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Review

# Flaws and criteria for design and evaluation of comparative organic and conventional cropping systems

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ABSTRACT

In this review, comparisons between organic and conventional cropping systems are discussed. Publications from four topics, crop yields, carbon sequestration, biological diversity and nitrogen leaching were selected as examples to point out pitfalls and shortcomings in comparative analysis that can weaken or even disqualify evaluations. Inconsistent results between different comparative studies were found to be pseudo-contradictions. As the experimental design of comparative organic and conventional cropping systems often is biased in some aspects, suitable denominators for comparative assessment are discussed (ratios per area, per product and per land demand for the same amount of product). Conditions for equitable evaluations are outlined in order to avoid biased design, inappropriate interpretations and flawed conclusions. We stress that respecting at least three stringency criteria will help to ensure the scientific quality of data interpretation of comparative studies: similar soil fertility status at start, comparable type of crop production, and quantification of off-farm organic and nutrient input.

## Contents

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## 1. Introduction

Organic agriculture is one of the methods frequently proposed for reducing the impact of agriculture on the environment (Seufert et al., 2012). Whereas rules exist for reasonably classifying production systems as 'organic' (IFOAM, 2005), corresponding standards are missing for other methods such as integrated farming, conservation agriculture, ecological intensified agriculture and others, all of which are classified as 'conventional'. Although exclusion of mineral fertilizers, synthetic pesticides and GMO is the principal difference between organic and conventional farming, organic and conventional cropping systems can differ far more—in terms of crop rotation, nutrient supply from manure or other organic amendments, weed control, soil management and crop protection. These differences can determine results of comparative studies to a large extent. Consequently, evaluations of comparative organic and conventional systems require that major differences in addition to mineral fertilizers and synthetic pesticides are also considered in the analysis. Only field experiments where each intervention is considered as a separate factor in the interpretation and rigorous boundary condition are observed can be correctly evaluated. In other words, all major system differences—temporal and spatial scales as well as indirect effects should be considered in a holistic analysis of results. A system that is sustainable at an experimental scale may not be so at a larger scale.

In previous articles, conflicting conclusions and difficulties evaluating comparative studies were pointed out (e.g. Kirchmann and Bergström, 2001; Kirchmann et al., 2008; Kätterer et al., 2012). In this paper, a more complete approach to address failures when evaluating comparative cropping systems is described and discussed. We argue that contradicting results are mainly due to inconsistencies in scale and boundary conditions. A common problem in the literature is that measurements made on individual crops are erroneously extended to discussion of productivity of entire farms or agricultural systems (e.g. Badgley et al., 2007; Seufert et al., 2012). Crop yields represent the field scale and comparative yields of crops grown with organic manures or mineral fertilizer do not represent cropping system productivity. Productivity of systems is defined as the ration of outputs to inputs used (Connor, 2013). Thus, upscaling organic yields to productivity of organic systems must include, for example, import of organic fertilizers and composts from other systems including conventional agriculture, extra land required for green manure crops, impact of frequent biological N-fixing crops on total yields over a crop rotation, differences in water use etc.

When attention is given to all the essential differences between systems affecting yields, conflicting results often become explainable and a better understanding of differences between farming systems can be gained.

The aim of this paper was to use published papers to (i) illustrate how differences in the design and scale can lead to incorrect conclusions; (ii) point out common pitfalls to be avoided, and (iii) define appropriate standards that are necessary to make scientific comparison of organic and conventional agricultural systems valuable. We hope that this paper can help readers to identify weaknesses of published and planned papers and improve the scientific understanding of comparative studies being free from ideological bias, political correctness, preconceived environmental opinions or confusing incentives.

## 2. Critical review of comparative organic and conventional studies—definition of stringent boundary conditions

Publications within four topics—crop yields, carbon sequestration, biological diversity and nitrogen leaching—were used to demonstrate frequent limitations in scientific evaluations of comparative studies. We focus on organic *vs* conventional farming systems but many of the concepts and the rationale developed here also applies to other system comparisons.

