Reply to the Editorial remarks:

Beste Jakob en Saskia,

Ik heb de laatste suggesties van Jakob nu opgenomen in de paper. Ik denk dat ik ze allemaal heb behandeld en ben ook wel erg tevreden met het resulaat ;-). Ik kan op dit moment de paper niet uploaden in het Copernicus-systeem maar hij is alvast aangehecht, zowel in Word met track changes als in pdf. Als Jakob nog eens toestemming kan geven, dan laad ik ook alles op in het Copernicus-systeem.

Vele groeten, Gerard

-----Original Message-----
From: Wallinga, Jakob [mailto:jakob.wallinga@wur.nl]
Sent: 20 December 2016 21:41
To: Gerard Govers <gerard.govers@kuleuven.be>
Cc: Keesstra, Saskia <saskia.keesstra@wur.nl>
Subject: Re: paper SOIL

Beste Gerard,

Nogmaals dank voor deze mooie bijdrage aan het special issue.

Zoals beloofd nog enkele opmerkingen en suggesties. De versie die ik bekeken heb is de versie die je eerder per mail gestuurd had (en de regel nummers daarin). Vetgedrukt woorden zijn suggesties voor aanvullingen, italics geeft een aanpassing weer. Ik zag net dat de versie die geupload is nog iets afwijkt van de mail versie (oa caption fig. 4 en mogelijk meer); in dat geval zijn enkele opmerkingen mogelijk niet meer relevant.

Ik heb zonet ook een officiele respons in het editorial systeem zetten, opdat je de finale versie kunt uploaden.

Algemeen:
waar meerdere referenties worden gegeven: spatie ontbreekt na de ;

Comments ref 1:
I would highly appreciate to have a summarizing figure about the different aspects of smart intensification as described in the manuscript including the most important measures of such a smart intensification. Particularly the latter is weakly developed in the whole paper. Is there any option to include organic management in such a strategy of smart intensification?

Ik kon niet goed vinden welke aanpassingen gedaan zijn in het MS in response op deze suggestie; zou je kunnen aangeven welke aanpassingen gedaan zijn, of uit kunnen leggen waarom deze suggestie niet is gevolgd?

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We hebben nu een figuur toegevoegd die naar onze mening de voornaamste elementen van smart intensification samenvat. We gaan bewust niet erg diep in op het verduidelijken van al die concepten omdat dat de paper veel te lang zou maken. Wat we wel duidelijk hebben proberen te maken (met een kleurcode) is dat het niet enkel gaat om environmental protection, noch enkel om economie. Het gaat, naar onze mening, om intensificatiestrategiën die een veelvoud van criteria in acht nemen die toekomstgericht, eco-efficiënt en sociaal acceptabel zijn.

Overige opmerkingen

Regel:

87- ANUAL amount of fertilizers

Changed

89 billion US per year

Changed to US $

93 - and Asia (ADD REF).

Ref added

96 - economic activities,

Changed

147 - missende spatie na vegetation

Changed

151 - is not always be

Changed

152 - ridges, and/or

Changed

220 - as an important

Changed

283 - moving there as an opportunity

Changed

296 - 298 - gehele zin checken en verbeteren

Changed

316 - amount of available kcal PER PERSON?

Changed

332 - Foregoing vervangen door Averting of door Preventing

Changed

348 - that it also allow > checken en verbeteren

Changed

359 - verwijzing naar Fig. 4 weglaten, of volgorde fig. 3 en 4 wijzigen

Order changed

Figure 2:
Deze figuur wordt duidelijker als de legenda in het figuur wordt geplaatst, en de afkortingen in de legenda worden vervangen door Cumulative erosion; C total; C arable land; C forest. Pijlen welke as (links of rechts) van toepassing werkt verduidelijkend.

Rephrase caption fig. 2:
Modelled cumulative erosion and carbon stocks as a function of crop yield in a hypothetical test area of 2900 ha for a total cerial yelad of 5000 ton. The total carbon stock (C total) is the combined carbon stock of arable land (C arable land) and that of forest (C forest)
We rephrased the whole caption and think that it reads a lot better now

366 - Give the s lope function of Nearing
Added

367 - are assumed to be
Changed

378 - refs needed for statements: gains are indeed possible (e.g. REFS), most report modest gains at best (e.g. REFS)
This sentence summarizes what follows below: we have extended the number of references in this section and referred the readers to various studies confirming this general statement.

379 - not clear whether 0.12 in USA or between 0 and 0.12.... > clarify

Clarfied

381 - Christopher et al. (2009)

Changed

383 - error - reference not found0

Changed

Figure 3:

labels are confusing: the second bar is for 0.0 to 0.25, so suggests to include 0 (which is given in the first bar......)

Changedd

388- carbon sequestration rates in arable land?
389 - Govers et al. (2013)

Both changed

Figure 4:
This figure needs more context / explanation. What is it based on (expert judgment, model, literature?). The pie charts and bars suggest at least semi-quantitative information, even if it is based on estimates or guesstimates; qualitative information cannot be presented in this form. In addition, in the main text, it is suggested that intensification will/may allow a reduction of the Agricultural land; whereas this figure suggests that intensification will still result in a decrease of natural (forest) land. Please make sure that the figure is in line with the text, or explain the differences.

We have rewritten the whole caption of the figure to make it clearer what we mean. Indeed, the information is semi-quantative rather than qualitative and this has been chaned.

420 – therefore
Changed

429 - reserves > add ref

I did look for such a refrerence but did not find it, so I changed the statement to 'may be'
452 - (e.g. Tiffen et al., 19994; Boyd ... (if statement repeatedly shown is correct)

Statement is correct: Boyd and Slaymaker refer to several studies, but I have added e.g. anyway ;-)

Met hartelijke groet,
jakob

Prof. Dr. Jakob Wallinga

Soil Geography and Landscape group, WUR (group leader)

Netherlands Centre for Luminescence dating (director)

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From: Gerard Govers <gerard.govers@kuleuven.be>
Sent: 19 December 2016 13:26
To: Wallinga, Jakob; Keesstra, Saskia
Subject: RE: paper SOIL

OK, prima, ik kijk er naar uit !

Vele groeten, Gerard

From: Wallinga, Jakob [mailto:jakob.wallinga@wur.nl]
Sent: 19 December 2016 09:29
To: Keesstra, Saskia <saskia.keesstra@wur.nl>; Gerard Govers <gerard.govers@kuleuven.be>
Subject: RE: paper SOIL

Klopt Saskia,

@Gerard: ik ben jullie paper nogmaals met veel plezier aan het doorlezen. Complimenten voor het artikel, dat leest als een wetenschappelijk onderbouwt pamflet. Een zeer goede bijdrage voor ons special issue.

Ik zal je vandaag of uiterlijk morgen een mail sturen met kleine correcties die nog doorgevoerd moeten worden (enkele zinnen die niet lopen).

Met hartelijke groet,
Jakob

Prof. Dr. Jakob Wallinga
Soil Geography and Landscape group, Wageningen University (group leader) Netherlands Centre for Luminescence dating (director) Droevendaalsesteeg 3 | 6708 PB Wageningen (GAIA building, room B123)
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From: Keesstra, Saskia
Sent: Monday, December 19, 2016 9:26 AM
To: Gerard Govers; Wallinga, Jakob
Subject: RE: paper SOIL

Beste Gerard
Jakob moet nu je paper beoordelen en dan goedkeuren (neem ik aan). Daarna kan het worden gepubliceerd.
Groetjes
Saskia

From: Gerard Govers [mailto:gerard.govers@kuleuven.be]
Sent: zaterdag 17 december 2016 5:13
To: Wallinga, Jakob; Keesstra, Saskia
Subject: paper SOIL

Dag Jakob, Saskia,

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Is er nog iets wat ik moet doen voor de SOIL paper ? Ik denk dat ik alles heb opgeladen: laat me weten als er nog iets moet gebeuren.

