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Letter to the Editor

Why do we need to standardize no-tillage research?

ABSTRACT

No-tillage is looked upon by many as a way to enable sustainable cropping intensification to meet future agricultural demands. Although no-tillage suggests merely the absence of tillage, in reality several components need to be applied to a conservation agriculture system to guarantee equal or higher yields and better environmental performance than with conventional tillage systems. No-tillage/conservation agriculture systems research has now been performed for more than half a century in many countries around the world, primarily for economic reasons, but also to reduce labour and energy consumption and improve environmental outcomes. However, an integrated approach to understanding this system requires standardized research methodology based on site-specific conditions. We contend that broad understanding is lacking of what conservation agriculture systems research means. This has led to a situation of conflicting research results because different technologies, methodologies, and definitions of conservation agriculture systems have been applied. The term no-tillage has been used despite considerable soil movement in the previous crop, to inject fertilizer or to establish the current crop. Similarly, the term no-tillage has been used for systems with very little or no crop mulch cover, extended fallow periods, alternating tillage and no-tillage, or crops grown in monoculture. By not performing no-tillage research in a systems approach, many problems can be encountered such as reduced yields, high erosion, low infiltration, elevated fertilizer and high pesticide use. Materials and methods in an experiment are often not descriptive enough to unveil peculiarities. By analysing the function of components of conservation agriculture systems in monofactorial experiments, synergetic interactions among components can be overlooked. In this editorial, we discuss the need to thoroughly describe materials and methods to avoid confusing interpretations of results. We contend that standardization of research methodologies in no-tillage/conservation agriculture systems is needed based on a thorough description of the whole system so that results from different researchers and regions of the world can be logically compared.

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Introduction

Worldwide literature on yield and environmental performance of no-tillage systems is inconsistent and even contradictory. In many cases, inconsistencies can be explained by a lack of common standards in how experiments in tillage systems were performed. Sometimes mulch tillage, reduced tillage, minimum tillage or other methods involving various degrees of soil tillage disturbance are coined no-tillage. This lack of common understanding of what no-tillage systems are, plagues research scientists as well as practitioners. Similarly, lack of crop rotation, extended fallow periods, and insufficient mulch cover or periodic tillage, violate the concept of no-tillage systems, now properly termed conservation agriculture systems as a more holistic description. If systems are named "no-tillage", but performed with various intensities of soil disturbance, lack of crop rotation and/or mulch cover, and fallow periods, inconsistent and contradictory results can be expected because a legitimate conservation agriculture system is not included in the experimental assessment. Use of local jargon and inconsistent definitions of no tillage by different researchers can cause misunderstandings of the implications of no-tillage on crop production and environmental outcomes (Derpsch et al., 2011). For example, some researchers have found that no-tillage sequesters carbon in the soil (Rasmussen et al., 1980; Kern and Johnson, 1993; West and Post, 2002; Sá and Lal, 2009; González-Sánchez et al., 2012), while others contend no effect or contradictory results (Baker et al., 2007; Blanco-Canqui and Lal, 2008), leading to major confusion in the research community as to the true effect of tillage systems on a key environmental response. Reasons for differing results can be associated with low biomass-C input and not only due to absence of tillage (Franzluebbers, 2010), as well as due to differences in soil composition (texture and native organic matter content), unique site conditions (temperature and moisture), and sampling at different soil depths: top soil layers vs. lower soil horizons. All too often experimental protocols are not rigorous enough to unveil real differences in tillage systems (Karlen et al., 1994; Calegari et al., 2008; Christopher et al., 2009).

Researching conservation agriculture systems is not a simple task. Frequently, researchers change only one factor in experiments, such as tilling or not tilling the soil. Some researchers avoid changing several factors at the same time, because this can result in interactions and therefore in undesired confounding interpretations. But since conservation agriculture encompasses three key

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principles, it is not enough to change tillage alone. The three key principles of conservation agriculture systems are: (1) minimizing soil disturbance, consistent with sustainable production practices, (2) maximizing soil surface cover by managing crops, pastures, and crop residues, and (3) stimulating biological activity through crop rotations, cover crops, and integrated nutrient and pest management (FAO, 2013). In a no-tillage system, crop residue management plays an equally important role as minimizing and even avoiding soil disturbance. There is a close linkage between minimum soil disturbance and crop residue management that should not be overlooked. Weed, insect, and disease control programmes, as well as fertilization, may need to be changed and adapted to the new system. If components within the system are not optimized, then the system will likely not be effective and will not reflect what progressive farmers are practicing. As long as this deficiency remains, the scientific literature will continue to be filled with uninformative, inconsistent, controversial and confusing research results about this system. In short, no-till is a system different than conventional agriculture, not easily distinguished by factorial separation of components.

