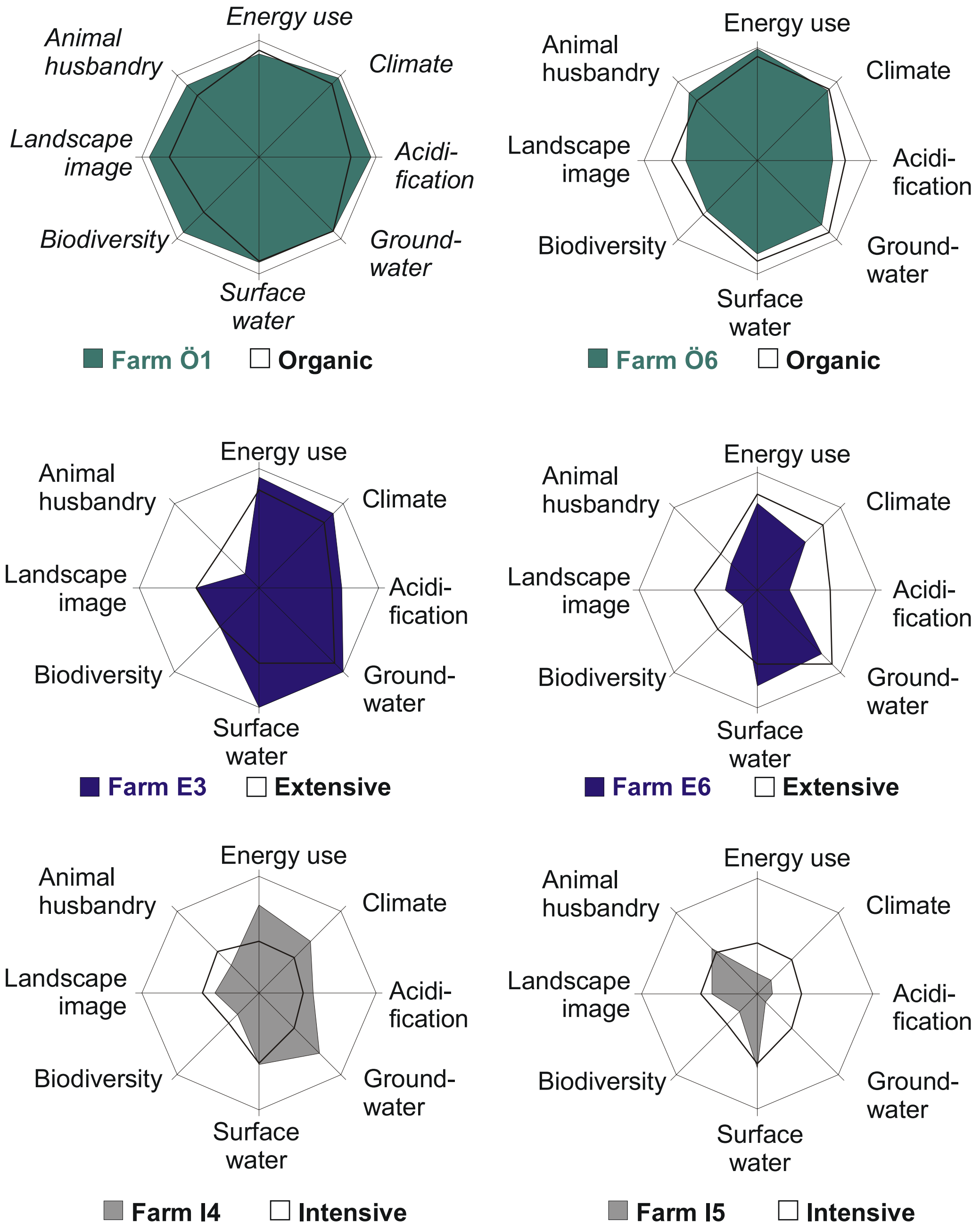


Figure 9: Inventory of selected impact categories and indicators of life cycle assessment of the farming systems intensive, extensive and organic (Haas *et al.* 2001).

Currently, on highly erodible soils of the southern hemisphere, conservation agriculture is predominantly based on conservation tillage. In the northern hemisphere, conservation agriculture has a wider aspect and is currently best realised by OAS, where conservation tillage is only of minor importance for preserving nature. The life cycle assessment method enables identification and evaluation of differences among agricultural production intensities according to their environmental impact and currently indicates OA as being the most sustainable approach, at least under the conditions of a (humid) temperate climate.

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