Vele groeten, Gerard

Gerard Govers
Department of Earth and Environmental Sciences KU Leuven<http://ees.kuleuven.be/> Director of Arenberg Doctoral School<http://set.kuleuven.be/phd>
Discover how you shape the world by making a PhD at the most innovative university of the European continent<http://www.shapetheworld.eu/>

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Soil Conservation in the 21st Century: Why we need Smart Agricultural Intensification

Gerard Govers[1], Roel Merckx[1], Bas van Wesemael[2], Kristof Van Oost[2]

[1] KU Leuven, Department of Earth and Environmental Sciences, Celestijnenlaan 200E, 3001 Leuven, Belgium
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Correspondence to: Gerard Govers (gerard.govers@kuleuven.be)

Abstract. Soil erosion severely threatens the soil resource and the sustainability of agriculture. After decades of research this problem persists, despite the fact that adequate technical solutions now exist for most situations. This begs the question as to why soil conservation is not more rapidly and more generally implemented. Studies show that the implementation of soil conservation measures depends on a multitude of factors but it is also clear that rapid change in agricultural systems only happens when a clear economic incentive is present for the farmer. Conservation measures are often more or less cost-neutral which explains why they are often less generally adopted than expected. This needs to be accounted for when developing a strategy on how we may achieve effective soil conservation in the Global South, where agriculture will fundamentally change in the next century. In this paper we argue that smart intensification is a necessary component of such a strategy. Smart intensification will not only allow to make soil conservation more economical, but will also allow to make significant gains in term of soil organic carbon storage, water efficiency and biodiversity, while at the same time lowering the overall erosion risk. While smart intensification as such will not lead to adequate soil conservation, it will facilitate it and, at the same time, allow to offer the farmers of the Global South a more viable future.

Introduction

The terrestrial land surface provides critical services to humanity and this is largely possible because soils are present. Humanity uses ca. 15 million km² of the total Earth's surface as arable farmland (Ramankutty et al., 2008). Besides this, ca. 30 million km² is being used as grazing lands: on all these lands grow plants which are either directly (as food) or indirectly (as feed, fibre or fuel) used by humans for nutrition and a large range of economic activities. Agricultural areas, especially areas used as arable land, have often been selected because they have soils that make them suitable for agriculture. But it is not only the soils on agricultural land that provide humanity with essential services. Also on non-agricultural land soils provide the necessary rooting space for plants, store the water necessary for their growth and provide nutrients in forms that plants can access. Both on agricultural and non-agricultural land soils are host to an important fauna whose diversity is, by some measures, larger than that of its aboveground counterpart (De Deyn and Van der Putten, 2005). Both on agricultural and non-agricultural land soils store massive amounts of organic carbon, the total amount of which (ca. 2500 Pg, Batjes, 1996; Hiederer and Köchyl, 2012) is much larger than the amount of carbon present in the atmosphere (ca. 800 Pg). Importantly, organic carbon storage per unit area is generally much higher on non-agricultural land (Poeplau et al., 2011; Hiederer and Köchyl, 2012). By allowing plants to grow, soils significantly contribute to the terrestrial carbon sink, which removes an amount equal to 30-40% of the carbon annually emitted by humans from the atmosphere (Le Quere et al., 2009). Soils, both those on agricultural and non-agricultural lands, are therefore a vital part of humanity's global life support system, just like the atmosphere and the oceans. An Earth without soils would be fundamentally different from the Earth as we know it and would, in all likelihood, not be able to support human life as we know it.

No further arguments should be necessary to protect soils from the different threats posed to them by modern agriculture and other human activities. Yet, as is the case with many other natural resources, soils are under intensive pressure. Organic carbon loss, salinization, compaction and sealing all threaten the functioning of soils to different extents in different areas of the world. One of the most important and perhaps the ultimate threat posed to soils is accelerated erosion due to agricultural disturbance. When soils are used for farming their natural vegetation cover is removed and they are often disturbed by tillage. The result is that, under conventional tillage, erosion rates by water on arable land are, on average, up to two orders of magnitude higher than those observed under natural vegetation. This acceleration creates a major imbalance as soil production is outstripped by soil erosion by a factor 10-100 so that soil is effectively mined (Johnson, 1987; Montgomery, 2007; Vanacker et al., 2007b). Eroded soil is, in many cases, truly lost and cannot be restored (although there are exceptions to this rule), which explains why land prices in areas heavily affected by erosion may remain lower than expected, even when excessive erosion has been halted for several decades (Hornbeck, 2012).

It is rather surprising that agricultural soil erosion still is such an important problem. Pre-industrial societies such as the Inca already understood that erosion threatened agricultural productivity and used soil conservation techniques such as terracing for centuries (Krajick, 1998). In France, environmental degradation by excessive water erosion of mountain hillslopes literally ruined the livelihood of entire mountain communities at the end of the 19th century (Robb, 2008). A similar situation developed in Iceland where excessive wind and water erosion forced entire villages to be abandoned in the same period. In both countries overexploitation of the natural environment by subsistence farmers through excessive deforestation and overgrazing were key factors. Both countries responded to this situation: in Iceland the first soil conservation service of the world was founded in

1907 (Arnalds, 2005), while France started an extensive programme to restore its mountain environments (RTM) as early as 1860 (Lilin, 1986). In the United States, the Dust Bowl years (1930s) moved the erosion problem high up the political agenda: President Franklin Roosevelt not only erected a Soil Conservation Service but also, famously, said ‘A nation that destroys its soils destroys itself’ (FAO and ITPS, 2015).

One might therefore expect that, by now, detailed information would exist on the status of the global soil resource and the necessary measures would have been taken to stop soil degradation due to human action and/or mitigate the consequences. Yet, this is clearly not the case: recent estimates of human-induced agricultural erosion amount to 25-40 Gt yr^{-1} for water erosion, ca. 5 Gt yr^{-1} for tillage erosion and 2-3 Gt yr^{-1} for wind erosion (Van Oost et al., 2007; Govers et al., 2014). Measured soil production rates are, on average, ca. 0.036±0.04 mm yr^{-1} (Montgomery, 2007) and are even lower on most agricultural soils because agricultural soils have a certain thickness and soil production rates decrease with increasing soil depth (Stockmann et al., 2014). Thus, over all agricultural land (arable and pasture) total soil formation would amount to maximum ca. 2 Gt yr^{-1} which implies that the global soil reservoir is depleted by erosion at a rate which is ca. 20 times higher than the supply rate. Although these numbers are only an approximation (for instance, they do not account for the fact that eroded soil may be re-deposited on agricultural land) they clearly illustrate that we are still far away from a sustainable situation: the rate at which the soil resource is being depleted is, over the longer term, a clear threat to agricultural productivity (FAO and ITPS, 2015). The loss of mineral soil is not the only issue: soil erosion also mobilises 23-42 Tg yr^{-1} of nitrogen and 14-26 Tg yr^{-1} of phosphorus (Quinton et al., 2010). These numbers may be compared with the annual application rate of mineral fertilizers, which are ca. 122 Tg yr^{-1} for N and ca. 18 Tg yr^{-1} of mineral P respectively~~ (see http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx)~~. At 2013 USA mineral fertilizer prices of ca. 1.35 USD~~/~~ (kg N)~~-1~~ and ca. 4.75 USD~~/~~ (kg P)$^{-1}$, (http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx) the annual amount of fertilizers mobilised by soil erosion is equivalent to ca. 35 billion US~~D~~ $ for N and ca. 80 billion US~~D~~ $ for P: this is a significant financial loss, even if one considers that the total global agricultural food production is nowadays valued at ca. 4000 billion US~~D~~ $ (http://faostat.fao.org/site/613/DesktopDefault.aspx?PageID=613#ancor). Most of these soil and nutrient losses take place in the hilly and mountain areas in the so-called Global South: a recent scientific appraisal by FAO and the ITPS (the Intergovernmental Technical Panel on Soils) showed that erosion problems are still increasing in Africa, Latin-America and Asia (FAO and ITPS, 2015). The situation is perceived to be improving in Europe and North America (FAO and ITPS, 2015), albeit that also in these regions soil losses are often still above the tolerable level (Verheijen et al., 2009). Thus, it is especially the agriculture in the Global South (Latin America, Africa, the developing nations of Asia and the Middle East), where it is often one of the main economic activities~~y~~, which suffers excessively from these losses.