There is a need for science-based, quantitative data and accurate descriptions of methods used to describe no-tillage systems to minimize confusion in the literature. Standardization of definitions and research methodologies is necessary to improve interpretations from the diversity of experiments conducted around the world. Researchers reporting their results need to ensure that materials and methods clearly reveal how tillage and management variables were performed. Detailed site conditions of the experimental setting are also needed. Several important questions need to be answered in a research protocol when doing no-tillage research:

- What was the duration of plough-tillage following conversion of native vegetation to agricultural production?
- How was the previous crop harvested, i.e. normal combine or stripper header and information on residue amount and distribution?
- What was the soil type, texture, organic carbon content, pH, CEC and slope?
- What was the cropping history and amount and quality (legume versus grass) of soil cover before starting the experiment?
- What was the soil water content at seeding/planting, soil temperature, and bulk density?
- What kind of seeding equipment was used and what was the configuration of the planter, e.g. equipment manufacturer, model number, speed of planting, residue managers, tines versus disc openers, seed slot closing mechanism and types of press wheels?
- Were uniform seed spacing and depth placement achieved and was plant population the same in all treatments?
- What percentage of the soil surface was disturbed while seeding?
- What was the percentage of soil covered with residues after seeding?
- What was the type and amount of biomass produced and returned to the soil in each system per year, e.g. was residue C:N ratio, particle size, and orientation (vertical or flattened) considered?
- Was a systems approach used or was tillage the only factor changed?
- Was seeding time and depth and fertilizer regime kept equal across treatments or optimized for the respective treatments?
- Which products and/or tools were used for weed control?
- Did weed control include use of different herbicides in different tillage systems and was any mechanical soil engaging weed control performed?
- How efficient was weed control in each system?
- Was insect, disease, and weed control taken into account for each system separately or was the same programme used in all systems?
- Were fertilizer programmes and especially N the same in different systems during the first few years after transition?
- What crop rotation and/or cover crop system was used? Was the cover crop planted using no-till techniques?

Additional questions might arise if researchers, technical staff, and tractor drivers have enough training, or the necessary knowledge on how a conservation agriculture system needs to be implemented to become fully successful. Have steps towards a successful transition to conservation agriculture systems been followed? (Duiker and Myers, 2005; Derpsch, 2008). Have researchers applied the same level of technology the majority of no-till farmers have implemented to be successful with their system and have they adapted the technology to the specific site conditions? Depending on how these questions are answered, different research outcomes might be expected. To achieve a valid system comparison, a minimum assurance of relevance needs to be developed in a research protocol and this needs to be reflected in the materials and methods of research publications to make it clear how results were obtained. Coming to an internationally agreed upon definition of terms and technology applied will help in making results from different parts of the world understandable. All of this may seem obvious to many experienced research scientists, but in reality, all too often some basic elements have not been accounted for in the execution of the research. For example, it may be that lower yields obtained under no-tillage in some studies may not be system inherent, but a consequence of research methodology or a lack of understanding of how no-tillage performs optimally compared with more traditional tillage systems.

Description of the conservation agriculture system

Conservation agriculture systems according to the FAO definition use no tillage and have seeds placed at a proper depth in untilled soil with previous crop or cover crop residues retained on the surface (Derpsch et al., 2011). Special no-till seeding equipment with discs (low disturbance) or narrow tines/coulters (higher disturbance) open a narrow slot into mulch-covered soil. The aim should be to move as little soil as possible to preserve surface residues and to reduce potential weed seeds from reaching the soil surface to germinate. With no tillage, no other soil disturbance is needed. If >50% of the soil surface is disturbed, even only superficially, then the system cannot be termed no-tillage and must be defined as mulch tillage or some other form (Linke, 1998; Sturny et al., 2007; CTIC, 2011). A successful no-tillage system requires adequate weed control. Therefore, weed control in no-tillage is often performed with (a) consideration of appropriate crop rotations, (b) use of adapted, aggressive species of cover crops, (c) termination of a cover crop with a mechanical non-soil-engaging tool like the knife roller or mulcher, and/or (d) application of appropriate herbicides.

No-tillage management has been successfully implemented on >100 Mha of cropland worldwide (Derpsch et al., 2010) and on about 70% of arable cropland in Brazil, Argentina, Paraguay, Uruguay, Australia and New Zealand. Cropping systems with two crops a year like the rice-wheat production system in the Indo Gangetic Plains (~6 Mha), where soil is not tilled prior to wheat, but is ploughed every year for rice, cannot be considered a no-tillage or conservation agriculture system, and therefore, are not included in the worldwide estimates of no-till (Derpsch et al., 2010) or conservation agriculture (FAO, 2012).

Success of conservation agriculture systems is based on diversification through crop rotation and cover crops and on continuous, permanent application of no-tillage (Ségui et al., 2006; Sturny et al., 2007). The system mimics nature, in which soil loosening is performed by a diversity of plant roots and soil fauna and flora (Sá et al., 2013; Tivet et al., 2013). The fact that soil is not tilled and remains permanently covered with crop residues leads to reduced soil erosion, increased soil biological activity and soil carbon sequestration, better conservation of water, better nutrient use efficiency, increased nutrient availability from biological activity, improved energy efficiency (Sturny et al., 2007), and higher economic returns through time (Derpsch et al., 2010). Moreover, no-till is a key farming system approach that meets the requirements of a sustainable agricultural production system, even under extreme soil and climate conditions. For example, the water conservation benefit of no-till over traditional till during dry periods is generally recognized (Derpsch et al., 1991; Baumhardt and Jones, 2002; Lampurlanés et al., 2002; Reicosky, unpublished data).

