CLIMATE CHANGE AND AGRICULTURE

REPORT No.2

No-till agriculture – a climate smart solution?

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About this paper series

Climate change is one of the biggest challenges facing our globalized world today. The poor population in developing countries will be particularly affected by global warming, of which developed countries are the major drivers. Science clearly indicates that a global temperature rise of 2°C above pre-industrial levels may change the face of the world irreversibly. A range of mitigation solutions is needed to avoid exceeding the 2°C limit. The need for truly sustainable and climate-friendly development is clear.

A glance at global mitigation potentials shows that changes in agriculture and land use, including deforestation in tropical areas, currently account for one-third of global greenhouse gas emissions (see Figure 1). Increasingly, therefore, agriculture is being recognized as part of the problem in international climate negotiations. While developed countries' emissions result mostly from industry, energy consumption and transport, FAO figures reveal that 74% of all agricultural emissions originate in developing countries, and 70% of the agricultural mitigation potential can be realized in these same countries.

Could agriculture therefore be part of the solution, particularly in developing countries? Globally, three-quarters of all malnourished people depend on agriculture and would be directly affected by international mitigation agreements aimed at agriculture. Various "climate-friendly" agricultural solutions have already been proposed: they include biochar and no-tillage agriculture. Against this background, MISEREOR uses this series of papers to examine whether these solutions actually lead to climate-friendly and equitable agriculture with a clear commitment to a pro-poor approach.

Figure 1

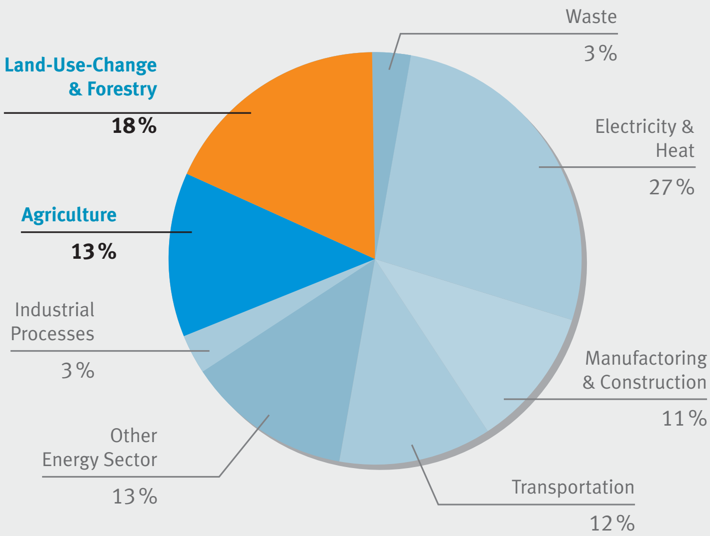

Figure 1: Sources of Global Greenhouse Gas Emissions. Agriculture is the primary driver of land use change and deforestation.
Source: EarthTrends, 2008; using data from the the Climate Analysis Indicators Tool (CAIT)

Photo: Neussl/MISEREOR

Two women in a corn field in DR Congo

Table of contents

About this paper series

Table of Contents, Imprint

Executive Summary 4

1. What is no-till? 5

2. No-till today 6
2.1 Side effects of no-till 7
2.2 Who is behind the no-till lobby? 9

3. No-till – really climate-friendly? 10
3.1 Carbon sequestration in no-till agriculture 11
3.2 Greenhouse gas emissions from no-till soils 11
3.3 Other climate impacts of no-till 12

4. No-till – benefiting the poor? 13
4.1 Crop yields and food security 13
4.2 No-till and rural livelihoods 14

5. No-till in the carbon markets 15

6. Conclusions 16

7. Annex 18

References

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Executive Summary

No-tillage farming systems or no-till, as an aspect of conservation farming, are actively promoted by international research and development organizations to conserve soils and by this, ensure food security, biodiversity and water conservation. Instead of tilling before seeding, seeds are deposited directly into untilled soil by opening a narrow slot trench or band. Today, it is also seen as mitigation and adaptation option and thus being promoted as a measure to be supported under the United Nations Framework Convention on Climate Change (UNFCCC). There are even many voices advocating no-till to benefit from any future and existing carbon market. But: Is no-till the solution to reduce the hunger in the world and to mitigate climate change?

Sorting the wheat from the chaff

It has been proven that no-till can significantly reduce soil erosion and conserve water in the soils. This is regarded as a basis for higher and more stable crop yields – but science shows that this is not necessarily true. Discouragingly, there are numbers of examples of no yield benefits or even yield reductions under no-till in developing countries, especially in the first up to ten years. However, particularly the crop yields are crucial for the food security of small-scale farmers and not whether a method is more efficient or not.

Although humus can be enriched under no-tillage, the sequestration of soil carbon, as result of the accumulated organic matter in the topsoil, is restricted to the upper 10 cm of the soil. Compared with ploughing, no carbon benefit – or even a carbon deficit – has been found at soil depths below 20 cm. This is why no-till makes little or no contribution to carbon sequestration and does not prove to reduce greenhouse gas emissions in croplands.

The quantification of carbon sequestration rates under no-till are highly doubtful. Anyhow, it is very likely that emission reductions generated from no-till projects in developing countries would serve to offset emissions from the industry and transport sector in developed countries. Those well quantified emissions from developed countries would thus be offset by uncertain reductions from agriculture projects. The overall aim of the UNFCCC – to avoid dangerous climate change – would be jeopardized.

Even if no-till became a promising mitigation option, other environmental problems would remain. No-till farming systems often come along with the industrialization of agriculture with high inputs of agrochemicals. On the one hand, small-scale farmers are not skilled in handling such chemicals. On the other hand there remains a risk that they apply cheap chemicals, which persist long-term in the environment. Efforts should therefore be strengthened on how to combine sustainable production systems such as organic agriculture with no-till practices.

To summarize, there are too many open questions and uncertainties concerning the impact of no-till on crop yields and carbon sequestration, so that no-till could not be sold as the solution for hunger reduction and adequate option to mitigate climate change but as an important part of integrated strategies. Therefore, we recommend keeping no-till and reduced till out of the carbon market unless reliable carbon offset quantification and monitoring can be undertaken at reasonable cost.

Photos: Flitner/MISEREOR, The Rodale Institute

What is no-till?