### 2.1. How large are yield gaps between organic and conventional crop production?

The central task of agriculture is to produce sufficient food with a minimum negative environmental impact. In a previous review on organic crop yields, Kirchmann et al. (2008) found organic crop yields being 25 to 50% lower than conventional ones and main factors limiting organic yields were lower nutrient availability, poorer weed control and limited possibilities to improve the nutrient status of soils. Opposite opinions exist whether organic farming can sufficiently feed the world (e.g. Badgley and Perfecto, 2007) or not (e.g. Cassman, 2007; Connor, 2008; Goulding et al., 2009). Thorough and detailed analyses of organic and conventional yields are necessary to be able to foresee whether organic methods can be a realistic option to provide sufficient food in the future (e.g. UN Millenium Project, 2005; FAO, 2012). According to official crop production records from Statistics Sweden (SCB, 2014), organic yields are generally lower for most crops grown in Sweden. Meta-analyses of yield differences between organic and conventional agriculture (e.g. Badgley et al., 2007; De Ponti et al., 2012; Ponisio et al., 2014) show that organic crops can match conventional yields in some studies, whereas in others it cannot. However, in these reviews, no or insufficient information is provided about reasons for why yield gaps can be small or large. In other words, yield determining factors such as number of legumes in rotation, rates of nutrient supplied, amount of manure transferred from conventional agriculture, soil fertility status, etc. are so far seldom taken into account in the evaluation. Meta-analysis is only meaningful when properly used. Philibert et al. (2012) showed that there is clearly a need to improve systematic reviews in agronomy; none of the 73 meta-analyses they reviewed satisfied all the recommended quality criteria. Selecting only years with highest organic yields for a comparison with conventional yields is not scientifically sound (Badgley et al., 2007). A review by Seufert et al. (2012) showed that gaps between organic and conventional crop yields widened from 20 to 34% when organic studies applying manure originating from conventional systems were excluded. Overlooking nutrient input to organic systems originating from conventional agriculture will cause biased results and yield data from organic systems receiving high rates of manure or other organic materials from conventional systems should be excluded from comparisons. Thus, factors limiting organic yields and reasons for high or low yield gaps between organic and conventional crops need to be better understood.

### 2.2. *Specific flaws*

#### 2.2.1. *Organic yields can depend on farming history and soil fertility status prior to organic farming*

Stopes et al. (2002) pointed out that comparisons of farming systems can be affected by management history and initial soil fertility status. The Norwegian study at Apelsvoll is an example of how a high initial soil fertility status greatly influenced organic yields and despite a much lower N input no or few significant differences to conventional yields were measured during initial years after the start of the experiments (Eltun, 1996). The reason was that the trial was established on soil previously being natural grassland having a high soil organic matter content resulting in high N mineralization and sustained high yields for a couple of years (Riley and Eltun, 1994). In contrast, a nutrient-depleted soil reduced organic compared to conventional yields with as much as 50% in a Swedish study run for 18 years (Kirchmann et al., 2007). In summary, soil fertility status must not be ignored in comparative trials.

#### 2.2.2. *Comparing systems with too diverse crop rotations is scientifically meaningless*

Through the definition of organic farming practices, i.e., the exclusion of synthetic inorganic fertilizers and synthetic pesticides, it seems inevitable that the design of organic farming systems will differ from conventional systems. There is a necessity of having legume-based crop rotations in organic farming whereas conventional systems need not rely on legumes for its N supply. Thus, even in strictly scientifically designed experiments, it is seldom possible to have identical crop rotations in organic and conventional systems. When different crops are grown in rotations, for example more perennials *vs* annuals, e.g. leak followed by 2-years ley *vs* potato followed by carrot and sugar beet (Vereijken, 1990) or 2-years ley *vs* no ley in rotation (Eltun et al., 2002), yield evaluations are misleading.