Definition of no-till

Due to frequent misinterpretations it seems necessary to better define this technology (Derpsch et al., 2011). No-tillage is a conservation farming system, in which seeds are placed into otherwise untilled soil by opening a narrow slot, trench, or hole of only sufficient width and depth to obtain proper seed placement and coverage. No other soil tillage is done (adapted from Phillips and Young, 1973; Köller and Linke, 2001; Köller, 2003). Although direct seeding is sometimes used synonymously with no-tillage and it is increasingly being used to place seed directly into undisturbed soil, some direct seeding equipment especially in Europe causes extensive soil disturbance at seeding that buries or mixes crop residues with the soil. Such techniques should rather be characterized by the umbrella term of mulch tillage and should not be used synonymously with no-tillage.

Reasons for yield discrepancies with change in tillage

Observations from all regions of the world have shown that similar or higher yields can be obtained with no-tillage compared with conventional tillage systems[9] (Dick et al., 1997; Baumhardt and Jones, 2002; Halvorson et al., 2002; Franzluebbers, 2005; Defelice et al., 2006; Duiker et al., 2006; Sturny et al., 2007). When yield with no-tillage is lower than with conventional tillage, some of the following reasons may be responsible:

- Lack of assessment of the time period between the conversion of native vegetation and no-till adoption. For example, if the conversion period was ≥20 years, the time to recover may be longer and could have a strong impact on yield and soil attributes.
- Lack of knowledge or experience on how to manage crops with no-tillage techniques. Guidance can be obtained from "critical steps to successful no-till adoption" (Derpsch, 2008) or "steps towards successful transition to no-till" (Duiker and Myers, 2005). A learning curve of farmers and researchers can often be the reason for initial yield depression with no-tillage.
- Lack of a systems approach when eliminating tillage. It is not sufficient to only stop tilling with all else managed the same way as in conventional tillage systems (e.g. planters should be adjusted or put weight on for optimum performance in each system, weed control should be optimized in each system, and disease and pest control need system-level attention).
- No-tillage may have been performed with bare soil conditions or with insufficient soil cover with crop residues. Surface residue cover is a key feature of conservation agriculture systems. Research by CIMMYT has shown that removing residues can lead to reduced yields and lower economic returns with no-tillage (Wall, 1999; Sayre et al., 2006).
- Lack of experience of the machine operator at seeding (e.g. inadequate regulation of seeding equipment, seed furrow staying open after seeding, too deep or too shallow seed placement, soil smearing because of excessive moisture, etc.).
- Inadequate no-tillage machinery, leading to poor plant establishment. Inadequate furrow closing and seed placement can lead to poor stand (e.g. seeds are placed too shallow or too deep, or seed to soil contact is insufficient). Frequently, researchers lack funds to buy adequate no-till seeding machinery, which has sometimes led to the use of conventional tillage seeding machines in no-till experiments producing poor results.
- Poor weed control (e.g. inadequate selection of herbicides or weed suppression techniques, insufficient or excessive dose of herbicide causing weed escapes, crop injury, non-uniform coverage, etc). Frequently, researchers insist on using the same herbicide programme for all treatments (conventional, minimum and no-tillage), because tillage is the only variable they want to change. This may favour one system, but be detrimental to the other system.
- Poor disease and insect control (e.g. using calendar applications for all treatments, instead of using system-specific pest management methods). System-specific pest management approaches are needed, because no-tillage systems may favour or disfavour some diseases and pests differently in comparison with other tillage treatments (Derpsch et al., 1991).
- N fertilization may not have been adjusted during the first few years of applying no-tillage technology or a leguminous crop may not have been seeded previously to provide the additional N needed initially to account for immobilization of N in surface residues and soil organic matter (Sá, 1999; Sá et al., 2007; Ferreira et al., 2009).
- No-tillage may have been implemented on an extremely degraded and/or eroded soil with very low organic matter content, in which micro- and macro-biological activity and fertility limit initial success. In such degraded soils, an advantage may be conferred to conventional tillage initially, through continued mineralization of N with tillage disturbance until organic matter is depleted.
- Inadequate crop rotation diversity (e.g. optimized rotations for conventional tillage may not be the same as for no-tillage). Additionally, conservation agriculture systems may have different opportunities for cover crop planting, whereas conventional systems may be limited due to time and moisture lost with tillage.

Systems research continues to pose a challenge to researchers, and that is the main reason why no-tillage adoption all over the world has been farmer driven and not researcher driven. Farmers are in better position to implement new farming systems than most researchers and university professors. Statistical techniques and requirements by scientific journals support reductionist methods changing only one factor at a time to avoid confounding factors, yet this often makes results of limited value when systems need to be compared. A conscious decision by researchers needs to be taken as to whether the system is more important for evaluation or a simple change of practice. An additional issue is that large plots should be used for experiments comparing tillage systems, but space is often at a premium on research stations and compromises

[9] Under conventional tillage we understand that the tillage operation is generally performed with a moldboard plough (full inversion of soil) or with a disc plough (inversion and mixing of soil) followed by several passes of levelling harrow. Type of implement and depth of tillage need to be described.

are made to use small plots and/or few replications. Further, technicians often need to regulate seeding equipment on the actual research plot, but improper regulation may occur prior to completion of seeding. As a result, problems could arise in terms of depth of seeding or leaving an open furrow that exposes seeds to bird, rat and/or slug damage, etc. Such problems can be avoided by establishing additional plots with the same tillage treatments and crops as in the actual experiment, which are exclusively used to adequately set up and adjust the equipment.