1

No-tillage or no-till, also referred to as zero tillage, is a soil cultivation system in which seeds are deposited directly into untilled soil. It is defined "as a system of planting (seeding) crops into untilled soil by opening a narrow slot trench or band only of sufficient width and depth to obtain proper seed coverage. No other soil tillage is done."[1] Conventional tillage completely inverts the soil, while no-till causes only negligible soil disturbance and the residues from previous crops remain largely undisturbed at the soil surface as mulch. Seeding systems that till and mix more than 50% of the soil surface while seeding cannot be classified as no-tillage.[2]

No-till farming is not concerned only with soil tillage – it encompasses four broad, intertwined management practices:

- Minimal soil disturbance (no ploughing and harrowing),
- maintenance of a permanent vegetative soil cover,
- direct sowing and
- sound crop rotation.[3]

These management practices also meet the definition of conservation agriculture.[3] No-till farming is also sometimes regarded as a component of sustainable land management (SLM) and better land husbandry (BLH) approaches.[4] No-till and conservation agriculture are therefore difficult to distinguish from each other. However, the Professional Alliance for Conservation Agriculture (PACA) defines the tillage practice of conservation agriculture as follows: "The practice of conservation agriculture advocates minimal soil disturbance and hence much less or no tilling is carried out."[5] This means that conservation agriculture can imply either less deep and/or less frequent tillage practices.

No-till as a component of conservation agriculture is today actively promoted by a growing number of research and extension programmes, supported by major international initiatives including the FAO, the Global Forum on Agricultural Research (GFAR) and the European Conservation Agriculture Federation (ECAF).

Certain prerequisites must be met for successful implementation of no-till farming. Like other agronomic technologies, it requires knowhow and a detailed understanding of soil-plant interactions. Special no-till equipment is needed: no-till is bound to fail if techniques for drilling seed into residues at the proper depth are not available.[6] In principle the method always involves the following stages:

- Handling loose straw or living mulch by cutting/moving aside or rolling;

A no-tilled field: corn in 30" rows in hairy vetch residue

Rolling a hairy vetch cover crop

- application of seeds and fertilizers;
- furrow closing;
- seed/soil compaction.

In developed and many transition countries this is done using sophisticated farm machinery (see picture above as an example).

In developing countries a variety of no-till equipment is available to smallholders. Planting devices range from manual tools to animal-powered devices and tractor- driven seeders.[7] Manual seeding of crops into plant residues is relatively easy and can be performed using equipment such as the jab planter (see picture next page). The simplest method involves using a hoe or pointed stick to make small holes at the required spacing; seed is then placed in these holes (see picture below), preferably with fertilizer or manure placed in another hole a few centimetres away.

Seeding with a jab-planter on a residue covered field

In the USA, Canada, Brazil, Argentina and Australia, all of which are key producers of wheat, rice, corn and soya for export, no-till has developed differently than in the countries of the developing world (parts of Central and South America, Africa, Asia). The no-till systems used in the firstmentioned group of countries involve less diverse crop rotation with little or no integration of livestock (which means that no organic manure is returned to the cropland) and with less frequent cultivation of forage legumes for soil fertility and weed control. In this study this system is defined as **"large-scale no-till"**. In the developing world livestock husbandry is practised on many smallholder farms. Forage legumes for livestock as well as other crops grown for self-sufficiency are therefore often included in the no-till crop rotation. In this study this kind of no-tillage is classed as **"small-scale no-till"**.

An animal traction direct seeder

Photos: Christian Thierfelder

2 No-till today

Recent studies estimate that there are about 111 million hectares of farmland under no-till worldwide (see Figure 2); this is about 8% of global cropland.[6] No-till is practised on farms of all sizes and using mechanized, animal-powered and/or manual methods — it encompasses diverse farming systems under temperate, subtropical and tropical conditions. However, the accuracy of data is limited as only a few countries around the world conduct regular surveys on the use of no-till and conservation agriculture practices.

Farmers who practise no-tillage for one crop and regularly plough or till the soil for the subsequent crop are not included in the statistics. This excludes millions of hectares from the reported estimates, as in many parts of the world no-till is practised temporarily as part of the crop rotation. For example, rice-wheat rotation is used on 5 million hectares in the Indo-Gangetic plains (covering parts of India, Pakistan, Bangladesh and Nepal), with no-till being practised before wheat cropping.[6] No-till is mainly practised in North and South America, with the top four countries being the USA, Brazil, Argentina and Canada. Not all countries in Latin America have taken up no-till on a large scale and it is much less used on the other continents. In Brazil no-till is practised on both large and small farms (small farms are defined as those of less than 50 ha), while in the USA, Canada, Australia and Argentina large-scale no-till farming predominates. Large-scale farms in developed countries usually involve a higher level of technology and less manpower per hectare than farms in developing countries.

No-tillage started in the USA, triggered by a disastrous dust storm in the mid-western states in the 1930s. This served as a wake-up call, highlighting the non-sustainable nature of agricultural systems that involve excessive soil cultivation.[8] Brazil's no-till experience dates back only 35 years; it was prompted by the need to search for sustainable tillage solutions. The rapid losses of soil organic matter from vast cropland areas within a few decades led to a significant decrease in agricultural productivity in the 1960s. Although initially applied in diverse farming systems, the situation changed in the 1990s when progress in seeding techniques and approval of the use of leaf-active total herbicides such as Roundup facilitated the adoption of no-till in industrialized monocultures. At the same time a competitive agricultural machinery industry was developing in Brazil, which now exports no-till equipment worldwide.[9] This led to an increase in large-scale no-till operations involving mono-cropping systems, including those using GMOs, at the expense of small-scale no-till operations with diverse crop rotations. In 2011 the area under no-till is as large as in the USA.

As shown in Figure 2, the adoption of no-till in developing countries is currently negligible by comparison with the expansion of this technology in developed and emerging countries of North and South America.

In many African countries, especially in southern and eastern Africa, no-till practices have been introduced in the last decade. Some countries have incorporated no-till into their government policies, driven by donors and development cooperation activities (see Section 2.2). Brazil's "zero-tillage" revolution is viewed as a potentially attractive method for reversing soil degradation and increasing land productivity in sub-Saharan Africa.[5] Conservation agriculture, including no-till activities and promotion programmes, is practised in particular in Kenya, Tanzania, Zambia, Zimbabwe, Lesotho, Swaziland, Mozambique and Malawi. The adoption rates of no-till, however, are relatively low. Current records list 10,000 small-scale farmers using no-till in this region; the number is steadily increasing.[1,4]