#### 2.2.3. *Organic yields relying on off-farm nutrient input from conventional agriculture are not representative*

One main reason for high organic yields, especially in studies from the USA, is access to off-farm organic manures. As amounts of manure available on organic farms are usually not sufficient to produce high yields, use of off-farm manures to organic systems is common (e.g. Denison et al., 2004; Drinkwater et al., 1998; Poudel et al., 2002). Through such off-farm nutrient sources it was achievable to obtain organic yields similar to those in conventional production. However, the dependence of yield performance in organic systems on input of nutrients from conventional systems is not a true measure of their productivity and transfer of all sources of nutrients from conventional to organic production should not be ignored. In a recent study of 63 organic farms in France, it was shown that nutrient inflow from conventional farming accounted for 23, 73 and 53% of nitrogen, phosphorus and potassium, respectively, over a two-year period (Nowak et al., 2013). Yields from organic studies using input of nutrients originating from conventional production are simply not relevant for comparisons with conventional yields. Lower yields are expected to be produced through organic practices even in the future, especially if import of nutrient sources from conventional agriculture will be limited as presently discussed by the European Commission (EU, 2014).

#### 2.2.4. *Missing yields due to crop failure or during years the soil is green manured or fallowed reduce total crop production over a rotation*

As mentioned above, yields of single crops do not represent the productivity of organic systems. Organic systems can include green manure crops or fallowed soil, i.e., years when no harvestable crop is obtained. For example, when comparing single crop yields from a six-year rotation, indicate organic yields are 35% lower than that of conventional crops (Ivarson et al., 2001). However, as one out of six years is a non-harvested green-manure crop in the organic rotation, including this year without any food production further reduces the mean organic yield by 17% and the actual, sizeable yield gap increases to 51.7%. Thus, to reveal true performance of cropping systems to feed the world, data on productivity over a whole rotation need to be evaluated.

In summary, yield comparisons between farming systems require consideration of the following:

- Site-specific differences in soil physical properties and the initial soil fertility status;
- Comparable crops in rotation;
- Input of off-farm nutrients from conventional to organic agriculture; and
- Accounting years without harvest in a crop rotation.

#### 2.2.5. *Does organic crop production sequester more carbon in soil?*

Organic crop production has been considered as one promising C sequestration measure and its potential effect has been estimated to be 3.8 Tg C $\text{yr}^{-1}$ in the EU-15 (Freibauer et al., 2004). However, what is the scientific evidence for this?

Annual C input to soil is the most important factor responsible for the buildup and sequestration of soil organic C (Kätterer et al., 2012). Thus, agricultural practices that result in higher net primary productivity (NPP) and yields implies that more C is added to soil through above- and below-ground (roots and rhizodeposits) crop residues (Bolinder et al., 2007). Since crop yields are lower in organic systems, the primary input of C through crop residues to soil is lower than in conventional cropping systems and the potential to sequester C as soil organic matter is consequently lower.

Still, comparisons of C contents of soils from organically managed or conventional fields show contradictory results. Soil organic matter concentrations have been reported to be higher (Reganold, 1988; Wander et al., 1994; Liebig and Doran, 1999; Droogers and Bouma, 1996; Marriott and Wander, 2006), lower (Lützow and Ottow, 1994; Petersen et al., 1997) or not to differ (Derrick and Dumaresq, 1999; Burkitt et al., 2007) in organic compared to conventional fields. Evidence of higher soil C content on organically managed farms is easily interpreted as a proven advantage of organic agriculture in sequestering more C in soil (Smith, 2004; Goh, 2011; Gattinger et al., 2012). Misleading interpretation of C sequestration through organic systems has been pointed out by Andrén et al. (1999), and a thorough analysis of published data by Leifeld and Fuhrer (2010) concluded that “the claim for beneficial effects of organic farming on soil carbon is premature and that reported advantages of organic farming for soil carbon are largely determined by higher and often disproportionate application of organic fertilizer compared to conventional farming”.

Meaningful assessments of carbon sequestration require that appropriate boundaries are applied, i.e. the scale and level of external C input to cropping systems must be considered. An appropriate basis for scientific comparisons of different cropping systems is that the C input to soil is related to the level of net primary production. Furthermore, crop residue management should also be considered, e.g. incorporation of above-ground crop residues in one system and removal and sell off in another system affects the amount of C added. Although it is not relevant with respect to food production as such, larger quantities of weeds in organic than in conventional systems can also contribute to the C input. For example, Kauer et al. (2015) showed that C input from weeds could represent as much as 20% of the total amount of crop residue inputs. Below, some papers comparing C contents in conventionally and organically managed soils were examined and discussed.