Region	Condition	Trend
Asia	Poor	Negative
Latin America	Poor	Negative
Near East and North Africa	Very Poor	Negative
Sub-Saharan Africa	Poor	Negative
Europe and Eurasia	Fair	Positive
Northern America	Fair	Positive

Southwest Pacific	Fair	Positive

Table 1 Conditions and trends with respect to soil erosion as assessed by experts (data from FAO and ITPS, 2015)

In this paper we reflect on why, despite these clear facts, effective soil conservation is not yet a done deal and what might be done about this. We argue that there is a need for a novel vision on soil conservation in the Global South, shifting the focus away not only from the technical issues of soil conservation but also away from soil conservation as such. Soil conservation efforts need to be framed into a general vision on how agriculture will develop in the South: this vision needs to account for soil protection, but must also guarantee food security and allow the development of an agricultural system that does provide a sufficient income to farmers. We will first assess possible reasons as to why soils do not yet get the protection they deserve. Thereafter we will discuss the building blocks of a vision on future soil conservation.

The status of soil conservation

Do we have the necessary data to guide soil conservation?

Investing in the application of soil conservation measures is only meaningful when erosion rates are higher than acceptable. This can most easily be established when erosion rates can reliably be quantified. Quantitative information is indeed available for North America and Europe (Cerdan et al., 2010; NRCS, 2010). However, the quality of our estimates of soil erosion rates by water for other areas on the globe is often poor. Sometimes, estimates are based on a limited number of data which are simply extrapolated to larger areas: this often leads to bias, simply because erosion rates are generally measured at locations where erosion intensity is much higher than average (Boardman, 1998; Cerdan et al., 2010). Also when models are used to make an extrapolation, estimates are often incorrect. This is due to two reasons: (i) the models that are used are often improperly calibrated, i.e. model parameters are set to values that are not appropriate for the location under consideration and (ii) the model parameterization may be correct but the spatial data used to drive the model are inappropriate. A typical example of the latter is when slope lengths are directly derived from a DTM so that the impact of slope breaks such as field borders is not accounted for (e.g. Yang et al., 2003). This can lead to a considerable overestimation of erosion rates (Desmet and Govers, 1996; Cerdan et al., 2010; Quinton et al., 2010). Erroneous predictions do not only make it difficult to identify the most vulnerable areas in which conservation measures are most urgent: they may also invalidate the cost-benefit evaluations of soil conservation programs and lead to disinformation of the general public about the extent and severity of the problem.

Although there is a clear need for better, quantitative data on erosion rates, the lack of such data is not the most important explanation as to why excessive soil erosion often still goes unchecked. While it may indeed be difficult to quantify erosion rates correctly, it is much easier to identify those areas where intense soil erosion is indeed a problem and where action is necessary, whatever the exact erosion rates are. This is, after all, what institutions such as the soil conservation services of Iceland and the United States did long before accurate erosion measurements were available. Simple visual observations on the presence of rills and gullies or wind deflation areas are clear indications that the implementation of conservation measures is necessary (Figure 1). Another reason why an exact quantification is not always necessary is that conservation measures generally are not proportional: Their implementation is most often of a yes/no type: one can decide whether or not to implement conservation tillage, but not by how much.

Figure 1. The presence of a dense network of rills is and significant deposition at the footslope (here in Huldenberg, Belgium in July 2006) is a such sufficient proof for excessive soil erosion (in this case erosion exceeded 100 t ha^{-1} in a single event)

Do we have the necessary technology for soil conservation?

There is no doubt that soil conservation technology has matured over the last decades: we now have the tools to effectively reduce erosion rates to acceptable levels in many, if not all, agricultural systems. Conservation tillage is the tool of choice in many areas, especially in the Americas. This is hardly surprising: erosion plot research has consistently shown that water erosion rates under conservation tillage are reduced by one to two orders of magnitude in comparison to conventional systems (Montgomery, 2007; Leys et al., 2010). Moreover, the effectiveness of conservation tillage as calculated by plot studies is likely to be underestimated: for various reasons the effectiveness of conservation does increase if the slope length increases (Leys et al., 2010). As a consequence, water erosion rates under conservation tillage on moderate slopes are generally very low (< 1 t ha y) and often comparable to those occurring under natural vegetation (Montgomery, 2007). Conservation tillage may also be used to drastically control wind erosion not only because residue cover does reduce the shear stress to which soil particles are exposed but also because the presence of residue helps to keep the surface soil layer moist, thereby increasing its shear strength.

~~However,~~ Conservation tillage is not always ~~be~~ the best tool. It may be difficult or impossible to apply with certain crops, such as potatoes grown on ridges, and/or difficult to introduce into specific agricultural systems as it may affect the overall workload or the gender balance of the workload (Giller et al., 2009). It may also not be sufficient to implement conservation tillage as processes such as gully erosion may not be effectively controlled and may in some cases even be enhanced by conservation tillage as the latter is much more effective in reducing erosion than in reducing surface runoff (Leys et al., 2010). However, also in such cases technological solutions do exist: they can consist of infrastructural measures such as stone bunds and terrace building in combination or vegetation measures such as grassed waterways, but also proper land use allocation can make a significant difference. Water and wind erosion rates can often be reduced to acceptable levels through the use of such measures in combination with modifications of tillage techniques and crop rotations (Sterk, 2003; Valentin et al., 2008; Nyssen et al., 2009). Not only arable land can be affected by excessive erosion. Grazing lands may suffer from a drastic reduction in vegetation cover due to overgrazing and compaction, again resulting in excessive water and/or wind erosion with rates up to two orders of magnitude higher than those observed under natural conditions (Vanacker et al., 2007b). Reduction of grazing pressure (at least in a first stage) and the introduction of controlled grazing are key strategies (i) to (i) restore the vegetation cover and (ii) to allow these lands to become productive again so that they can be sustainably used (Mekuria et al., 2007). Such measures can be further supported by the planting of trees (Sendzimir et al., 2011). Reforestation may also be a solution as it reduces erosion rates to near-natural levels but it has evident implications for the type of agriculture that can be supported (Vanacker et al., 2007b). Thus, as is the case on arable land, the key to erosion reduction on grasslands is in most cases the maintenance or restoration of a good vegetation cover, possibly supported by technical measures.

Erosion in agricultural areas is often not directly related to agricultural activities but also to the infrastructure related to these activities such as roads and field boundaries. Unpaved roads on sloping surfaces are not only important sources of sediment in many agricultural areas (Rijsdijk et al., 2007; Vanacker et al., 2007a) but also in cities (Imwangana et al., 2015). Water is often concentrated at field boundaries, again therebyleading to gully formation (Poesen et al., 2003). Again, the necessary technological know-how to control such erosion phenomena is available: check dams, better water drainage infrastructure, the implementation of field buffer zones and a better landscape organisation all help to reduce sediment production on road networks and in built-up areas.

Why then is soil conservation not more generally adopted?

Thus, neither the lack of conservation technology nor the lack of data on the erosion hazard can fully explain why efficient soil conservation measures are still not implemented on most agricultural land, especially in the Global South. It has indeed long been clear that several factors other than (the lack of) scientific knowledge or data hamper the adoption of conservation tillage. These factors include the training level of the farmer, the farm size and work organisation as well as access to information. However, a thorough analysis by Knowler and Bradshaw (2007) showed that the effect of these variables was often ambiguous (when different studies are compared) and that few, if any, variables showed a consistent effect. One might conclude from this that changing farming practices must be inherently difficult, as our understanding of controlling factors is relatively poor and many barriers to the adoption of novel technology need to be overcome. This is not only a problem in the Global South: also in Europe the adoption of conservation tillage is slow in many countries due to a multitude of factors, including the fact that soil tillage is deeply rooted in the culture of many farmers (Lahmar, 2010).