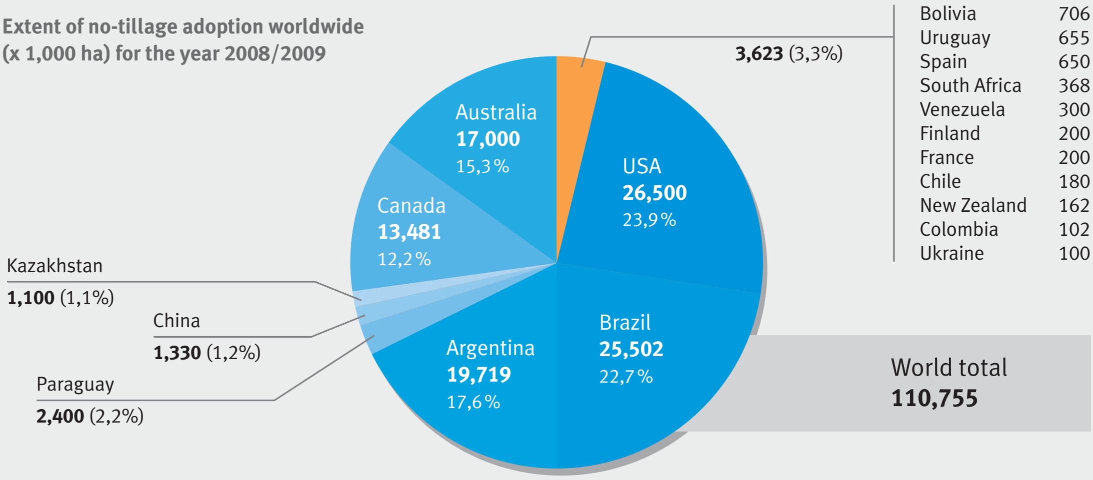
2.1 Side effects of no-till

No-till was initially developed as a farming method for conserving soil and water resources (see Table 1 in the annex). It has been proven that with no-till operations soil erosion can be reduced significantly.[3,4]

Scientific sources and statistics affirm that no-tillage today often comes "in a package" with monocultures, genetically modified crops and extensive herbicide use. This is partly a reflection of economic interests of lobby groups that promote the zero-tillage approach (see Section 2.2); it also points to the fact that no-till is well-suited to those mentioned practices. Negative environmental side effects are not necessarily inherent in the practice of no-till; instead they are associated with the way no-till is currently implemented.

Figure 2

Extent of no-tillage adoption worldwide (x 1,000 ha) for the year 2008/2009



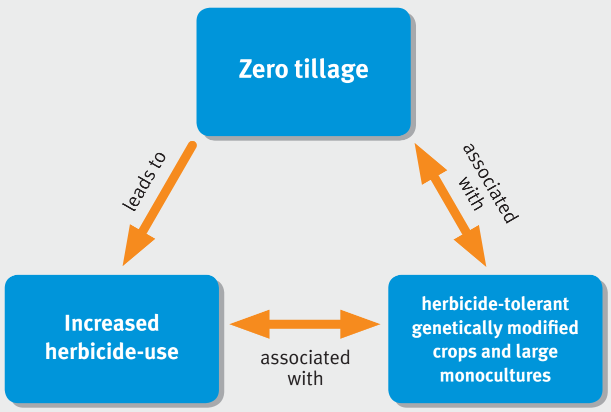
Data compiled from Derpsch et al. (2010), mainly based on estimates made by farmer organizations and agro-industry.

By comparison with the total body of scientific literature on no-till agricultural systems, little attention has been paid to critical analysis of the environmental side effects of no-till. We identified only a few scientific papers that deal critically with no-till.[10] Research and development organizations that are interested in promoting no-till are even accused of stifling criticism. However that may be, most of the literature highlights – sometimes enthusiastically – the benefits associated with the practice and hails no-till as a panacea for problems such as erosion and low productivity in developing countries.[4]

Despite the paucity of critical literature, a great deal can be deduced from the scientific discussion of the practices associated with no-till: monocultures, genetically modified crops and reliance on herbicides for weed control (see Table 2 in the annex). Figure 3 illustrates the interactions between these characteristics and zero-tillage: large-scale no-tillage is most easily practised when herbicides are used for weed control. This again is easiest when herbicide-resistant crops are grown.

Figure 3

Interactions between zero tillage (= no-till) and increased herbicide use, herbicide-tolerant GMO crops and large-scale mono-cropping systems



Source: Author's own graphics

High herbicide use is the most prominent side effect of no-till agriculture today. It is the substitute mechanism for controlling weeds that would otherwise be controlled (at least in large-scale farming) by ploughing, other more intensive tillage techniques, manual weeding, and crop rotations that include forage legumes, which are known to suppress weeds and fix nitrogen. Excessive herbicide use causes a variety of environmental problems. Soils and water are affected,[11] as are diverse wildlife habitats.[12] Herbicides – especially the broadband herbicide glyphosate, better known as Roundup – also affect humans.[13] Hailed initially as a modern all-round solution for weed control, Roundup was soon applied extensively, exacerbating the global problem of resistant weeds. Over 352 glyphosate-resistant weed populations have been listed by the Herbicide Resistance Action Committee (HRAC).[14]

However, it is frequently argued that herbicide-resistant crops lead to a decrease in herbicide use by comparison with industrialized conventional systems.[15] Because of the problems described above, this might not be so in the case of no-tillage systems, which are frequently referred to as examples in studies of glyphosate-resistant weeds.[16] Critical voices claim that some weeds are particularly well-adapted to no-tillage.[17]

Proponents argue that herbicide-resistant Roundup Ready soybean cultivation is beneficial to the environment because it resulted in an expansion of no-tillage practices in Latin America. As large-scale no-till relies on herbicide use as the primary weed control mechanism, it "may have further stimulated the use of herbicides in Roundup Ready soy".[18]

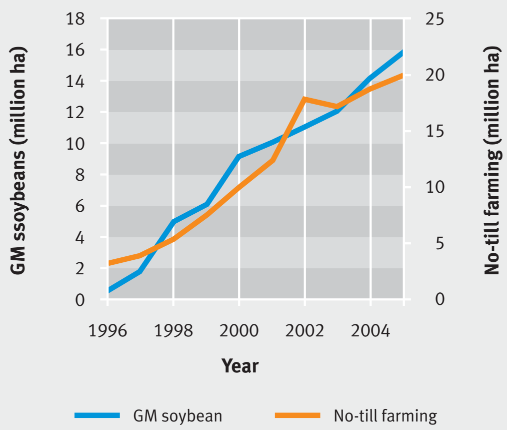
The three countries with the largest area under GMO cultivation – the USA, Brazil and Argentina – are those with the largest no-till areas.[9] Figure 4 shows the proportional increase of no-till farming and GM soybeans in Argentina from 1996 to 2004.