### 2.3. Specific flaws

#### 2.3.1. Input of off-farm manures and composts resulting in higher soil C contents cannot be accounted for as C sequestration by the cropping system

Organic farming systems using organic materials of off-farm origin such as composts, manures or organic wastes from food industries, etc. often show higher C contents in soils than soils of conventional farming systems not importing the same quantities of organic fertilizers (e.g. Clark et al., 1998; Gunapala and Scow, 1998; Bulluck et al., 2002; Marriott and Wander, 2006). Similarly, examining soil C contents in organic systems having livestock and applying animal manure with conventional systems without livestock and no animal manure provide evidence for higher C contents in organic system (e.g. Wander et al., 1994; Friedel, 2000; Pulleman et al., 2003).

However, comparing organic mixed farming with almost stockless conventional systems as a proof of the superiority of organic system (Gattinger et al., 2012) was strongly criticized by Leifeld et al., (2013). Larger application rates of manure to organic than conventional systems through purchase create non-system-specific differences (Faerge and Magid, 2003). When it is obvious that the increase in soil organic matter in organic trials can be attributed to purchase and high input of organic fertilizers as the single most important driver, it is not a proof of the ability to sequester more carbon in soil. From a global point of view and a given scale (e.g. village, county, country), applying manure is not a true C sequestration practice since manure is in most cases recycled to soil anyhow (Powlson et al., 2011). Thus, the positive effect of manure applications on soil organic matter contents is the same regardless if manure is applied in an organic or conventional production system.

#### 2.3.2. Exclusive use of cover crops in one system only is a design error

The green manure effect of cover crops on soil organic carbon stocks is often overlooked. Use of cover crops increases crop residue input and thereby soil organic carbon stocks. A meta-analysis showed that the annual increase in soil carbon through cover crops was, on average, 0.32 Mg C $ha^{-1}$ $yr^{-1}$ (Poeplau and Don, 2015; Poeplau et al., 2015). Thus, selecting organic systems using cover crops and conventional ones without cover crops can lead to misinterpretation (Foereid and Høgh-Jensen, 2004). Yet, many comparative studies are characterized by having 2 or 3 cover crops in the organic rotation but none in the conventional one (e.g. Eltun et al., 2002; Aronsson et al., 2007; Kirchmann et al., 2007). The inclusion of cover crops in only one system leads to wrong conclusions. In order to make unbiased comparisons, non-system specific differences between organic and conventional rotations need to be avoided.

In summary, two main factors may cause a bias in the interpretation of C levels of comparative organic and conventional systems:

- Higher application rates of manure or other organic amendments than those that correspond to the production level of the system; and
- Inclusion of cover crops in only one system.

#### 2.3.3. Can organic crop production increase biological diversity?

Organic agriculture has been promoted as a possible way to improve diversity and richness of natural species, as, on average, a 10% higher diversity was found in organic compared to conventional fields (Schneider et al., 2014). Despite benefits at the field level (Bengtsson et al., 2005; Gabriel et al., 2006; Tuck et al., 2014) it is not easy to link agricultural management with biodiversity (Pelosi et al. (2010). A key question is whether introducing large scale organic farming also can increase biodiversity at the landscape, regional and global level? Before a full appraisal of organic farming as a tool to increase biodiversity can be made, two important aspects need to be considered.

### 2.4. Specific flaws

#### 2.4.1. Non-cropped areas on farms and adjacent land is of major importance for biodiversity

Gains in biodiversity of organically cropped fields (Bengtsson et al., 2005; Schneider et al., 2014) were not reflected in species richness at the farm and landscape level. Other non-production habitats on farms and in the landscape as a whole such as isles within fields, hedges, tree rows, areas with wild flowers, wetlands, etc. were found to have a major impact on habitat diversity and quality and have an equilibrating effect. In other words, the number and type of specific habitats within the landscape have an as large or even larger effect on biodiversity than gains in cropped fields. One needs to remember that crop production on arable fields aims to produce one or two crops at a time purposely not providing a large number of habitats. Even if a larger population of species in organic than conventional fields increases biodiversity to some extent, Schneider et al. (2014) stresses that additional measures are needed to create habitats for rare species. Examples are set-aside areas with flowers attracting insects, creation of specific plots within fields for protection of birds, building of wetlands for reptiles, etc.