Researchers have seldom acknowledged their mistakes in scientific manuscripts. As an exception, Kahnt (1976) reported that his early no-till research (1965–1968) led to lower yields compared to conventional plough tillage, because conditions for successful application were lacking. He listed ten conditions for success in no-tillage systems, of which only two or three were met in the early days of his research. He pointed out that not fulfilling one of the following conditions could lead to yield depression:

1. Sufficient horsepower of the tractor
2. Strong hydraulic system (for operating 3-point-linked equipment)
3. Appropriate seeding equipment
4. Accounting for the possibility of greater N fertilizer application needed with no-tillage
5. Availability of appropriate herbicides
6. Appropriate crop types
7. Adapted varieties
8. Appropriate crops preceding no-tillage establishment
9. More adapted crop rotations for no-tillage
10. Familiarity with the technique and experience of persons involved in the research.

The human management factor is very important when it comes to putting no-tillage technology into practice, a factor usually ignored. Generally, higher management skills are required with no till systems. If people involved in the research or in practical farming are not mentally prepared to accept, or do not believe in the system, then it will most likely fail (Bieber, 2000). Often, performance of no-till seeding equipment is highlighted as a reason for success or failure of no-tillage, but the performance of people operating machinery is equally or more important. Therefore, yield differences obtained from various tillage system comparisons may have little to do with the treatments applied, but rather the people involved in executing the research, i.e. technicians, managers, and/or tractor drivers.

"Each farmer, tractor driver and/or extension educator first must get acquainted with innovations and gain experience with them before he can truly understand and accept new agricultural practices. Once he understands and accepts the new practices, he can then apply them and recommend them to other farmers. Getting accustomed to the sight of a no-tilled field after planting is difficult, because our experience and education bias us towards expecting a 'clean tilled field' as under conventional tillage. The different goals of tillage operations with their advantages and disadvantages for the soil, plants and economic performance, have often not been sufficiently discussed or critically evaluated" (Kahnt, 1976).

Vital importance of crop residue cover in a no-till system

No-tillage without soil cover results in poor crop performance and yield (Ashburner, 1984). In a low-rainfall area of Bolivia, highest yield was obtained from no-tillage and crop residue retention, intermediate yield from different tillage systems with conventional to minimum tillage, and lowest yield from no-tillage and no residues (Wall, 1999). Similar results were obtained by Sayre et al. (2006) under rainfed conditions in the highlands of Central Mexico. Yield and economic return of wheat and maize were drastically reduced when residues were removed from the no-till system. Sayre et al. (2006) concluded that "no-tillage without crop residues on the soil surface leads to disaster".

Soil cover is therefore of vital importance in a conservation agriculture system. Many of the benefits and advantages of a no-tillage system come from permanent cover of soil but there are also some equally important key effects resulting from not tilling the soil (Ségui et al., 2006; Derpsch, 2007). In other words, it is not alone the absence of tillage, but the presence of crop residues on the soil surface that results in better performance of no-tillage compared with conventional tillage. Surface crop residues serve as a primary form of organic matter input to concentrate soil biological activity, conserve moisture and moderate soil temperature extremes. Failure to pay attention to soil cover has resulted in poor performance of no-tillage systems (e.g. lower yields, runoff, erosion, low biological activity, etc.).

Crop residue cover is needed to increase water infiltration into soil and reduce runoff and erosion (Roth, 1985; Govaerts et al., 2007). Very high erosion rates have been recorded in no-till without residue (Gomez et al., 2003). Limited crop residue cover also leads to high water evaporation, reducing production and water use efficiency.

Importance of diversification of crops with crop rotation and cover crops

Green-manure cover crops and crop rotation play an important role in achieving adequate soil cover and diversity in a no-till system. Development of successful cover cropping in no-till systems has been a major factor in the unprecedented growth of this technology in South America (Derpsch and Benites, 2003).

In drier climates, farmers are often concerned that green manure cover crops remove too much moisture from soil, leaving too little available for cash crops. This is and should always be a concern. Using crop species that use less moisture and timely management of cover crops are needed. For example in Argentina and in France, respectively, more intensified cropping and use of cover crops increased water use efficiency compared with clean fallow (Gil et al., 2010; Frederic Thomas, personal communication). This has also been observed by farmers in the United States and elsewhere, in which shading of soil by cover crops resulted in lower soil temperature and water evaporation. In different regions of the United States, farmers have found opportunities to include cover crops profitably in dryland farming systems by integrating crop and livestock production (Franzluebbers and Stuedemann, 2007; Franzluebbers, 2011). Highly variable precipitation is conducive for selective grazing of cover crops in high-precipitation years, while maintaining sufficient crop residue for system function.

According to the Sustainable Agriculture Network (SARE/SAN, 1998) in the United States, "cover crops slow erosion, improve soil, smother weeds, enhance nutrient and moisture availability, help control many pests and bring a host of other benefits to your farm".