As explained, negative side effects connected with no-tillage are partially due to the way the practice is currently implemented, even though alternative weed control options exist even for reduced or no-tillage systems.[20] However, there is empirical evidence that in the smallholder context labour requirements increase enormously when fewer or no herbicides are used.[4] Combining no-tillage with organic farming practices no doubt poses a major challenge for research on weed control and implementation.

To summarize, no-tillage in conventional agriculture today is associated with the typical and well-known environmental impacts of industrial agriculture with high external inputs, including the use of herbicides and expensive machinery. It may have some positive effects, such as reduced soil erosion (see Section 5), but it is likely to support the further spread of industrialized large-scale agriculture, since it is used to justify the use of herbicides and herbicide-resistant GMOs. In its current implementation it tends to run counter to the shift towards environmentally sound organic agriculture, which functions without costly external inputs such as agrochemicals. Especially for poor smallholder production in developing

Figure 4

Adoption of GM soybean and no-till seeding in Argentina



Data from Trigo and Cap (2006).
Source: Duke, S.O., & Powles, S.B. (2009). Glyphosate-resistant crops and weeds: Now and in the future. AgBioForum, 12(3&4), 346-357.

countries, organic agriculture is able to provide many benefits at low cost by involving diverse cropping systems, crop rotation, legumes, and mixed farming with livestock.

2.2 Who is behind the no-till lobby?

The World Bank and the FAO are the most important multinational institutions supporting no-till and conservation farming practices as a means of sustainable rural development. The Global Forum on Agricultural Research (GFAR) and the Consultative Group on International Agricultural Research (CGIAR) with its 15 research centres are highly involved in research into and dissemination of conservation agriculture and no-till for sustainable rural development in developing countries. The Cereals Systems Initiative for South Asia (CSISA), for instance, is mandated to increase farm productivity and smallholder income in South Asia through the accelerated development and deployment of new crop varieties and sustainable crop management technologies such as no-till. The project is being implemented by the CGIAR institutions the International Rice Research Institute (IRRI), the International Maize and Wheat Improvement Center (CIMMYT), the International Food Policy Research Institute (IFPRI) and the International Livestock Research Institute (ILRI).

The international development organizations seem to be in favour of promoting conservation agriculture in general rather than no-tillage exclusively. The CSISA project in the Indo-Gangetic plains is a good example. Local farmers perform some kind of tillage in the form of soil puddling prior to rice cropping and no-till is only applied to wheat cropping. This project focuses on smallholder farmers who employ low-tech seeding equipment and apply pesticides and synthetic fertilizers. Pesticides and synthetic fertilizers do not necessarily have a negative impact on long-term sustainability if applied according to good practice and combined with other important agro-ecological measures such as diverse crop rotation, alley cropping and intercropping. According to FAO officials, the FAO does not promote only the deployment of agrochemicals in its projects and training courses on conservation agriculture. The FAO and many other multinational institutions involved in international development cooperation aim instead to provide a broad range of options for utilizing no-till farming with and without agrochemicals in the smallholder context.[21]

The Brazilian experience has been accompanied and supported by the World Bank and the FAO as well as former German Technical Cooperation (now: Gesellschaft für internationale Zusammenarbeit; GIZ) and the French International Agricultural Center for Development (CIRAD), which has worked closely with several state and federal programmes. CIRAD adapted reduced tillage methods being practised in Europe and USA in the early 1970s to semi-tropical conditions and introduced them to Brazil.[3]

A critical component is the lead given by farmer-led organizations, for example the Brazilian organizations Federação Brasileira de Plantio Direto na Palha (FEBRAPDP) and Associaçao de Plantio Direto no Cerrado (APDC). These organizations cooperate closely with manufacturers and providers of agricultural equipment, agrochemicals and seeds.[9] The success of no-till agriculture, which was initially introduced by small- and medium-scale enterprises in Brazil, was further stimulated by major players in the agrochemical industry such as Monsanto. The deployment of their products and similar ones from other agrochemical companies displaced the use of conventional crop seeds and alternative weed-control measures and facilitated the adoption of large-scale no-till practices, which are now common practice in Argentina, the USA, Canada and Australia.

In the USA the Conservation Technology Information Center (CTIC) plays an important role as a multi-stakeholder initiative dedicated to no-till. The CTIC is a national public-private partnership comprised of members of the agricultural industry, associations, conservation organizations and producers; it is supported by the U.S.

Environmental Protection Agency (EPA), the Natural Resources Conservation Service and other public bodies. It is dedicated to the principles of conservation agriculture, particularly no-till farming, which in practice means large-scale no-tillage with a significant proportion of GMO crops along with the appropriate pesticide toolbox and state-of-the-art agricultural machinery.

Only a handful of **organic growers** practise no-till, although the countries with the largest areas of land under organic agriculture, such as Australia, Argentina and the USA,[22] are also among the top five no-till countries. There is a lack of scientific evidence that no-till can be used effectively in organically managed agricultural systems; the available knowledge of organic no-till is fragmented and based on single cases, so that it cannot currently be used by the International Federation of Organic Agriculture Movements (IFOAM) for extensive promotion. Leading research institutions such as the Brazilian Agricultural Research Corporation (EMPRAPA), the Research Institute of Organic Agriculture, Switzerland (FiBL) and the Rodale Institute, USA, are conducting research on no-till and reduced tillage. However, more research and development is required to validate the research results obtained under various pedo-climatic and agronomic conditions and to overcome the weed management problem which has been encountered in nearly all trials so far.

3 No-till – really climate-friendly?

No-till agriculture is widely promoted as a climate-friendly farming system, and the IPCC Fourth Assessment Report attributes greenhouse gas mitigation potential to no-till.[23] Greenhouse gas mitigation effects that some important review papers[24] link to no-till are:

1. Soil carbon sequestration;
2. reduction of GHG emissions from soils;
3. reduction of fossil fuel use;
4. reduction of synthetic nitrogen fertilizer use.

A further description of these effects and their impact on greenhouse gas mitigation as induced by no-till can be found in **Table 3** in the annex.

According to the findings of recent meta-analyses, the effectiveness of no-till is fairly low for soil carbon sequestration and for the reduction of nitrous oxide (N_2O) emissions from cultivated soils (see in detail Table 3 in the annex). This contradicts the widespread belief of some no-till proponents and lobby groups[25] and earlier esti-

Photo: Pohl/MISEREOR

Oxes ploughing the fields

mates of the sequestration potential of no-till,[26] which is also considered in the latest IPCC report.

These aspects are of particular importance because benefits in the areas of carbon sequestration and greenhouse gas mitigation are used by no-till proponents and the agrochemical industry as arguments for inclusion of large-scale no-till in the carbon market (see Section 5).