#### 2.4.2. Lacking yield perspective

One major consequence of organic agriculture—lower crop production per area - must be taken into account: 'Growing less food per acre leaving less land for nature' (Borlaug and Dowswell, 1994). Intensive agriculture requires less land to produce the same amount of food. Conversion of intensive into extensive cropland applying organic practices would need additional land to produce the same amount of food. The consequences of more land demand diverted to organic production systems must be considered when their impact on biodiversity is determined (Green et al., 2005; Hole et al., 2005). A key question is whether conversion of cropland into organically managed fields and additional transformation of natural land is beneficial for quality and quantity of habitats as compared to conventional farming? Only when consequences of land use change on biodiversity are considered, an answer whether organic farming is an option or a threat to biodiversity can be found. Hopefully, the condition of producing sufficient food through different agricultural systems finds its way into the design and performance of biodiversity studies.

In summary, evaluating the impact of cropping systems on biodiversity must include:

- Inclusion of non-field habitats on farms and adjacent areas for biodiversity; and
- A yield perspective 'Growing less food per acre leaving less land for nature' finding its way into the conceptual framework for comparing biodiversity of cropping systems.

### 2.4.3. *Does organic crop production reduce nitrate leaching?*

One of the main arguments for changing over to organic crop production is that it is supposed to be beneficial for the environment reducing nitrate leaching, which is a major environmental concern (Koepf, 1973; Kristensen et al., 1994; Drinkwater et al., 1998). A compilation of the literature showed both the sequence and type of crops grown, and the intensity of N input was different in organic and conventional systems (Kirchmann and Bergström, 2001). Conventional farms tend to operate at greater input levels of most nutrients than organic systems, as revealed by 'farm-gate balances' one may expect that this also results in larger leaching losses, primarily of N. However, is this really the case?

## 2.5. *Specific flaws*

### 2.5.1. *Lack of synchronicity between release of N from organic manures and demand for N by crops*

The main difference between organic and conventional agriculture regarding the use of plant nutrients is the exclusion of soluble inorganic fertilizers in the former. Therefore, to understand the difference in leaching behavior between organic manures and inorganic fertilizers is central. This was done with respect to N in two lysimeter studies in which $NH_4NO_3$ was compared with differently treated animal manures (Bergström and Kirchmann, 1999) and green manures (Bergström and Kirchmann, 2004) showing that leaching of fertilizer N was lower throughout than from organic manures. This is a clear indication that organic N sources are more vulnerable to leaching than inorganic N fertilizers. The reason is that inorganic N is often released from organic sources during periods when there is no crop uptake of N. In cold and humid regions, such as Sweden, this often coincides with climatic conditions in autumn, when both soil temperatures and moisture content are high enough to trigger mineralization of organic N fractions and annual crops are harvested. Nitrogen is released from organic manures during periods without a crop (autumn, winter, early spring) and is highly exposed to leaching due to the frequent precipitation. Simply, there is poor synchronicity between crop demand and N release from organic manures. Residual manure N in soil is exposed to leaching after harvest. A leaching experiment with pig slurry applied in increasing amounts to lysimeters clearly corroborated this (Bergström and Kirchmann, 2006). When rates of slurry N were applied at or above the application rate of inorganic fertilizer-N, loads were significantly larger but crop yields were not increased. Similarly, long-term Swedish field studies corroborate that leaching losses of N were lower from conventional than organic cropping systems (Aronsson et al., 2007; Torstensson et al., 2006).

### 2.5.2. *Different main and cover crops in rotations highly affect leaching losses*

One important factor influencing N leaching from cropping systems is the design of crop rotations. The necessity of having legume-based crop rotations in organic systems whereas conventional crop production does not rely on legume-rich rotations for its N supply, illustrates the difficulty in designing identical crop rotations.