Clearly, farming systems are, to some extent, 'locked in': they rely on well-tried technology, division of labour and crop types and are therefore difficult to change. There are, nevertheless, also cases where farming systems change rapidly and conservation technology is quickly incorporatedadopted. Once the necessary technology was available, conservation tillage spread very rapidly through most of Argentina and Brazil: in Argentina, it took ca. 20 years (from 1990 to 2010) to bring ca. 80% of the arable land under no-till (Peiretti and Dumanski, 2014), thereby effectively halting excessive soil erosion on most of the arable land of the country. In Brazil, more than 25 million ha of land was under no-tillage in 2006, while whereas the technique was virtually unused before 1990 (Derpsch et al., 2010). Rapid changes in agricultural systems are not limited to the adoption of conservation tillage.

When subsistence farmers in remote areas gain access to profitable markets, very rapid changes can occur, even in areas where existing technology is poor: such changes can have very negative effects in terms of soil degradation rates as a switch to cash cropping may introduce crops to which a much higher erosion risk is associated (Valentin et al., 2008). Thus, while cultural and technological barriers to change certainly do exist, farmers are most certainly capable of rapid change. Whether such rapid change occurs critically depends on whether farmers think change will bring them a personal gain.

This is where the problem lies. Under some conditions, the adoption of conservation technology is indeed clearly economically beneficial to the farmer: this appears to be true for large farming operations in (sub-) tropical regions growing cash crops such as soy beans (Peiretti and Dumanski, 2014). But in most other cases the direct benefits of the implementation of conservation agriculture and/or other soil conservation measures are small, if they exist at all. This appears to be the case for both large-scale mechanised agriculture in the temperate zone as well as for marginal hillslope farming in developing countries (Knowler et al., 2001). In both scenarios, potential savings are offset by additional costs: in mechanized systems the cost of machinery and agrochemicals offsets savings in fuel costs (Zentner et al., 1996; Janosky et al., 2002) while in traditional hillslope farming extra work hours are needed to maintain conservation structures and some land has to be sacrificed to implement these structures, thereby reducing overall yields (Nyssen et al., 2007; Quang et al., 2014). Importantly and contrary to common belief, crop yields do not rise significantly in conservation systems if no additional inputs are provided: this is true for advanced technological systems (Van den Putte et al., 2010; Pittelkow et al., 2015) as well as for tropical smallholder farming (Brouder and Gomez-Macpherson, 2014). As a consequence, farmers often do not have direct incentives to implement soil conservation measures and change becomes difficult to implement.

One may argue that benefits should not only be considered at the level of the individual farmer, but also at the societal level, where soil conservation may generate co-benefits. Often carbon storage and biodiversity protection under conservation systems are mentioned as ~~an~~ important ecosystem services for which farmers could be paid. Research in the last decade has consistently shown that carbon storage gains in conservation systems are lower than was anticipated two decades ago and is generally well below 1 Mg C ha^{-1} yr^{-1} ((Oorts et al., 2007; Angers and Eriksen-Hamel, 2008; Christopher et al., 2009; Eagle et al., 2012; Govers et al., 2013). Furthermore, ~~and that~~ paying farmers to store carbon would only be viable at much higher carbon prices than the current market prices, which are around 10-15 USD ton^{-1} (Grace et al., 2012; Govers et al., 2013). Paying farmers ~~for the carbon they store~~ at current market prices can only generate a relatively small economic benefit for the farmer and prices would have to rise significantly for soil carbon storage to become an important element on the farmers' balance sheet.

On the other hand, soil conservation generally has a positive impact on (soil) biodiversity on the farm land as soils are less frequently disturbed (Mader et al., 2002; Verbruggen et al., 2010). Where agriculture is interspersed with densely populated areas, additional co-benefits may consist of a reduction of flooding and/or siltation of sewage systems and water treatment plants, which are important problems in many areas in Europe (Boardman et al., 1994). These benefits, however, are difficult to convert to financial income for the farmer. This is not only because the economic value of increased biodiversity on farmland is difficult to quantify but also because such on-farm benefits in biodiversity have to be weighed against possible off-farm losses (see below). The reduction in flooding risk, on the other hand, will generally not be considered as a benefit by society but rather as damage repair: the problems were caused by agriculture in the first place.

The way forward

How then should we proceed to stimulate a more rapid adoption of soil conservation measures to protect the world's soil resource? The answer to this question will obviously depend on the characteristics of the local agro-ecological system. Agricultural systems show a large variety so that not only the factors impeding the adoption of conservation tillage vary locally (Knowler and Bradshaw, 2007) but also the tools that societies have at their disposal to reduce it.

Western societies with highly developed information systems tackle the problem by a policy combining regulation (e.g. by forbidding the cultivation of certain crops on land that is very erosion-prone) and subsidies or compensations in combination with well-guided campaigns to inform farmers on the potential benefits and risks for themselves as well as for the broader society. Such combined approaches do have demonstrable success in various parts of Europe and North America where farmers are not only well trained and highly specialized but also depend to a large extent on subsidies, giving the administrations the necessary financial leverage to stimulate or even coerce farmers (Napier et al., 1990). As a result erosion rates in North America have gone down considerably over the last decades and are still declining (Kok et al., 2009). One may therefore assume that in these societies erosion rates can be reduced to tolerable levels provided that the necessary policies are maintained and/or strengthened. Countries having a strong central government that can impose decisions on land use and soil conservation, as is the case in China, can successfully reduce erosion: the excessive erosion rates on the Chinese Loess Plateau were strongly reduced through massive government programs implementing erosion control measures (Chen et al., 2007; Zhao et al., 2016)

These approaches are, at present, not possible in most countries of the Global South. Many governments in the Global South are not able to implement a successful soil conservation policy as they do not dispose of the necessary data and/or the necessary political and societal instruments to do so. At first sight it may therefore appear unlikely that soils will become effectively protected in most of the developing world within a foreseeable time span. Yet this conclusion foregoes the fact that agriculture in the Global South, and especially in sub-Saharan Africa, will see fundamental changes in the next decades. At least three fundamental tendencies can be identified that will ~~fundamentally~~ change the nature of agriculture in the Global South in the 21st century: these should be accounted for when developing a vision on soil conservation.

In ~~most~~ many areas where soils are most seriously threatened, the human population will continue to grow strongly. In the next decades, the locus of world population growth will shift in an unprecedented manner. Population growth in the North has stopped and many regions in the Global South will follow suit in the next decades: Asia is expected to reach its maximum population around 2050. China's population will peak around 2030 and that of India no later than 2070. Latin America will follow around 2060 (http://esa.un.org/unpd/wpp/, Lutz and KC, 2010; Gerland et al., 2014). Sub-Saharan Africa is a different matter: here the demographic transition started only after the Second World War and the population will continue to grow rapidly during most of the 21st century. As a result of these diverging tendencies the distribution of the world's population will have changed beyond recognition in 2100: Europe's share in the global population will have fallen from its maximum of ca. 22 % in 1950 down to ~~just 5.7~~ ca. 6 % in 2100, while the share of Africa will rise from ca. 9 % in 1950 to ca. 39 % in 2100 (http://esa.un.org/unpd/wpp/).

The population in the South will also become more urban. By 2050 ca. 2/3 of the global population is expected to live in cities (as compared to ca. 55% at this moment). Urbanisation rates are especially high in Africa where the fraction of urban population is expected to increase from 40% in 2014 to 55% in 2050 and in Asia, where urbanisation will increase from ca. 47.5% to ca. 65% over the same period (United Nations, 2014). There is no alternative for this evolution: despite all their problems, cities are the engines of modern economic development as they allow a population to create the added value that is so desperately needed through advantages of scale, intense interaction and exchange (Glaeser, 2011). This is the fundamental reason of the attractiveness of cities and the major factor explaining rural to urban migration: poor rural populations perceive the city as a place of opportunity and moving there~~ir~~ as an opportunity to improve their own lives or at least those of their children (Perlman, 2006; Saunders, 2011). A consequence of this massive migration movement is that rural populations rapidly age and that the average farm worker is significantly older than the average non-farm worker (40 vs. 34 years in Africa, http://www.gallup.com/poll/168593/one-five-african-adults-work-farms.aspx). Clearly the evolution sketched above is a generalisation: local dynamics depend, amongst others, on the presence of attractive labour opportunities in the cities and the local availability of land (Ellis-Jones and Sims, 1995).