3.1 Carbon sequestration in no-till agriculture

The less the soil is disturbed, the more organic matter can be retained in the form of stored carbon, which therefore does not contribute to global warming in the form of CO_2 emissions. No-till supporters therefore claim that no-till contributes to greenhouse gas mitigation through enhanced carbon sequestration in the soil.[29] To date, only a few long-term studies of soil organic carbon changes under different tillage regimes have been conducted in developing countries.

Conversion from conventional tillage to no-till is often considered to be an efficient carbon sequestration strategy with a sequestration rate of 367-3667 kg CO_2 ha^{-1} $year^{-1}$.[25] This view, however, is largely based on findings from studies of carbon change in topsoil only (<30 cm), which ignores the possible management-induced redistribution of soil carbon at different soil depths. It thus may simply be an artefact of shallow soil sampling.

In a recent meta-analysis, global data was assessed from 69 paired experiments in which soil sampling extended deeper than 40 cm. The distribution of carbon in the soil profile changed significantly but no increase in total soil organic carbon was found. The study highlighted the fact that the complex patterns of soil carbon change under different cropping systems need to be considered when assessing soil carbon dynamics under various management practices.[27]

We found one positive example from an irrigated research site in Zimbabwe where an enrichment of soil organic carbon was found after five years of no-till. Cumulative soil carbon stocks in the 0–60 cm profile were higher under no-tillage than under conventional soil cultivation. On average, no-till sequestered 780 kg C ha^{-1} $year^{-1}$ at 0–30 cm depth (=2.860 kg CO_2 ha^{-1} $year^{-1}$).[28]

However, there is no clear scientific evidence confirming whether or to what extent no-till stimulates carbon sequestration in agricultural soils globally. In Africa the potential carbon gain for reduced tillage appears to be low for degraded soils and low/medium for non-degraded soils.[29] The benefits of enhanced soil carbon under no-till are more a function of increased inputs of organic matter in the form of mulch than of the tillage practice itself.[4]

3.2 Greenhouse gas emissions from no-till soils

There is no clear scientific evidence on how no-till affects the flux of the greenhouse gases nitrous oxide (N_2O) and methane (CH_4) from soils. The global warming potential of these gases is, respectively, 296 and 23 times more than that of CO_2 .

Effect of no-till on carbon sequestration and nitrous oxide emissions from Argentine pampean soils

To determine the potential of no-till to mitigate global warming a meta-analysis of published studies in the Argentine pampas was carried out in 2006.

Averaged over years a 2.76 t ha^{-1} soil carbon increase was observed in no-till systems compared with tilled systems (although no differences were detected with reduced till).

Emissions of N_2O were greater under no-till, with a mean increase of 1 kg N ha^{-1} $year^{-1}$ in the denitrification rate for humid pampean scenarios. The increased emissions of N_2O might outweigh the mitigation potential of no-till arising from carbon sequestration in about 35 years and therefore contribute to global warming.[23]

Field measurements have shown both decreased and increased emissions of N_2O under no-till conditions.[30] The different duration of the experiments may explain the contradicting observations. In a meta-analysis of paired experiments on the influence of tillage treatments it was found that newly converted no-till systems increase global warming potential relative to conventional tillage in humid and dry climate regimes, and longer-term adoption (<10 years) only significantly reduces global warming potential in humid climates.[23]

Greater pore continuity and the presence of ecological niches for methanotrophic bacteria in no-till systems appear to lead to increased CH_4 uptake relative to conventional tillage.[31] The few studies reporting CH_4 flux differences between conventional and no-till systems all showed a significant enhancement of CH_4 uptake

Photo: Schaaf/MISEREOR

Corn field in Brazil

with no-till adoption. However, this did not necessarily influence the overall global warming potential of no-till systems because of the low CH_4 uptake rates usually found in soil.[23]

Great potential, although not directly related to no-till, is seen in the water management of rice cropping systems because of corresponding CH_4 emissions, which contribute 12% of total agricultural greenhouse gas emissions.[22] The success of no-till sowing of wheat after rice in the South Asian rice-wheat belt is encouraging.[32] However, intense ploughing of water-saturated soil (puddling) for the rice crop and lack of residue mulch due to prior removal or burning at the time of sowing wheat minimize benefits. Attempts are now being made to establish double no-till rice-wheat systems and the first positive results from farm trials have been reported from West Bengal.[33]

3.3 Other climate impacts of no-till

The greatest effect of no-till on greenhouse gas mitigation appears to result from fuel savings, as has been reported from typical mechanized farming conditions in the USA, Brazil and Paraguay. This is confirmed by all the reports so far and applies in particular to large-scale no-till (but also to small-scale no-till when fuel-driven farm machinery is used), because the energy used for ploughing activities is no longer required. No-till leads to diesel saving of more than 50%[34] or even greater when direct planters are employed and no other soil preparation is carried out (an essential requirement for classification as no-till). Greenhouse gas emissions from farm machinery are put at 158 million t CO_2e (= 2.5% of total agricultural greenhouse gases); a significant proportion of this can be saved through no-till-induced diesel savings.[35]

The claim of proponents of the no-till system that no-till reduces synthetic nitrogen fertilizer use and the corresponding CO_2 and N_2O emissions from fertilizer production is not substantiated by the scientific literature. The high carbon-to-nitrogen ratio of the mulch layer appears to favour nitrogen immobilization, which may even require additional nitrogen fertilizer. However, significant nitrogen fertilizer savings can be obtained when nitrogen-fixing legumes – ideally forage and agroforestry legumes – are included in no-till crop rotations, as is the case in small-scale no-till that includes livestock that use some of the forage legumes.[4]

It can be concluded that the current body of scientific literature does not substantiate the high expectations of no-till associated with its potential contribution to carbon sequestration and reduced greenhouse gas emissions from soils. Due to the lack of scientific evidence for soil carbon sequestration, the present and future role of no-till in the carbon market must be questioned (see Section 5).

No-till – benefiting the poor?

No-till farming appears to benefit adaptation to climate change rather than mitigation. Conserving soil and water resources are important measures for adapting agricultural systems to climate change, which is particularly likely to affect regions in sub-Saharan Africa and South Asia.[22] Thus no-till could harbour great potential for adapting smallholder farming systems to changing climatic conditions.