Despite lower average N flows in organic systems, there can be a large input of N in years when legumes are grown. Specific studies with leguminous crops showed that the supply of N to soil through legumes can be relatively high, for example more than 400 kg N $ha^{-1}$ $yr^{-1}$ in lucerne ley (Andrén et al., 1990) and up to 200 kg N in roots of clover (Dahlin and Stenberg, 2010). During subsequent mineralization of leguminous material, up to 50% of the amount of N can be released within 2 months (Kirchmann and Bergqvist, 1989). Thus, years after ley or N-fixing green manure crops, nitrogen supply can be as high as through inorganic fertilization.

More legumes in organic than conventional rotations (Kirchmann and Bergström, 2001; Kirchmann et al., 2007) and mineralization of N-rich legume residues (Thorup-Kristensen et al., 2003) highly affect N losses (Aronsson et al., 2007). Thus, it is difficult to compare leaching data due to different crops being included in organic and conventional rotations.

Crops causing highest leaching losses are legumes when ploughed under, potatoes and vegetables (Østergaard et al., 1995; Torstensson et al., 2006). Consequently, comparing an organic rotation with one potato-year and a conventional rotation with two potato-years will result in higher losses from the latter (Korsaeth and Eltun, 2000).

Whether cover crops are grown during autumn or the soil remains bare also has a major impact on N leaching. This aspect requires special attention. An earlier review showed that the proportion of years with cover crops was, on average 15% in organic systems and 10% in conventional systems (Kirchmann and Bergström, 2001). Furthermore, a meta-analysis showed that leguminous cover crops commonly used in organic crop production did not reduce N leaching whereas non-leguminous cover crops dominating conventional cropping systems reduced N leaching by 50% (Valkama et al., 2015).

### 2.5.3. *Different N input intensities between systems need to be corrected for*

Normally mean fertilization intensity over a crop rotation is lower in organic than conventional systems. Torstensson et al. (2006) found mean amounts of N fixed through legumes over an organic rotation to be 70 kg N $ha^{-1}$ $yr^{-1}$ and mean N applied in the conventional rotation to be 97 kg N $ha^{-1}$ $yr^{-1}$. A compilation of data from a wide range of studies showed that the average input was 88 kg N $ha^{-1}$ $yr^{-1}$ in organic systems and 165 kg N $ha^{-1}$ $yr^{-1}$ in conventional systems (Kirchmann and Bergström, 2001) followed by yields differences between systems. To test the principal question how more or less nitrogen applied affects N leaching in different systems is actually very difficult. Instead, different N use intensities between organic and conventional systems can be corrected for when the land area needed to produce the same amount of the same crop is taken into account.

In summary, the most important factors affecting N leaching, irrespective of whether the system is organic or conventional, are:

- Source and application time of N;
- Number and type of main crops and cover crops in rotation; and
- Rate of N input.

## 2.6. *Assessing environmental impacts of cropping systems per input, per yield or per land demand?*

As the experimental design of comparative organic and conventional cropping systems often is biased in some aspects, there is a need to find a useful denominator disregarding inevitable differences. Output from agricultural systems and farm operations like tillage or irrigation is commonly expressed per area. However, expressing losses to the environment such as greenhouse gases or leaching of nutrients per area disregards cropping intensity and losses per crop yield is a more relevant measure. Furthermore, since arable land is a limited resource globally, there is a need to account for land (often also time) to compare systems by using the land equivalency ratio (Hiebsch and McCollum, 1987).

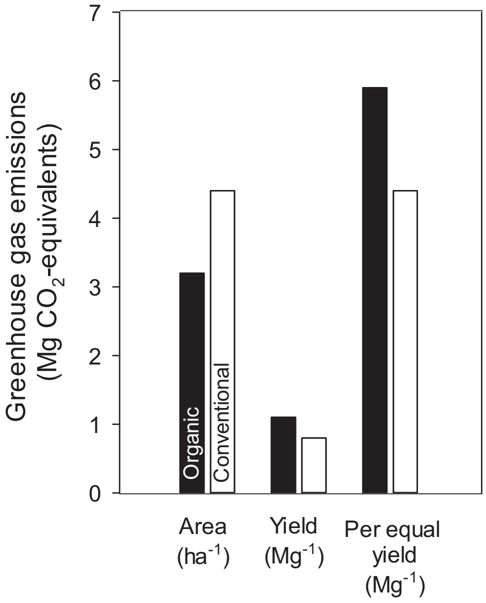

**Fig. 1.** Gaseous emissions expressed as $CO_2$ equivalents (including $CO_2$, $N_2O$ and $CH_4$) for winter wheat from a comparative organic and conventional field study. Data from Flessa et al. (2002). Mean organic wheat yield was 3.0 Mg and mean conventional 5.6 Mg ha$^{-1}$.