It is not overly optimistic to expect that, while population growth continues, at the same time *these populations will gain in purchase power*. While incomes in southern Asia and especially sub-Saharan Africa are nowadays much smaller than those in the North, their growth rates are, fortunately, much bigger. For example, Ethiopia's economy has, over the last decade, consistently been growing at 8 to 10% per year, leading to a rise of the per capita Gross National Income from 110 US~~D~~ $ (2015 dollars) in 2004 to 550 US~~D~~ $ in 2015 (http://data.worldbank.org/country/ethiopia).

~~The~~ Combined, ~~impact of~~ these tendencies will ~~clearly~~ lead to an increased market demand for food. ~~Apart from this, the nature of the demand will shift as~~Furthermore, diets will move away from a diet largely based on cereals towards a more varied (but not necessarily healthier) food palate in which meat is likely to have a larger share than is currently the case. Global estimates therefore sometimes predict that global food production (in terms of kcal) will increase ~~by~~ more or less double in the first half of the 21st century (Tilman et al., 2011) but an increase in demand by 60-70% is more likely (Alexandratos and Bruinsma, 2012). As (relatively) more people will live in cities, there will be relatively fewer people working on the land to produce the food that is necessary. Furthermore, as most of future population growth will take place in sub-Saharan Africa, food demand will rise most rapidly in this area.

Thus, agriculture in the Global South will be fundamentally different from what it is now in less than a century. More food will have to be produced with less people and the increasingly urban population will more and more rely on markets to obtain the food it needs. This begs the basic question: how can we make sure that the soils necessary to produce all this food are sustainably managed and preserved for future generations?

Soil conservation in a changing global context

Two contrasting pathways can be followed to meet the expected increase in food demand in the Global South. More food can be produced either by extending the area over which current food production systems are applied or by agricultural intensification, i.e. by increasing the amount of food produced per unit of land.

Both pathways are, in principle, possible: until present, Africa has followed the first path. Over the last five decades, the increasing food demand of African populations has mainly been met by increasing the area used for farming, while yields per unit of surface area remained stable and very low (Henao and Baanante, 2006). This evolution sharply contrasts with the one observed in most parts of Asia: here agricultural production was mainly increased through intensification (Henao and Baanante, 2006). In Asia, the Green Revolution led to a dramatic rise in agricultural yields through the combination of new crop varieties, better farming technology and the increased use of fertilizers. As a consequence, Asia now manages to feed its population much better than it did in 1970: the amount of available kcal per person rose from ca. 2000 kcal to ca. 2400 kcal (South Asia) or even 3000 kcal (East Asia) in 2005 (Alexandratos and Bruinsma, 2012) despite the fact that the amount of land used for agriculture did only marginally increase (Henao and Baanante, 2006) and despite the fact that the population in these regions increased from 0.98 billion to 1.53 billion (East Asia) and from 1.06 billion to 2.20 billion (South Asia) over the same period (http://esa.un.org/unpd/wpp/).

While the challenge for African agriculture is not dissimilar to that of Asia in the 1960s, Africa does not necessarily have to go down the same route. In principle, it could continue to follow the areal extension strategy policy for some time to come. At present, ca. 290 million ha of agricultural land is in use in Africa, but another 400 million ha of African land is suitable (good) or very suitable (prime) for agriculture (Alexandratos and Bruinsma, 2012). Therefore, there is scope for a strategy whereby significantly more land would be used for agriculture than is the case at present although this would pose important problems: a large fraction of the suitable land is located in politically unstable countries and/or far from existing markets (Chamberlin et al., 2014).

An areal extension strategy may, at first sight, be attractive from the point of view of soil conservation. One might indeed argue that this would be based on agricultural technology that has been in use for decades, and may therefore be best suited to increase agricultural production without causing excessive soil degradation. Indeed, the occurrence of erosion in mechanised, intensive agricultural systems is often attributed to the loss of traditional soil conservation methods (Bocco, 1991). Foregoing Averting intensification and aiming at area extension may therefore seem a suitable solution to avoid excessive soil degradation as traditional farming methods can be maintained and optimised to be as environmentally friendly as possible. Many organisations do indeed stress environmental protection and sustainability as key issues to be addressed in the further development of African agriculture and explicitly state that Africa should indeed follow a path different from the Asian Green Revolution (De Schutter, 2011).

While it is evident that we should learn from agricultural developments in Asia and avoid the dramatic negative effects the Asian Green Revolution had in some places, we argue here that tropical smallholder farming does need intensification for soil conservation to become successful. This intensification should be smart: it not only needs to be sustainable and to avoid jeopardising the capability of the natural resources to meet the needs of future generations. Intensification strategies should also maximise the opportunities of current and future farmers to generate an acceptable income by providing them with access to profitable markets and supplying them with the necessary knowledge and technology to produce for these markets. Smart intensification requires an approach that does not focus on the conservation of natural resources only alone but also on the creation of added value using a future-oriented perspective and the quantity and quality of food production and supply. Clearly, improving the livelihood of the farmers and farming communities should be a key element. However, the capability of this farming community to provide the necessary agricultural supplies to an ever growing non-farming population also needs to be taken into account.. Thus, it is not only important to consider the current socio-economic conditions but also how demographic and socio-economic conditions are likely to change in the future. We argue that smart intensification will not only make soil conservation more achievable but that it would also allow to reap~~ing~~ additional environmental benefits that may be lost when a less intensive or less future-oriented development path is chosen. As is the case for ‘smart cities’, we do not believe a single, all-encompassing definition of smart intensification can be formulated. However we summarized the components that we consider to be essential in Figure 2. In the rest of the paper we focus the discussion on how soil conservation may benefit from smart intensification.

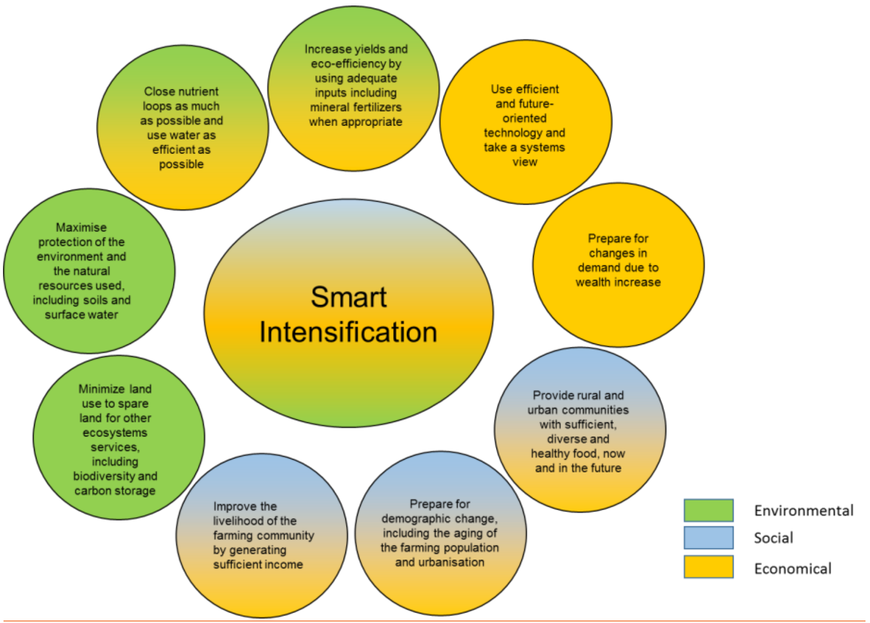

Figure 2 Different aspects of smart agricultural intensification. Colouring refers to main reason as to why each aspect is important

Smart intensification will allow to spare the most erosion-prone land from agriculture thereby reducing landscape-scale erosion rates. When farmers select land for arable production, they will select the most suitable land that is available. In general this means that, for obvious reasons, flatter land is preferred over steeper land~~, for obvious reasons~~ (Van Rompaey et al., 2001; Bakker et al., 2005). Steep lands are generally much more difficult to cultivate than flatter areas and yields can be expected to be lower in comparison to yields (for the same amount of inputs) on flat land, because soils are intrinsically less productive and/or because soil productivity is negatively affected by accelerated erosion (Stone et al., 1985; Ellis-Jones and Sims, 1995; Lu and van Ittersum, 2004). The combination of both effects (more labour required and lower yields) invariably implies that the net returns of arable farming decrease with increasing terrain steepness. The total amount of erosion as well as the amount of erosion per unit of crop yield will therefore necessarily increase when area expansion is preferred over intensification (Figure 3~~Figure 2~~, Figure 5~~Figure 4~~).