There is detailed scientific evidence that no-tillage conserves the natural resources of soil and water through various mechanisms (Table 2, see annex). The mulch layer minimizes evaporation for a certain period of time, and in regions of low rainfall this can conserve water and increase the water-use efficiency of the cultivated crops. Furthermore, the change in infiltration and runoff rates can have major effects on the total water balance, which is important in sustainable production systems. As a meta-analysis has shown,[27] the permanent soil cover and low disturbance resulting from no-till also increase soil organic matter, at least in the top 10 cm of the soil. This therefore improves soil aggregate stability. **Soil erosion control is seen as the clearest benefit of no-till. Decreases in soil erosion and water losses through runoff are often spectacular and are reported from many field sites.**[36]

4.1 Crop yields and food security

As a result of its success in Brazil, no-till is viewed as a sustainable means of improving food security and rural livelihoods in developing countries. The significant soil- and water-conserving effect of no-till systems is regarded as a basis for higher and more stable crop yields.[37] However, the scientific literature reveals a diverse picture ranging from higher yields as a result of no-till to no yield benefits and even yield reductions.

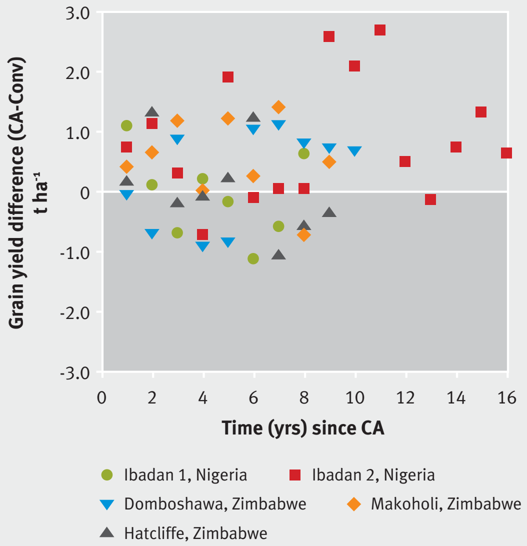
Discouragingly, there are numerous examples of no yield benefits or even yield reductions under no-till in developing countries. As Figure 5 shows, crop yields tend to be variable, especially in the first years of no-till. Factors that suppress short-term yield benefits are soil nutrient immobilization, poor germination, increased weed competition, residue-borne diseases, stimulation of crop pests, and waterlogging, especially in poorly drained soils.[5] Even though yield suppression is likely to occur, especially during the first five years of no-till, the soil improves gradually over time on account of the build-up of organic matter and the resulting effects on soil physics, chemistry and biology. This may be the reason why ten years after the introduction of no-till in conservation agriculture there has been only one reported instance of yield decrease from field trials in Africa, while there have been seven of yield increase (Fig. 5).

These findings are in contrast to those from Brazil where farming operations, especially in South Brazil, produced significant yield benefits from no-till. The extent of soil degradation in the 1960s and '70s was so severe that crop productivity had reached a critical level.[3,9] The principle of soil and water conservation as induced by no-till was introduced at the same time as the rise in crop yields occurred. However, it should be borne in mind that these impressive yield increases over decades cannot be attributed solely to no-till technology but may also result from plant breeding and fertilizer and herbicide use.

Proponents of no-till claim **labour savings** as an important benefit of no-till. This appears to be true for large-scale operations where adequate machinery and agrochemicals for plant protection are available. In the

Figure 5

Maize grain yields ($t\ ha^{-1}$) under conservation agriculture practice compared with conventional tillage over time



Data are from Lal (1991) for sites Ibadan I and II, Nigeria; Vogel (1993) and Nyagumbo (2002) for Domboshawa, Zimbabwe; Moyo (2002) for Makoholi, Zimbabwe; Nyagumbo (2002) and Munyati (2000, upublished) for Hatcliffe, Zimbabwe smallholder context of the world's poor the situation seems to be different. Especially in manual cropping systems, land preparation and weeding are very labour-intensive. As shown elsewhere,[38] not tilling the soil often results in weed pressure. And unless herbicides are used, the increased labour required for weeding under no-till may outweigh the labour savings obtained by not ploughing. Since women are usually in charge of hand-weeding there is a risk that under no-till the labour burden is shifted to them; this effect has been reported in one of the few published socio-economic studies of no-till.[39] **While in developed countries gross margins or net financial returns determine the productivity of agricultural systems, the capacity to produce sufficient crop yield from a plot of land for food is the key determinant for smallholders in developing countries.**

4.2 No-till and rural livelihoods

The potential of no-till agriculture is limited in drought-prone areas, particularly in the semi-arid tropics where annual rainfall is less than 800 mm and the dry season lasts more than five months. Large parts of Africa fall into these zones. While no-till principles are also valid there, it may not be possible to apply them to their full extent. For successful no-till farming the generation of biomass as dead or living mulch is crucial. But biomass production is naturally limited in areas of low rainfall, and the need to feed livestock in the dry season competes with the principle of retaining crop residues on the soil surface. Crop residues, in particular maize stover, are used as fodder for livestock, especially in smallholder farming systems in sub-Saharan Africa. Consequently, biomass for mulching is often in critically short supply so that the targeted application rates cannot be reached. Other constraints in many African regions are residue removal by termites or burning practices to clear land because of rodents, pests and weeds. **Thus in many mixed farming systems, particularly in semi-arid areas where livestock are of significant importance, the costs of retaining crop residues as a mulch may be too great in relation to the potential benefits, which are often difficult to quantify.**[4]

In the medium and long term no-till may stabilize crop yields in the smallholder context and enable labour savings, but it may require the introduction of regular pesticide application. The contribution of pesticide production to the global emission of agricultural greenhouse gases is relatively low,[4] but the practice of "pesticide-based agriculture" poses a great risk to humans and the environment. Practitioners are often not skilled in handling agrochemicals that are toxic to humans and there remains a risk that cheap chemical agents that persist long-term in the environment will be applied.

Photo: Flitner/MISEREOR

Woman working in the field, Burkina Faso

Furthermore, there is a risk that no-till agriculture will promote land-grabbing from the world's poor. The higher net returns that are achievable, particularly under large-scale no-till, encourage agro-industrial investors to buy cheap land from countries where land use rights are unregulated. Carbon credits for no-till agriculture will increase the risk of expanding large no-till GMO operations which compete with local communities in developing countries for valuable soil resources.

To summarize, it cannot be assumed that no-till will bring benefits to farming systems and rural communities in general simply because benefits have been demonstrated at the plot level or in other countries. A farming system consists of many interacting components and is subject to a range of bio-physical, socio-economic and cultural constraints. A technology can only be considered as successful innovation when fully embedded within the local social, economic and cultural context.[40] Thus the suitability and adoption of a new technology in one place – for example, the use of no-till in South America – does not imply that the conditions for adoption necessarily exist in developing countries such as those in sub-Saharan Africa.