Framing a protocol for no-tillage research

Several issues should be accounted for to avoid systematic errors leading to skewed results and reduced yields when conducting no-till research. A science-based research protocol is needed and the most important points should be highlighted in the materials and methods section of scientific papers when describing the experiment. We suggest the following:

(1) *System description*: The system-level strategy should be described and changes made according to that system. Changing only tillage will result in an artificial system and not reflect the conditions of practical farming.
(2) *Cropping and tillage history*: Description is needed of the crops and type of tillage preceding the experiment. Fallow periods before starting the experiment need to be recorded. Duration of the no-till system prior to the experiment must be described.
(3) *Soil condition before the experiment*: Details are needed of soil type, texture, organic carbon content, pH, CEC, percent soil cover, amount and quality of crop residues, and whether residues were evenly distributed on the soil surface. Soil structural condition (e.g. stability of surface aggregates, drainage status, and presence or absence of hardpans) needs to be reported.
(4) *Soil fertility*: Report if, when, and how soil pH and nutrient deficiencies were corrected prior to the experiment. Soil fertility needs to be monitored during the duration of the experiment. When necessary, lime should be applied frequently in small amounts (e.g. infrequent and large applications can lead to wide swings in surface pH and 'acid roof' formation, which can lead to poor surface root proliferation and nutrient uptake and poor weed control besides other problems).
(5) *Weed control*: Adequate and system-specific techniques need to be employed. Ground cover should be weed free at seeding (i.e. previous vegetation needs to be controlled). Herbicide name, formulation, and date and amount of product applied need to be recorded. Weeds need to be monitored throughout the experiment.
(6) *Planting/seeding equipment details*: Provide manufacturer, model number, planting speed, and configuration used for each system treatment. Special attention should be given to soil opening tools (tines, discs) and furrow-closing devices. Researchers should not be reluctant to mention brand names and models in materials and methods since this information is very important when interpreting no-tillage experiments. Equipment needs to achieve uniform seed depth and guarantee good seed-to-soil contact. Hair-pinning of crop residue, open slots after seeding, compaction of soil on top of the seed, etc., should be avoided, but these issues need to be recorded and mentioned in materials and methods when they happen. Approximately the same number of plants/ha need to be achieved in each system compared. Plant counts/m^2 should be performed a few weeks after seeding and at least once again at harvest. This does not apply if system specific varieties are used.
(7) *Soil moisture at seeding*: Describe and monitor soil moisture conditions, as excessive moisture can lead to hair-pinning and poor seed to soil contact in a no-till system, which could lead to poor germination. Adequate moisture content for seeding should be achieved in all treatments. This is an especially tricky point in tillage research, because soil moisture varies between tillage systems and conditions for optimal seeding may be different for different tillage systems. Rains on Thursdays can be a horror for tillage researchers in warmer climates! On Friday the soil may be still too wet to seed and on Monday may already be too dry, as often it is difficult to organize seeding on weekends.
(8) *Soil disturbance*: During seeding, level of disturbance (depth and soil volume) even in no-tillage needs to be recorded, especially the row spacing and width of the seeding slot. No-tillage with high-disturbance tines can yield quite different results in terms of soil CO_2 emissions and water losses compared to low-disturbance no-till seeding with discs (Reicosky, unpublished data).
(9) *Plant biomass produced*: Seasonal and yearly measurements are needed (t/ha dry matter), especially if studying soil carbon sequestration or if organic matter is an important research objective. These measurements are especially important in long-term no-tillage experiments.
(10) *Insect and disease control*: Control measures should account for system requirements and avoid routine calendar applications for all treatments. Continuous monitoring of insect and disease development is necessary. If calendar applications are used, this needs to be recorded.
(11) *Nitrogen requirements*: During the first three to five years, no-tillage may require greater N fertilizer inputs than conventional tillage systems (10–30 kg N/ha greater for cereal crops). Equal N application rates may lead to yield reductions in no-tillage during initial years of the experiment (Sá, 1999; Sá et al., 2007; Ferreira et al., 2009). Sufficient N has to be applied in the right way to avoid volatilization losses and also to avoid excessive soil disturbance when applying it. If additional N is not applied in no-tillage this has to be specifically mentioned. If a leguminous cover crop is used, an estimate of the N available to the economic crop should be included.
(12) *Crop rotation*: Using inadequate crop sequences is detrimental to no-tillage systems, and monoculture is inconsistent with conservation agriculture. No-till after legumes, and especially perennial legumes, can be a good way to start no-till without expecting a reduction in yield. Varieties need to be mentioned as they may respond differently to different tillage treatments.

All of the above suggests that the best way of conducting robust tillage comparison studies is to engage a multi-disciplinary team in the project, including experienced agronomists and practitioners with sound agronomic know-how.