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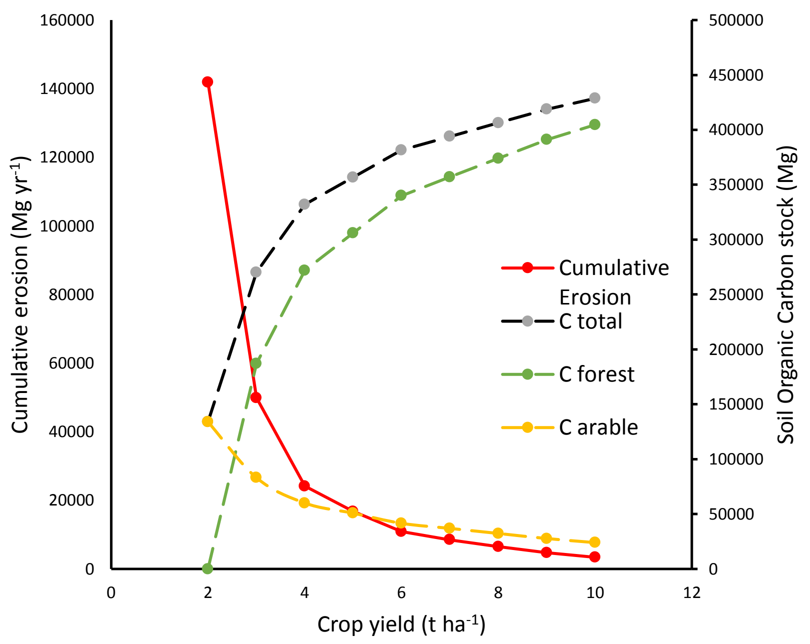
Cumulative erosion (Mg yr-1)
Soil Organic Carbon stock (Mg)
Crop yield (t ha-1)
Cumulative Erosion
C total
C forest
C arable
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100000
80000
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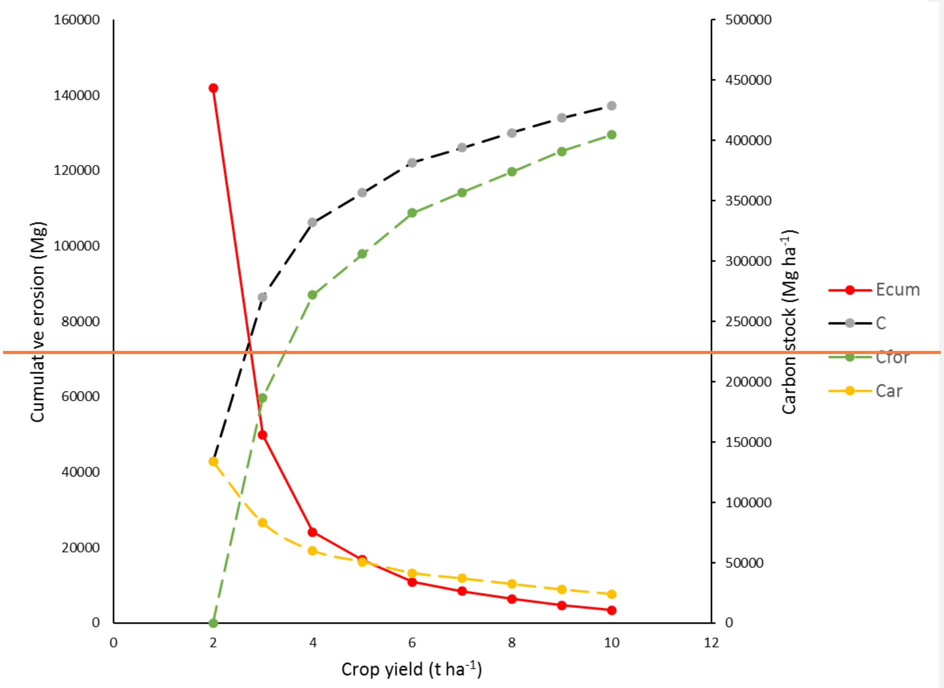

Figure 3~~2~~ Modelled ~~C~~cumulative erosion ~~(Ecum)~~ (left axis) and soil organic carbon stocks (right axis) vs. crop yield per ha for a hypothetical test area of 2900 ha and assuming a total cereal production of 5000 ton. ~~over the total area (C), on arable land (Car) and under forest (Cfor) vs. crop yield in a hypothetical test area of 2900 ha for a total cereal yield of 5000 ton.~~ We assumed that slope gradients (S (tan)) were uniformly distributed between 0.02 and 0.58, i.e. an area of 100 ha in each 0.02 slope class. The crop yield shown is the crop yield on a zero slope and relative crop yield (P) is assumed to vary with slope ($P=1-S^{0.5}$). Erosion is assumed to vary with slope gradient according to the slope function derived by Nearing (1997) and an erosion rate of 10t ha^{-1} y^{-1} is assumed on a 0.09 slope. Soil organic carbon stocks per unit area are assumed to be 40 ~~t~~ Mg ha^{-1} on arable land and 170 ~~t~~ Mg ha^{-1} under forest (Poeplau et al., 2011). The total soil organic carbon stock (C total) clearly increases with increasing crop yield because the gain in ~~C~~soil organic carbon stocks on forested land (C forest) is much more important than the loss on arable land (C arable). ~~learly, low-yield scenarios are detrimental for landscape-scale C storage.~~

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Increasing agricultural production in Africa through areal extension alone would therefore imply that overall soil losses would increase much more rapidly than agricultural production would. If, on the other hand agricultural yields on good agricultural land would be improved, it may be possible to set aside some of the marginal land that is currently used for arable farming. The somewhat counterintuitive result of this will be that, even if erosion rates on the arable land that remains in production would increase due to intensification, the overall soil loss (at the landscape scale) would still decrease (Figure 3~~Figure 2~~).

Smart intensification will conserve soil carbon which will, on its turn, reduce erosion risks. Over the last decades, a significant body of scientific literature has emerged on the potential of agricultural land to store additional soil organic carbon through the use of appropriate management techniques. While studies do suggest that some gains are indeed possible, most studies report modest gains at best. ~~Under conservation tillage,~~ Reported average sequestration rates under conservation tillage in Canada are between 0 and 0.14 Mg C ha^{-1} yr^{-1} in Canada

(VandenBygaart et al., 2010) ~~and~~ while an average sequestration rate of 0.12 Mg C ha^{-1} yr^{-1} ~~in~~ has been calculated for the USA (Eagle et al., 2012). In a study covering 12 study sites in three Midwestern states of the USA Christopher et al. (2009) did not find any significant increase in soil organic carbon storage under no-till in real farming conditions. Experimental studies also showed that under agroforestry gains in soil organic carbon are ~~very~~ small, with an average of 0.25 Mg C ha^{-1} yr^{-1} (Govers et al., 2013) ~~**(Error! Reference source not found.)**~~. These findings contrast not only with claims in the literature (Ramachandran Nair et al., 2009), but also with the observation that soil carbon stocks on natural (or undisturbed) land are generally much higher (often more than three times higher) than those observed on arable land~~: carbon stocks under forest can be three times as high as stocks on arable land~~ (e.g. Poeplau et al., 2011; Hiederer and Köchyl, 2012).