No-till in the carbon markets

5

No-till already forms part of the carbon market, as there are a few mitigation protocols covering such techniques which are implemented in ongoing projects to generate offsets. Examples are the **"Continuous Conservation Tillage and Conversion to Grassland Soil Carbon Sequestration"** and the **"Sustainably Managed Rangeland Soil Carbon Sequestration Offset Projects"** protocols of the Chicago Climate Exchange CCX (which terminated its operation in 2010). The CCX defined sequestration values for seven geographical zones of the US. The default sequestration values used in this methodology range between 0.5 – 1.5 t CO_2e/ha/y and are thus very coarse, as they apply to very large and heterogeneous areas and to a wide range of different practices that all can be subsumed under "conservation tillage".[41] The Government of Alberta, Canada, adopted the **"Quantification Protocol for Tillage System Management"**, which is based on default carbon sequestration values (t CO_2e/ha) that differentiate between five geographical zones in Canada and three levels of tillage intensity (full tillage in the baseline vs. reduced or no-tillage in the project). The sequestration values for full to no- tillage conversion range from 0.2 to 0.6 t CO_2e/ha/y.[42] Finally, the Verified Carbon Standard **(VCS)** methodology **"Adoption of sustainable agricultural land management (SALM)"** assesses mitigation potential on the basis of soil carbon models with input data on practices, areas, outputs, etc. No measurements of soil carbon levels are required, though.[42] All these protocols allow for various types of conservation tillage, with no-till being only one option among others.

No-till is also mentioned in some of the Nationally Appropriate Mitigation Actions **(NAMAs)**, which currently capture any mitigation action undertaken by developing countries. NAMAs are not part of the carbon market, but we mention them here because they are an emerging approach to climate policy in the context of the Kyoto Protocol and potential successors. Examples are the NAMAs of Brazil and Ghana. However, these remain very non-specific, providing nothing more than a rough estimate of areas under no-till by 2020 in the case of Brazil and an undertaking to support minimum tillage from Ghana.[44]

Given the discussion above (e.g. Section 4.1), the quantifications of carbon sequestration under no-tillage are highly doubtful and these protocols are not adequate for capturing no-tillage projects for the carbon markets. As long as no clear sequestration potential can be claimed for no-tillage projects, there is no purpose in including them into the carbon markets. Even if further research were to show that no-tillage has real sequestration potential under some conditions, its inclusion may be problematic since default values and modelling results may remain too coarse. Reliable soil carbon measurements are feasible and require soil sampling to depths of at least 50 cm to determine soil carbon concentrations. This is accompanied by determination of soil bulk densities along the soil profile to the same depth to enable soil carbon stocks to be calculated. These measurements are time-consuming if they are to be representative at plot level and even more effortful at farm or even landscape scale, which means that monitoring of carbon offset projects might fail implementation in protocols.

Further challenges arising from the carbon market context concern the reliability of emission offsets and a potential bias towards industrialized agriculture. Emission reductions generated from no-till projects would most likely serve to offset emissions from industry and transport in developed countries. As those are largely based on fossil fuel combustion, their quantification is relatively easy and reliable. **Even in the most favourable cases, agricultural mitigation projects will not reach this reliability. For no-till projects, for example, the assessment of nitrous oxide emissions will greatly add to the uncertainty of emission reduction estimates even if carbon sequestration does not do so. Well-quantified emissions in developed countries would thus be offset by uncertain reductions from agricultural projects.**

Standardization of agricultural production processes, large-scale production, monocultures, etc. would be favourable for reliable quantification of mitigation potentials in no-till projects. Support of no-till as a mitigation measure could thus be used as an argument for corresponding support of such industrialized agricultural production systems. As discussed in Section 3.3, the link between no-tillage and industrialization of agriculture is already evident and largely at odds with several key aspects of sustainability. Even if no-tillage were to become a promising mitigation option in some circumstances, with reliable and efficient quantification, the environmental problems would remain. Further guidelines would be needed to ensure that no-till mitigation projects were sustainable.

6 Conclusions

No-till was initially developed as a farming method for conserving the natural resources of soil and water. It has been proven that, with no-till, soil erosion can be reduced significantly, even to rates below soil formation rates. No-till seems to be an appropriate strategy for ***adapting*** agricultural production systems to climate change by preserving water and soil resources that climate-change scenarios identify as being particularly threatened.

The accumulation of organic matter in the topsoil of croplands because of permanent soil cover by mulch is a key mechanism for the observed soil and water conservation benefits. The accumulation of soil organic matter and therefore soil carbon is, however, restricted to the upper 10 cm of the soil. **By comparison with ploughing, no carbon benefit or even carbon deficits have been found at soil depths below 20 cm. No-till makes little or no contribution to carbon sequestration in croplands.**

In addition, it has been shown that after a few decades these croplands can actually change from sinks to sources of greenhouse gases. There is a considerable lack of knowledge on greenhouse gas emissions from croplands other than paddy rice areas, especially in developing countries. By far the majority of research into greenhouse gases in agricultural soil-plant systems has been conducted in developed countries.

Carbon offset strategies like the Clean Development Mechanism (CDM) are if at all feasible for industrial processes, where greenhouse gas emissions can easily be measured. Agricultural fields, however, are subject to complex biological processes and exhibit extensive heterogeneity. This makes it difficult to obtain the reliable soil carbon measurements which would be essential for the quantification of sequestered CO_2 and the generation of corresponding credits. In addition, the trade-off between the build-up of organic matter for carbon sequestration and the increased risk of nitrous oxide release as a result of carbon-induced denitrification processes in soils is not thoroughly understood and therefore poses another major challenge to the quantification of carbon gain for any soil management system, including no-till. **Consequently, it seems impossible to include no-till in carbon offset strategies until science has progressed to allow for clear and affordable measurements.**

We acknowledge the benefits of no-till for farmers, smallholders and rural communities in South America, where through the combination of plant cover, minimal soil disturbance and sound crop rotations soil and water can be conserved while crop yields are stabilized or rise. However, there is also reason for great concern, as diverse crop rotations have been neglected and simplified over the years and instead higher rates of pesticide application have been introduced. This process has been further accelerated by the expansion of herbicide-tolerant GMO crops, which has led to a huge increase in herbicide-resistant weeds, which are then controlled by even higher doses of potentially toxic agrochemicals. **It is unclear whether GMO crops plus pesticides led to the massive expansion of no-till in South America or whether no-till actually eased the widespread adoption of GMO crops plus the required pesticide packages.**

Any transfer of the successful expansion of no-till in South America to developing countries must therefore be undertaken with caution. Agricultural production in smallholder environments aims at feeding the local population

Photo: Grossmann/MISEREOR

Weighing the corn

and sustaining rural livelihoods and relies therefore on crop productivity. Higher crop yields are rarely achieved with no-till farming, especially in the first ten years of its introduction. Livestock husbandry and the prevalent drought in semi-arid countries in the developing world exert an enormous pressure on the plant biomass needed as mulch for successful soil and water conservation. Sustainable land management strategies should focus on adapting land management to the prevailing site conditions rather than attempting to manipulate site conditions to meet the requirements of a particular practice.