Conclusions

Depending on how no-tillage research is conducted, different results can be obtained in terms of soil carbon sequestration, soil moisture retention, seed germination/plant establishment, weed infestation, soil fertility, soil biological activity, and crop yields. We assert that it is imperative to profoundly understand and master the no-till or conservation agriculture system before implementing it or attempting to research the system. Until the scientific community agrees on an internationally recognized definition of no-tillage techniques, inconsistent and contradictory research results will continue to fill the literature regarding tillage system comparisons. Standardized research approaches are necessary to be able to compare results from different researchers, different regions, and different systems to avoid confusion and misinterpretation. Even after introducing standard definitions and descriptions of no-till techniques, contradictory results may be reported – but could probably be understood and explained, if more and precise information on site and management conditions would be delivered.

We contend that elaborating experimental protocols and detailing how tillage/no-tillage research was conducted in materials and methods of scientific publications will rectify some discrepancies in the literature and lead to better system-level development of no-tillage, which is a system adopted successfully by many thousands of farmers all over the world. To achieve comparable results in conservation agriculture system research, a minimum record of practices, equipment details, and crop observations need to be described in a research protocol and reflected in scientific publications to make it clear how the results were obtained. An absolute minimum list of considerations should be:

(1) Site conditions with soil composition, soil type, and climatic conditions.
(2) Percentage of soil surface covered with residues (amount and quality) after seeding.
(3) Percentage of soil surface that has been disturbed while seeding.
(4) Crop sequences and/or rotations that have been used.
(5) Weed control methods, degree of soil disturbance, herbicides and rates that have been used.
(6) Brand name and model of no-tillage seeding equipment used and planting speed.
(7) Configuration of furrow opener and closing devices of seeder.
(8) Nitrogen application rates that may be different in the initial phase of system development.

No-tillage research conducted without considering these issues may yield results that may have nothing to do with a legitimate conservation agriculture system, but rather reflect peculiarities of a compromised management approach or assessment. System-level evaluation of no-tillage requires that complete systems be compared, not just a change in tillage in the absence of other important components of the system. Previous no-till research needs to be considered in light of these issues to understand the value of the experiments reported.

The unfortunate, but common practice of using laconic, non-descriptive statements in the materials and methods section of publications (e.g. "the experiment included three tillage treatments, conventional, minimum and no-tillage") or not describing in detail how the experiment and no-tillage system were carried out needs to come to an end and energetically rejected. It is not enough to define no-tillage just briefly like it is often seen in literature "the soil was left undisturbed from harvest to planting". Instead, a description is needed of the entire no-tillage system or strategy. In the same manner, conventional or alternative management systems need to be fully described.