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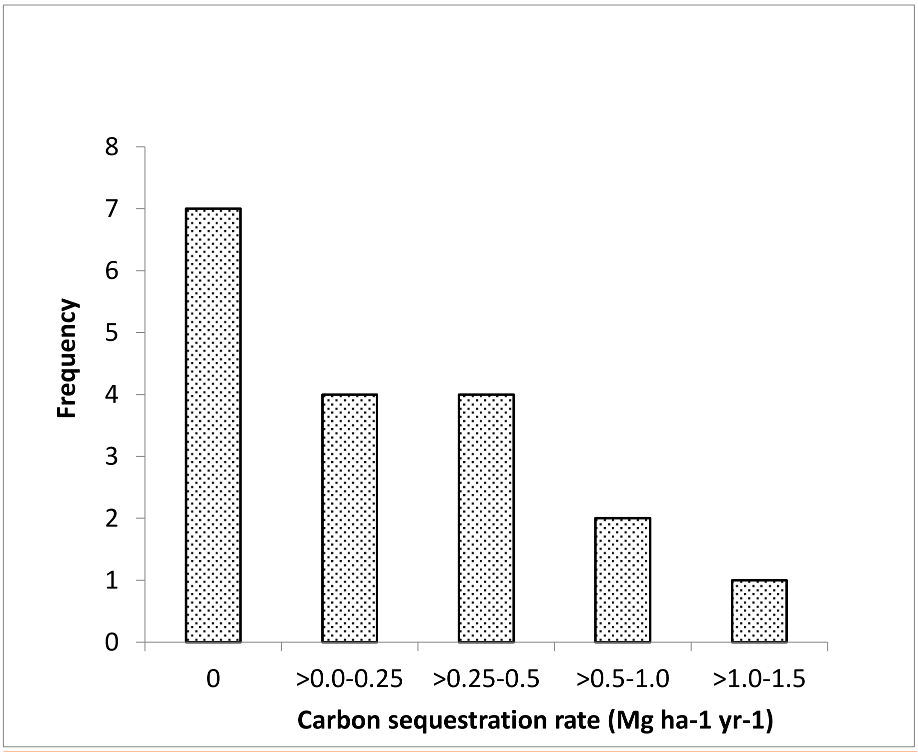

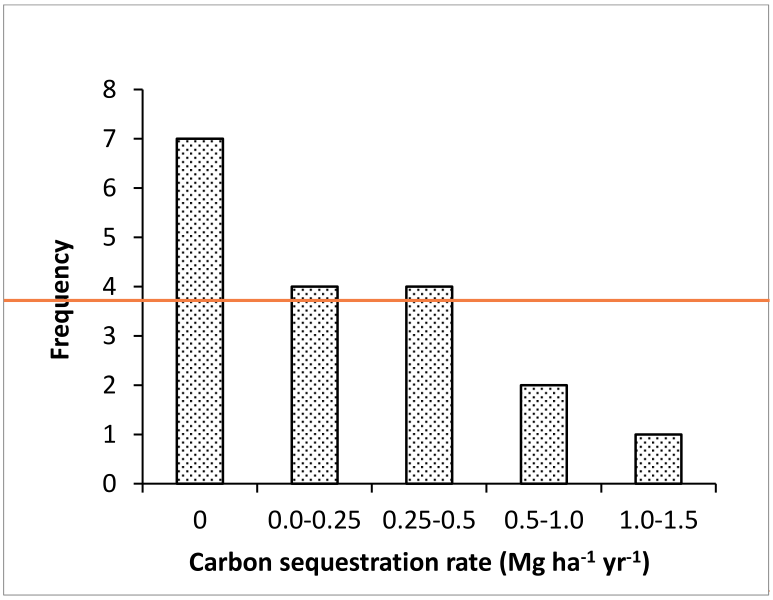

Figure 43 Frequency distribution of experimentally observed carbon sequestration rates under agroforestry. Data from 18 paired field studies in both (sub-)tropical and temperate climates (details and references of studies in (Govers et al., 2013)). The average soil organic carbon sequestration rate reported over all 18 studies is 0.25±0.33 Mg ha^{-1} yr^{-1}.

The latter is related to two main factors: (i) biomass is not removed from natural land, which results in larger organic carbon inputs and (ii) these lands are not mechanically disturbed which reduces carbon respiration rates. Thus, more soil carbon will be conserved when the amount extent of agricultural land is reduced and more land is preserved under or restored towards natural conditions. An additional beneficial effect of the latter is that , on agricultural land, soil organic carbon stocks may increase on agricultural land with increasing agricultural yields, provided that the residual biomass is adequately managed (VandenBygaart et al., 2010; Minasny et al., 2012): this, in turn, will reduce the erosion and degradation risk (Torri and Poesen, 1997). Thus, again intensification will allow to preserve more carbon then areal extension (Figure 3Figure 2, Figure 5Figure 4).The fact that intensification is beneficial for soil carbon conservation has also been demonstrated at the global level: agricultural intensification has allowed to avoid ca. 161 Pg of carbon emissions from the soil to the atmosphere between 1960 and 2005 (Burney et al., 2010).

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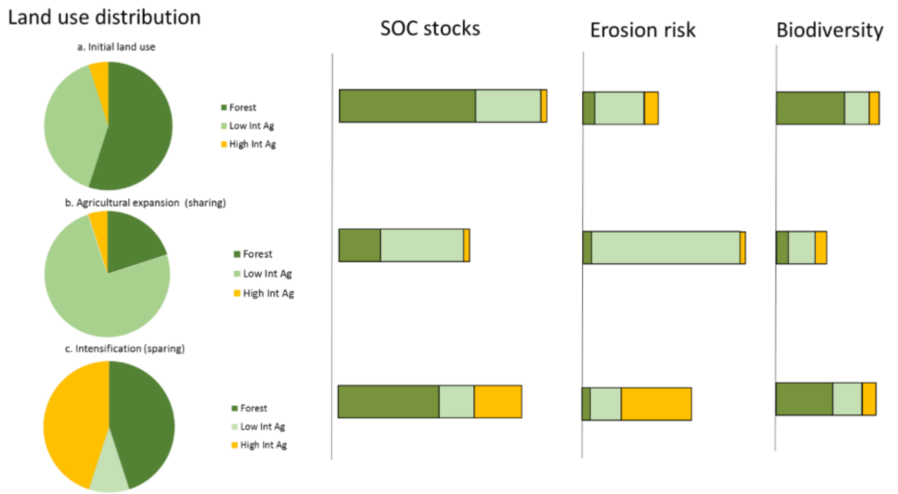

Figure ~~5~~4 Semi-quantitative ~~Qualitative~~ illustration of the effects of a~~n~~ significant increase of agricultural production through smart intensification (sparing land) vs. agricultural expansion (sharing land) on soil organic carbon stocks, the erosion risk and biodiversity. We assume that in a given area the required increase in agricultural production is such that, if yields are not increased, the entire area that is potentially suitable for agriculture (80% of the total area) has to be used for agriculture and that smart intensification would reduce the area needed to ca. 55% of the total area. The bar graphs give a semi-quantitative assessment~~Intensification is~~, at the landscape scale, of the impact of these alternatives according to current scientific insights. Smart intensification is beneficial with respect to ~~SOC~~ soil organic carbon storage because soil organic stocks under natural forest are much higher than under arable land (e.g. Poeplau et al., 2011). ~~,~~ Smart intensification will reduce total soil erosion because less marginal (sloping) land needs to be taken into production (e.g. Van Rompaey et al., 2002). Finally, smart intensification is beneficial for ~~as well as~~ biodiversity because ~~gains from land sparing outweigh those from low intensity agriculture.~~ more forest is preserved and the biodiversity of undisturbed forests is much higher than that of land used for agriculture (e.g. Phalan et al., 2011a).

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Smart intensification will help to make agriculture in the South more water-efficient. Agriculture is by far the largest global consumptive user of blue water (water extracted from rivers and groundwater): at the global scale, over 80% of all consumptive water use is related to agricultural activities (e.g. Doll et al., 2009). As the amount of available water will not significantly increase in the future, a more efficient water use is a prerequisite to increase agricultural production in the South. Less productive systems are often more water-intensive, i.e. more units of water are needed for each unit of crop that is produced. Striving towards higher yields will remedy this problem as it allows to increase the amount of crop produced per unit of water (Rockström et al., 2007). Higher yields are therefore a means to increase water conservation and to make sure that more water is available for the functioning of non-agricultural ecosystems. Clearly, the realisation of this potential requires other measures as well such as a realistic pricing of water and water use monitoring in areas where water scarcity is a problem so that inefficient use of this scarce resource can be prevented. Again, the implementation of such systems will be far more efficient in high-yield systems as the return per unit of capital cost will be higher.