We recommend that:

1. No-till and reduced till should be kept out of the carbon market unless reliable carbon offset quantification and monitoring (accounting for both soil carbon sequestration and GHG emissions) can be introduced, and unless compliance with important sustainability criteria, such as food security, rural livelihood provision, biodiversity and toxicity aspects is assured.
2. A clear distinction should be made between the possible advantages and disadvantages of no-tillage (or reduced tillage) on the one hand and herbicide and GMO use on the other. Especially with regard to the subsequent identification of policy instruments, this distinction is indispensable in order to avoid giving false incentives.
3. No-till or reduced till should not be promoted as a general or even sustainable practice in agriculture. Instead, no-till or reduced till are just two methods out of many that are useful in specific situations and under specific conditions but which may fail to perform well under other circumstances. Agricultural practices should always be adapted to the local conditions and should be sustainable.
4. The benefits of no-tillage must not be used as a justification for industrialized agriculture, and the drawbacks of no-tillage must not be neglected.
5. The focus should be on reduced tillage rather than on no-till only. As recent research shows, reduced tillage is easier to combine with environmentally friendly organic practices than no-tillage and makes it possible to realize some of the benefits of no-till agriculture while avoiding its drawbacks. The main aim should thus not be to further develop no-till agriculture as a well-specified system but rather to promote as little tillage as possible within the context of sustainable production systems such as organic agriculture.
6. Support should be provided for more research on and further development of sustainable tillage practices. The aim should be to promote 1.) soil and water conservation, 2.) climate change mitigation (accounting for both the effects on GHG emissions and soil carbon sequestration), 3.) climate change adaptation, 4.) reduction of toxic effects (pesticide and herbicide load), 5.) stabilization and increase of yields and 6.) support for rural livelihoods in general, i.e. taking a holistic view of sustainable agriculture.

7

Annex

Table 1

Resource conservation and climate change adaptation measures induced by no-tillage (conventional tillage as baseline)

Conservation/ adaption measure	Mechanism	Possible impact	Scientific evidence for the given criterion	Evidence given
Soil conservation	Increase in soil organic matter in topsoil	Various indirect impacts including reduced soil erosion and increased plant availability of soil water	Reported for topsoil (0-10 cm) according to global meta-analysis;[27] Reported for 0-40 cm horizon according to meta-analysis from Argentine pampas studies;[45] soil organic matter increase also reported from trials in a developing country.[28]	yes
Soil conservation	Increased soil aggregate stability	Reduction of soil erosion	Many papers show soil aggregate stability improvement[46] also in field trials in developing countries[47]	yes
Soil conservation	Reduced soil loss	Reduction of soil erosion	Many papers show reduced soil loss due to no-till[48,49]	yes
Water conservation	Reduced run-off	Reduction of soil erosion	Many papers show reduced run-off due to no-till[48,49]	yes
Water conservation	Reduced evaporation losses	More plant-available soil water	No-till decreased evaporation during periods of frequent rainfall, but evaporation in no-till was faster during the summer dry period due to non-disturbed capillary action[50]	yes/no
Water conservation	Increased water infiltration	More plant-available soil water, increased recharge of aquifers and reduction of soil erosion	Many papers show increased water infiltration induced by no-till; these include studies from developing countries[51]	yes
Water conservation	Higher soil water retention	More plant-available soil water, increased recharge of aquifers	Many papers show increased water infiltration induced by no-till;[52] these include studies from developing countries[51]	yes

Table 2

Environmental side effects associated with no-tillage

Typical characteristic of no-till system	Evidence	Relation to no-tillage	Environmental side-effects	
Increased herbicide use	Zero tillage is frequently associated with increased use of chemicals[11,20,53]	Not inherent to no-till – other weed control options exist[45]	Diverse health and environmental impacts, e.g.:	Major source of groundwater pollution[46] and freshwater ecosystems[47]
				Herbicide resistance: resistances develop in weeds due to the increased herbicide use[54,55]
				Adverse effects on terrestrial wildlife (plants, soil organisms, insects, mammals, birds)[48,56]
				Direct toxicity effects on human health[57]
Frequent use of GMO crops	Many no-till farming areas use GMO crops which are resistant to a specific herbicide (which in turn increases herbicide use)[45] Frequently argued that GM crop use supports adoption of no-tillage[49]	Not inherent – linked to increased herbicide use	Adverse effects are debated, but criticisms include:	Toxicity effects[45]
				Horizontal gene transfer to wild plant relatives – a threat to biodiversity with unpredictable impacts on habitats[45]
				Increased herbicide use (and resulting resistances)[45]
Often monocultures	No-till farming systems are frequently characterized by monocultures	Not inherent –but often linked with highly industri-alized farming		Low natural and agricultural biodiversity
				Weak system resistance to pests and diseases[45]

Table 3

List of greenhouse gas mitigation measures associated with no-tillage farming (conventional tillage as baseline)

Mitigation measure	Impact	Scientific evidence	Effectiveness
Soil carbon sequestration	CO_2 reduction through sequestration	No carbon offset according to global meta-analysis;[27,58] carbon offset reported according to meta-analysis from Argentine pampas studies;[45] carbon offset reported in one field trail for developing country[28]	no to little effect
Reduction of greenhouse gas emission from soils	a) Reduction of N_2O emissions from soils b) Enhanced CH_4 uptake (sequestration) from soils	a) N_2O reduction only after 10 years of adoption for hu-mid climate regimes; no reduction for dry climates but with high uncertainty according to meta-analysis[24] b) Enhanced methane uptake according to meta-analysis[20]	no to little effect
Reduction of fossil fuel use (only applicable to mechanized farming)	CO_2 reduction through fossil fuel savings	Fuel consumption decreased 70% (CTIC, 1997) in USA, 66% in Brazil,[59] and 36% in Paraguay[60]	high effect
Reduction of synthetic nitrogen fertilizer	a) CO_2 reduction due to less fertilizer production b) N_2O reduction due to less fertilizer production c) N_2O reduction from less fertilized cropland	a) - c) remain uncertain especially for smallholders[4] a) - c) are effective when legumes are part of crop rotation[4]	little effect

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