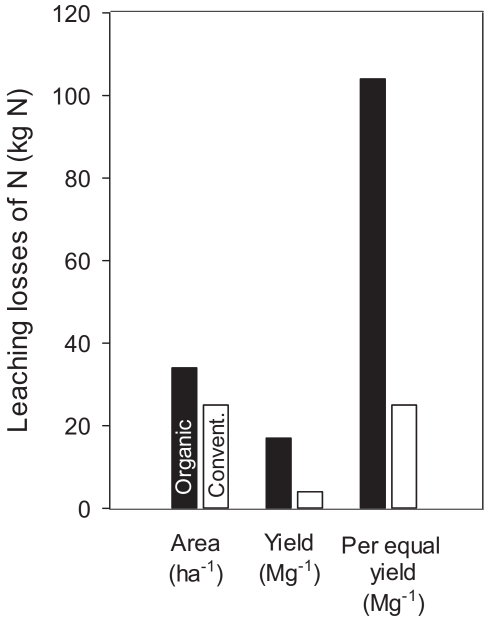

**Fig. 2.** Leaching of nitrogen from a long-term organic and conventional field trial. Data from Torstensson et al. (2006). Mean crop yield was 2.0 Mg over the organic rotation and 6.1 Mg ha$^{-1}$ over the conventional rotation.

### 2.6.1. *Expressing environmental emission per yield (or equal yield)*

Presenting environmental footprints of agriculture per cropped area can be misleading as cropping intensity is not taking into account (e.g. Korsaeth, 2008). Low-yielding systems with small emissions can be ranked environmentally superior over intensive systems with larger emissions. Concerning gaseous emissions not causing local pollution, release per product (Burney et al., 2010) is the most relevant and functional unit (Fig. 1).

On the other hand, leaching of nutrients may affect an adjacent water body or may end up in a remote water body. Thus, both nutrient flows per area and amounts leached per product are relevant units. Fig. 2 illustrates how leaching estimates expressed per area will deviate from those expressed per yield and equal yield (same amount produced by organic and conventional farming).

### 2.6.2. *Indirect impact of yield on land-use change—why is it important?*

Today, about one third of total agricultural production is depending on irrigation (Siebert and Döll, 2010). The efficiency of irrigation is generally lower in low-yielding systems requiring more land for agriculture. Similarly, more land and water is required to produce the same amount of food through organic farming. Conversion from low- to high-yielding agriculture or vice versa causes an indirect land use change (iLUC). When iLUC means conversion of natural grasslands or forests into agricultural land (Ramankutty and Foley, 1999), biodiversity will be reduced, greenhouse gas emissions be increased and critical ecosystem services be depleted. In regions with surplus of arable land, iLUC could mean that fallowed land can be used for alternative land use such as production of bioenergy (Tonini et al., 2012). Today, the environmental impact of iLUC is quantified through Live Cycle Assessment (LCA) although methods how to estimate environmental impact differ between LCA studies (Flysjö et al., 2012; Tidåker et al., 2014). In summary, footprints of iLUC must be considered in a balanced comparison of farming systems. Fig. 3 illustrates how iLUC affects the need for more arable land for organically grown crops to compensate for lower yields.

### 2.6.3. *Expressing biodiversity per area - or per area needed to produce the same amount of food?*

Biodiversity is commonly expressed in relation to unit land area with extensively cropped fields often showing a slightly higher biodiversity than intensively ones (see chapter above). Also, estimates of biodiversity of cropping systems need to be put into a land-demand perspective. High-yielding systems require less land to produce the same amount of food, sparing land for nature, and maintain ecosystem services and a rich biodiversity.