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Smart intensification is beneficial for biodiversity at the landscape scale. Environments where intensive agriculture is dominant are often very poor in terms of biodiversity. One might therefore suggest that, in order to preserve biodiversity, one should ~~therefore~~ avoid intensification and maintain a certain biodiversity on agricultural lands. Again, such a strategy would necessarily imply that more land would be needed to produce the same amount of agricultural goods. Recent studies have consistently shown that such a strategy is not beneficial for biodiversity at a larger scale: the biodiversity gained on agricultural land is, in general, not sufficient to compensate for the additional biodiversity loss due to agricultural land expansion (e.g. Phalan et al., 2011b; De Beenhouwer et al., 2013; Schneider et al., 2014). Thus, land sparing and concentrating intensive agriculture on designated areas is generally a better strategy than land sharing with low-intensity agriculture that will occupy a much larger fraction of the available land (Figure 5~~Figure 4~~). Sparing will not always be the best strategy as this will ~~invariably~~ depend on local conditions: for instance, wildlife-friendly agriculture ~~is~~ may be the best solution in the buffer zones around wildlife reserves.

Smart intensification will increase the added value of the land used for agricultural production and hence make the implementation of conservation measures economically sound. Clearly the economic value of a good such as arable land depends on the economic return that can be gained from the use of it. Intensification will allow to increase these returns. This is especially true for sub-Saharan Africa where yields are still abysmally low (Neumann et al., 2010). While there are many reasons for this, a key factor is that African soils are chronically underfertilized (Henao and Baanante, 2006; Keating et al., 2010). The amount of fertilizer used per unit of surface are of agricultural land in Africa is only 10% of what is being used in Europe or the United States: the consequence is that, in many cases, the nutrient balance of many African agricultural systems is negative, i.e. more nutrients are removed through harvesting than there are supplied by fertilization (Smaling et al., 1993; Henao and Baanante, 2006). This negative balance is further aggravated by soil erosion, which annually mobilises more nutrients than are applied in sub-Saharan Africa (Quinton et al., 2010). Even a modest increase in fertilizer use may therefore allow to significantly boost agricultural yields in sub-Saharan Africa, at least if this increase would be accompanied by other measures such as the introduction of high-yield varieties and the necessary training for the farmers (Sanchez, 2010; Twomlow et al., 2010; Mueller et al., 2012).

Higher agricultural yields will ~~clearly~~ increase the added value that may be produced per unit of agricultural land and hence its value. A consequence of this is that the economic stimulus to implement conservation measures on this land will increase as land will become a more precious resource. Furthermore, intensification will also reduce the overall conservation investment that has to be made as the acreage that needs to be treated will be smaller which will allow to concentrate the available resources on a smaller area. Finally, many conservation strategies are based on the use of crop residue (i) to ~~(i)~~ return nutrients and carbon to the soil and (ii) to reduce the soil erosion risk. Such strategies are likely to be more successful when more residue per unit of area is available. Case studies have repeatedly shown that the mechanisms described above can indeed lead to more effective soil conservation under increasing intensification and population pressure (e.g. Tiffen et al., 1994; Boyd and Slaymaker, 2000)

Smart intensification will help to create the market opportunities needed for sustainable agriculture. The dramatic increase in population that will occur in the South over the next century, in combination with rapid urbanisation and economic growth, make the transition towards a market-oriented agriculture inevitable. This is not a bad thing: all too often we have a far too rosy view on the potential of subsistence agriculture. The truth is that subsistence farming does not generate the necessary financial means for the farmers to get out of poverty, although improvements in agricultural technology may contribute to increased food security (Harris and Orr, 2014). Only when farmers have access to markets they can generate an income that allows them to fully participate in society so that they can not only benefit from the material perks of modern life but also provide a high quality education to their children and the necessary health care to those who need it: soil conservation as such cannot achieve this

(Posthumus and Stroosnijder, 2010). Case studies support that a symbiosis between the development of a market-oriented agriculture and soil conservation is indeed likely as market access provides farmers with the economic incentives to implement soil conservation measures (Boyd and Slaymaker, 2000). Again, the transition from a subsistence to a market-oriented system will almost inevitably have to be accompanied by intensification as the latter will~~, again,~~ allow a better return on both capital and input investment.

Smart intensification will not be sufficient to achieve adequate soil conservation (but it will help). The points raised above illustrate that adequate soil conservation is much more likely to be achieved if more intensive agricultural systems are developed in the Global South as the economic and environmental stimuli to implement soil conservation measures will be much larger. Yet, the experiences in Europe and Northern America illustrate that this may not be sufficient to achieve adequate soil conservation and that government stimulation (through financial measures) and/or coercion may be necessary to further reduce soil degradation. It is, however, the magnitude of such efforts and their effectiveness that should be considered. The societal efforts and costs that will be needed to achieve adequate soil conservation will be far smaller when less land is used for agriculture as much less land will need treatment. Furthermore, one may also imagine that efforts to convince farmers to adopt conservation measures will be more successful in an intensive, market-oriented agricultural system as they will, generally, be more open to changes and both governments and other stakeholders will have more leverage in discussions on how the agricultural system needs to be organised. This is, obviously, no guarantee for success as potential direct financial benefits may seduce the stakeholders to neglect the necessary investments to achieve long-term sustainability. The latter is a problem that occurs everywhere where environmental and economic concerns conflict and, while general principles to resolve such problems have been formulated (Ostrom, 2009), specific policies to deal with this conflict will depend on local conditions.

Conclusions

All too often, soil conservation is discussed in isolation, whereby much attention is given to the effectiveness of technical solutions in reducing excessive soil and water losses at a given location. Agriculture, however, is a system wherein lateral connections at different scales are very important: actions at a specific location will necessarily have implications at other locations. Agricultural systems are also subject to constant change as they respond to changes in population numbers, population distribution, economic wealth and cultural preferences. A coherent vision on the development of soil conservation in 21st century needs to account for this context and needs to consider both the spatial and temporal dynamics of agricultural systems.

While it is certainly true that conservation technology can be further developed other considerations may be more important for the successful implementation of soil conservation programs. In our view, smart intensification is an essential ingredient of any strategy seeking efficient soil conservation while at the same time meeting the growing food demands of a strongly increasing, more urbanised global population. Smart intensification will help to reduce the land surface area exposed to a high soil degradation risk while it will, at the same time, increase the return on the soil conservation measures that will still be necessary. Smart intensification will also allow to reap additional environmental benefits in terms of soil organic carbon storage, biodiversity and water availability. It will also be directly beneficial to the farmer, allowing her/him to produce food for more people and to achieve an acceptable income. It is therefore no surprise that, when considering these other angles, other researchers have reached similar

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conclusions, stating that agriculture in the Global South and particularly in Africa needs to intensify and that the exclusive focus on smallholders as engines for growth needs to change (Collier and Dercon, 2009).

Intensification is not a panacea that magically solves all problems. Striving towards higher crop yields will require the use of more external inputs, including the use of mineral fertilizers. This is often assumed to be detrimental to the environment: yet this only will be true if fertilizers are used excessively, as is the case now in many areas of the world (Sattari et al., 2012; Lassaletta et al., 2014; Zhang et al., 2015). If correctly used, the environmental benefits of judicious mineral fertilizer use will more often than not outweigh their potential negative impacts by reducing the amount of land needed for agricultural production (Tilman et al., 2011). Furthermore, intensification will require higher energy and capital inputs per unit of surface area: these extra investments will partly be compensated by the fact that a smaller area of land needs to be cultivated but access to markets will often be essential to make intensification profitable.

Smart intensification as such will not be sufficient to reduce soil loss to acceptable levels: also in intensive systems, soil losses are often higher than is tolerable and conflicts between (long-term) environmental and (short-term) economic goals will be present. Yet, they will be easier to tackle when we give smart intensification adequate consideration in any plan on future agricultural development in the Global South.

Acknowledgement

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