References

Ashburner, J.E., 1984. Dryland tillage practices and studies in Algeria. In: FAO Panel of Experts on Agricultural Mechanisation, 6th Session, October, Adana, Turkey, p. 22.
Baker, J.M., Ochsner, T.E., Venterea, R.T., Griffis, T.J., 2007. Tillage and soil carbon sequestration – what do we really know? Agric. Ecosyst. Environ. 118, 1–5.
Baumhardt, R.L., Jones, O.R., 2002. Residue management and tillage effects on soil-water storage and grain yield of dryland wheat and sorghum for a clay loam in Texas. Soil Tillage Res. 68, 71–82.
Bieber, R., 2000. Greater profits with rotation systems: South Dakota farmer makes conservation pay. CTIC Partners 18 (October, (5)) 4–5.
Blanco-Canqui, H., Lal, R., 2008. No-tillage and soil-profile carbon sequestration: an on-farm assessment. Soil Sci. Soc. Am. J. 72, 693–701.
Calegari, A., Hargrove, W.L., Rheinheimer, D.S., Ralish, R., Tessier, D., Tourdonnet, S., Guimaraes, M.F., 2008. Impact of long-term no-tillage and cropping system management on soil organic carbon in an Oxisol. A model for sustainability. Agron. J. 100, 1013–1019.
Christopher, S.F., Lal, R., Mishra, U., 2009. Regional study of no-till effects on carbon sequestration in the Midwestern United States. Soil. Sci. Soc. Am. J. 73, 207–216.
CTIC (Conservation Technology Information Center), 2011. CTIC homepage: http://www.ctic.purdue.edu/media/pdf/TillageDefinitions.pdf. (accessed May 2011).
Defelice, M.S., Carter, P.R., Mitchell, S.B., 2006. Influence of tillage on corn and soybean yield in the United States and Canada. Crop Manage., doi:10.1094/CM-2006-0626-01-RS.
Derpsch, R., 2007. How to get no-tillage to the next level. In: Proc. No-Till on the Plains Winter Conference, AIM Symposium, 1 February 2007, Salina, Kansas.
Derpsch, R., 2008. Critical steps to no-till adoption. In: Goddard, T., Zoebisch, M.A., Gan, Y., Ellis, W., Watson, A., Sombatpanit, S. (Eds.), No-till Farming Systems. World Assoc. Soil Water Conserv., pp. 479–495.
Derpsch, R., Benites, J.R., 2003. Situation of conservation agriculture in the world. In: Proc. II World Congr. Conserv. Agric., 11–15 August 2003, Iguassu Falls, Brazil, pp. 66–70.
Derpsch, R., Roth, C.H., Sidiras, N., Köpke, U., 1991. Controle da erosão no Paraná, Brasil: Sistemas de cobertura do solo, plantio direto e preparo conservacionista do solo. SP der GTZ N(245), Eschborn, Germany, pp. 272.
Derpsch, R., Friedrich, T., Kassam, A., Li, H.W., 2010. Current status of adoption of no-till farming in the world and some of its main benefits. Int. J. Agric. Biol. Eng. 3, 1–25.
Derpsch, R., Friedrich, T., Landers, J.N., Rainbow, R., Reicosky, D.C., Sá, J.C.M., Sturny, W.G., Wall, P., Ward, R.C., Weiss, K., 2011. About the necessity of adequately defining no-tillage – a discussion paper. In: Proc. 5th World Congr. Conserv. Agric., 26–29 September 2011, Brisbane, Australia.
Dick, W.A., Edwards, W.M., McCoy, E.L., 1997. Continuous application of no-tillage to Ohio soils: changes in crop yields and organic matter related soil properties. In: Paul, E.A., Paustian, K., Elliott, E.T., Cole, C.V. (Eds.), Soil Organic Matter in Temperate Agroecosystems. CRC Press, Boca Raton, FL, pp. 171–182.
Duiker, S., Myers, J.C., 2005. Steps Towards a Successful Transition to No-till. Coll. Agric. Sci., Agric. Res Coop. Ext., Penn State Univ., , pp. 36.
Duiker, S.W., Haldeman Jr., J.F., Johnson, D.H., 2006. Tillage × hybrid interactions. Agron. J. 98, 436–442.
FAO (Food and Agriculture Organization), 2012. CA Adoption Worldwide; FAO AQUASTAT Database on CA Adoption., In: http://www.fao.org/ag/ca/6c.html (accessed June 2012).
FAO, 2013. Basic Principles of Conservation Agriculture., In: http://www.fao.org/ag/ca/1a.html (accessed January 2013).
Ferreira, A.O., Sá, J.C.M., Briedis, C., Figueiredo, A.G., 2009. Desempenho de genótipos de milho cultivados com diferentes quantidades de palha de aveia-preta e doses de nitrogênio. Pesq. Agropec. Bras. 44, 73–179.
Franzluebbers, A.J., 2005. Soil organic carbon sequestration and agricultural greenhouse gas emissions in the southeastern USA. Soil Tillage Res. 83, 120–147.
Franzluebbers, A.J., 2010. Achieving soil organic carbon sequestration with conservation agricultural systems in the southeastern United States. Soil Sci. Soc. Am. J. 74, 347–357.
Franzluebbers, A.J., 2011. Four farms in the USA: case studies of northeastern, southeastern, Great Plains and Midwestern farms. In: Tow, P. (Ed.), Rainfed Farming Systems. Springer Verlag, Heidelberg, pp. 1157–1184.
Franzluebbers, A.J., Stuedemann, J.A., 2007. Crop and cattle responses to tillage systems for integrated crop-livestock production in the Southern Piedmont, USA. Renewable Agric. Food Syst. 22, 168–180.
Gil, R.C., Peralta, G., Coronel, J., Salomón, C., Vidal, G., 2010. Eficiencia de uso del agua en ambientes semiáridos y sub-húmedos del Nordeste Argentino: un análisis comparativo de líneas de desarrollo en ambientes de Chaco, Formosa y Corrientes. In: Proceedings on CD, XVIII Congreso AAPRESID: El Cuarto Elemento. 11–13 August 2010, Rosario, Argentina, p. 9.
Gomez, J.A., Battany, M., Renschler, C.S., Fereres, E., 2003. Evaluating the impact of soil management on soil loss in olive orchards. Soil Use Manage. 19, 127–134.
González-Sánchez, E.J., Ordóñez-Fernández, R., Carbonell-Bojollo, R., Veroz-González, O., Gil-Ribes, J.A., 2012. Meta-analysis on atmospheric carbon capture in Spain through the use of conservation agriculture. Soil Tillage Res. 122, 52–60.
Govaerts, B., Fuentes, M., Mezzalama, M., Nicol, J.M., Deckers, J., Etchevers, J.D., Figueroa-Sandoval, B., Sayre, K.D., 2007. Infiltration, soil moisture, root rot and nematode populations after 12 years of different tillage residue and crop rotation managements. Soil Tillage Res. 94, 209–219.
Halvorson, A.D., Wienhold, B.J., Black, A.L., 2002. Tillage, nitrogen, and cropping system effects on soil carbon sequestration. Soil Sci. Soc. Am. J. 66, 906–912.
Kahnt, G., 1976. Ackerbau ohne Pflug. Voraussetzungen.In: Verfahren und Grenzen der Direktsaat im Körnerfruchtbau, Ulmer, Stuttgart, pp. 39–40.
Karlen, D.L., Wollenhaupt, N.C., Erbach, D.C., Berry, E.C., Swan, J.B., Eash, N.S., Jordahl, J.L., 1994. Long-term tillage effects on soil quality. Soil Tillage Res. 32, 313–327.
Kern, J.S., Johnson, M.G., 1993. Conservation tillage impacts on national soil and atmospheric carbon levels. Soil Sci. Soc. Am. J. 57, 200–210.
Köller, K., 2003. Techniques of soil tillage. In: Soil Tillage in Agroecosystems. CRC Press, Boca Raton, FL, pp. 1–25.
Köller, K., Linke, C., 2001. Erfolgreicher Ackerbau ohne Pflug, 2. Aufl. DLG Verlag, Frankfurt a. M., pp. 176.
Lampurlanés, J., Angás, P., Cantero-Martínez, C., 2002. Tillage effects on water storage during fallow and on barley root growth and yield in two contrasting soils of the semi-arid Segarra region in Spain. Soil Tillage Res. 65, 207–220.
Linke, C., 1998. Direktsaat–eine Bestandsaufnahme unter besonderer Berücksichtigung technischer, agronomischer und ökonomischer Aspekte. Univ. Hohenheim Diss., , pp. 482.
Phillips, S., Young, H., 1973. No-tillage Farming. Reiman Associates, Milwaukee, WI, pp. 224.
Rasmussen, P.E., Allmaras, R.R., Rohde, C.R., Roager, N.C., 1980. Crop residue influences on soil carbon and nitrogen in a wheat-fallow system. Soil Sci. Soc. Am. J. 44, 596–600.
Roth, C.H., 1985. Infiltrabilität von Latossolo-Roxo-Böden in Nordparaná, Brasilien. In Feldversuchen zur Erosionskontrolle mit verschiedenen Bodenbearbeitungssystemen und Rotationen. Göttinger Bodenkundliche Ber. 83, 1–104.
Sá, J.C.M., 1999. Manejo da fertilidade do solo no sistema plantio direto. In: Siqueira, J.O., Moreira, F.M.S., Lopes, A.S., Guilherme, L.R.G., Faquin, V., Furtini Neto, A.E., Carvalho, J.G. (Eds.), Soil Fertility, Soil Biology, and Plant Nutrition Interrelationships. Soc. Bras. Ci. Solo. UFLA, Lavras, MG, Brazil., pp. 267–320.
Sá, J.C.M., Lal, R., 2009. Stratification ratio of soil organic matter pools as an indicator of carbon sequestration in a tillage chronosequence on a Brazilian Oxisol. Soil Tillage Res. 103, 46–56.
Sá, J.C.M., Cardoso, E.G., Santos, J.B., Ferreira, A.O., Ferreira, C.F., Massinham, A., Junior, D.S., Sá, M.F.M., 2007. Manejo de fertilizantes nitrogenados em sistemas de produção envolvendo os cultivos de soja/trigo e soja/milho no sistema de plantio direto. In: Anais do Simpósio sobre Nitrogênio e Enxofre na Agricultura Brasileira/edição de Tsuioshi Yamada, Silvia Regina Stipp e Abdalla e Godofredo Cesar Vitti., Piracicaba. IPNI, Brasil, pp. 722.