For example, Borlaug (2006) calculated that 1.1 billion hectares of forest and natural ecosystems were saved from transformation into managed arable fields between 1950 and 2000 through technologies increasing yields (Erisman et al., 2008). Waggoner (1994) outlines a possible scenario that a population of ten billion people actually can revert one third of today's cropland to wilderness in future. Thus, meaningful comparisons of cropping systems on biological diversity as a whole must include crop yield data and species richness and diversity in regional or remote natural ecosystems potentially being converted to or saved from transformation to arable land.

## 3. Conclusions and outlook

For providing enough food, fibers and other ecosystem services for a growing population with less negative impact on climate and nature, agricultural systems have to be optimized in many dimensions at the same time. Searching for better and more efficient agricultural practices requires strict scientific tests and correct interpretations of results. However, a number of comparative organic and conventional cropping systems were found to be characterized by biased design, erroneous interpretations and flawed conclusions. Given the fact that dissimilarities between organic and conventional cropping system are unavoidable, we stress that among the various differences between systems, a minimum standard of conditions must be followed to ensure meaningful evaluations:

a The initial soil fertility status must be similar between plots, sites, farms or regions;

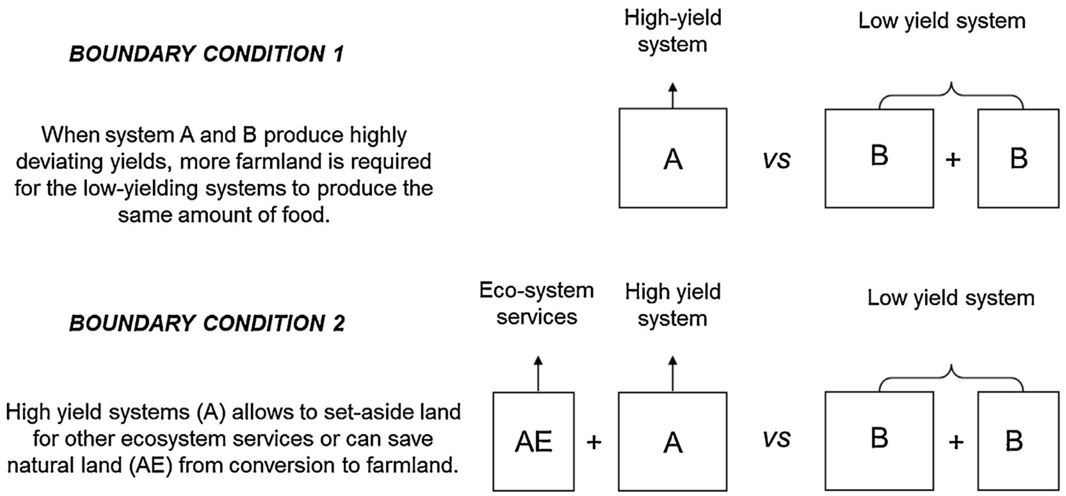

**Fig. 3.** Comparing cropping systems with greatly deviating yields. Low yield systems induce land use change.

b Only the same type of crop production are ideally compared—same animal systems, similar types of crops in rotation of food, vegetable or energy producing systems without animals; and

c Rates of off-farm C and nutrient input to each system must be quantified.

Even if the above-mentioned conditions are taken into consideration, the environmental impact of agricultural systems should be expressed per unit crop product or other intensity measures rather than on an aerial basis. For example, expressing nutrient leaching and greenhouse gas emissions per product revealed that conventional crop production was more environmentally friendly than organic one.

A more sustainable production of sufficient food and fibers for a growing human population is one of the greatest contemporary challenges and deserves our wholehearted attention. Projections of population growth and awareness that arable land is a limited resource globally indicate that intensification of agricultural production on existing arable land is the way to produce sufficient food. Cropping systems with lower intensity (e.g. organic ones) demand more land to produce the same amount of food. The key goal of intensified and sustainable agriculture is to increase yields with minimal environmental disturbances. This review provides evidence that systems based on scientifically verified best agronomic practices are superior over organic ones with respect to yield, nutrient leaching, greenhouse gas emissions and conservation of biodiversity.

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