Sá, J.C.M., Séguy, L., Tivet, F., Lal, R., Bouzinac, S., Borszowskei, P.R., Briedis, C., dos Santos, J.B., Hartman, D.C., Bertoloni, C.G., Rosa, J., Friedrich, T., 2013. Carbon depletion by ploughing and its restoration by no-till cropping systems in Oxisols of sub-tropical and tropical agro-ecoregions in Brazil. Land Degrad. Dev., http://dx.doi.org/10.1002/ldr.2218 (in press).
SARE/SAN (Sustainable Agriculture Research and Extension/Sustainable Agriculture Network), 1998. Managing Cover Crops Profitably. Handbook Series 3. , In: http://www.sare.org 212 p9.
Sayre, K., Govaerts, B., Martinez, A., Mezzalama, M., Martinez, M., 2006. Comparison of alternative conservation agriculture technologies for rainfed production in the highlands of Central Mexico, 28 August–3 September 2006. In: Proc. 17th ISTRO Conf., Kiel, Germany, pp. 1012–1018.
Ségui, L., Bouzinac, S., Husson, O., 2006. Direct-seeded tropical soil systems with permanent soil cover: Learning from Brazilian experience. In: Uphoff, N., Ball, A.S., Fernandes, E. (Eds.), Biological Approaches to Sustainable Soil Systems. CRC Press, Taylor and Francis, Boca Raton, FL, pp. 323–342.
Sturny, W.G., Chervet, A., Maurer-Troxler, C., Ramseier, L., Müller, M., Schafflützel, R., Richner, W., Streit, B., Weisskopf, P., Zihlmann, U., 2007. Direktsaat und Pflug im Systemvergleich–eine Synthese. AGRARForschung (now Agrarforschung Schweiz) 14, 350–357.
Tivet, F., Sá, J.C.M., Lal, R., Briedis, C., Borszowskei, P.R., Santos, J.B., Farias, A., Eurich, G., Hartman, D.C., Nadolny, M.J., Bouzinac, S., Séguy, L., 2013. Aggregate C depletion by plowing and its restoration by diverse biomass-C inputs under no-till in sub-tropical and tropical regions of Brazil. Soil Tillage Res. 126, 203–218.
Wall, P., 1999. Experiences with crop residue cover and direct seeding in the Bolivian highlands. Mountain Res. Dev. 19, 313–317.
West, T.O., Post, W.M., 2002. Soil organic carbon sequestration rates by tillage and crop rotation: a global data analysis. Soil Sci. Soc. Am. J. 66, 1930–1946.

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