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

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Abstract

While the implementation of soil conservation depends on a multitude of factors, it is also clear that rapid change in agricultural systems only happens when a clear economic incentive is present. This fact, as well as the fact that agriculture will change fundamentally in the Global South over the next decades, need to be accounted for when developing a vision on how we may achieve effective soil conservation in the Global South. In this paper we argue that smart intensification is a necessary component of such 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 viable future

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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, fiber or fuel) used by humans for nutrition and a large range of economic activities. These numbers illustrate the central role played by agricultural soils in the functioning of even the most sophisticated human societies: to a large extent, these areas have been selected because they have soils that make them suitable for agriculture. But it is not only the soils on agricultural land that do provide us 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 soils on agricultural and non-agricultural land 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, carbon storage per unit area is generally much more important on non-agricultural land (Hiederer and Köchyl, 2012). By allowing plants to grow, soils significantly contribute to the functioning of 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 other natural resources, soils are under intensive pressure. Organic carbon change, 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 (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 heavily affected by erosion may remain lower than expected, even after excessive erosion has been halted for several decades (Hornbeck, 2012). Leaving agricultural erosion unchecked is synonymous to the unsustainable mining the global soil resource.

It is rather surprising that agricultural soil erosion still is such an important threat to the soil resource. The detrimental effects of erosion have been recognised for a long time: the modern fight of industrialized countries against excessive erosion started in countries such as Iceland and France. In France, environmental degradation by excessive water erosion of mountain hillslopes literally ruined the livelihood of entire mountain communities at the

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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 by the end of the 19th century. 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 y^{-1} for water erosion, ca. 5 Gt y^{-1} for tillage erosion and 2-3 Gt y^{-1} for wind erosion (Govers et al., 2014b; Van Oost et al., 2007). Measured soil production rates are, on average, ca. 0.036±0.04 mm yr^{-1} (Montgomery, 2007) and even lower on most agricultural soils because agricultural soils can be expected to have a certain thickness (Stockmann et al., 2014). Over all agricultural land (arable and pasture) total soil formation would amounts to maximum *ca.* 2 Gt 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 approximate (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, is 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 of nitrogen and 14-26 Tg of phosphorous (Quinton et al., 2010): these numbers may be compared with the annual application rate of mineral fertilizers, which are ca. 122 Tg for N and ca. 18 Tg 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) and ca. 4.75 USD/(kg P) the amount of fertilizers mobilised by soil erosion is equivalent to ca. 35 billion USD for N and ca. 80 billion USD for P: such amounts are considerable, even if once considers that the total global agricultural food production is nowadays valued at ca. 4000 billion USD (http://faostat.fao.org/site/613/DesktopDefault.aspx?PageID=613#ancor). Most of these soil and nutrient losses takes place in the hilly and mountain areas in the so-called Global South: a recent scientific appraisal by FAO and ITPS showed that erosion problems are still increasing in Africa, Latin-America and Asia. The situation is perceived to be improving in Europe and North America (Table 1), 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, where it is often still the main economic activity, which suffers excessively from these losses.

In this paper we will reflect on why, despite these clear facts, effective soil conservation is not yet a done deal and soils continue to suffer from excessive degradation, especially in the Global South (Latin America, Africa, the developing nations of Asia and the Middle East) and what might be done about this. We will argue that, especially for the Global South, there is a need for a novel vision on soil conservation, 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 to develop

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agriculture 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 farming communities. Before discussing different the different building blocks of such a vision we will first assess possible reasons as to why soils do not yet get the protection they deserve.

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 is indeed is indeed available for North America and Europe (Cerdan et al., 2010b; 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 (Cerdan et al., 2010a). However, also when models are used, estimates are often incorrect. This is mainly due to two interrelated 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 (Govers et al., 2014a). Erroneous predictions do not only make it sometimes 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 hardly the only 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 service of Iceland and the United States did, long before accurate erosion measurements were possible. Simple visual observations on the presence of rills and gullies or wind deflation areas allow in many cases to identify areas with excessive erosion rates necessitating the implementation of conservation measures. Another reason why an exact quantification is not always necessary is that conservation measures are generally not proportional: their implementation is most often of a yes/no type: one does decide whether or not to implement conservation tillage, but not by how much.

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 necessary tools at our disposal 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

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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 (Leys et al., 2010; Montgomery, 2007). 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 are generally very low (< 1 t ha y) and comparable to those occurring under natural vegetation(Montgomery, 2007). Conservation tillage may also be used to drastically control wind erosion because 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 need not always be the weapon of choice for the soil conservationist. 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). In other cases 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 but also proper land use allocation. Erosion rates can often be reduced to acceptable levels through the combined use of stone bunds, exclosures, check dams and modifications of tillage techniques and crop rotations (Nyssen et al., 2009; Valentin et al., 2008). Wind erosion may also be controlled through a combination of techniques, e.g. combining mulching and wind breaks (Sterk, 2003).

Not only arable land can be subjected to excessive erosion: grazing lands may also suffer from a drastic reduction in vegetation cover, again resulting in water and/or wind erosion. Reduction of grazing pressure (at least in a first stage) and the introduction of controlled grazing are key strategies to (i)restore the vegetation cover and (ii)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 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 leading 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.

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Why then is soil conservation not more generally adopted?

Thus, 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 long been clear that several factors other than (the lack of) scientific knowledge or data hamper the adoption of conservation tillage. These factors include farmers training level, farm size and work organisation as well as access to information. Many studies do suggest that these factors indeed play a significant role in the adoption of soil conservation technology, but the analysis by Knowler and Bradshaw (2007) showed that the effect of 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).

The studies discussed above suggest that 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 incorporated. 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 78.5% 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 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 farmers in remote subsistence systems 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 in agriculture, farmers and farming systems are, most certainly, capable of rapid change. The capacity to change will obviously depend on a multitude of factors, but what appears to be certain is that farmers will change practices rapidly if they perceive a clear personal benefit. In other conditions, change may indeed be or may not even happen at all.

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 true 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 cases, potential savings are offset by additional costs: in mechanized systems the cost of machinery and agrochemicals offsets savings in fuel costs (Janosky et al., 2002; Zentner et al., 1996) while in 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 (Pittelkow et al., 2015; Van den Putte et al., 2010) 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 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 (Christopher et al., 2009; Govers et al., 2013a) and that paying farmers to store carbon would only be viable at much higher carbon prices than the current market prices (Govers et al., 2013a; Grace et al., 2012) . Thus, paying farmers for the carbon they store at market prices can only generate a relatively small economic benefit for the farmer and carbon 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. 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 have to be weighed against possible off-farm losses. 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. It is therefore not so surprising that in the Global North administrations often opt for coercion to make sure the necessary soil conservation measures are implemented (Napier et al., 1990).

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 be dependent of the local agro-ecological system: indeed, it is not only true that the factors impeding the adoption of conservation tillage vary locally (Knowler and Bradshaw, 2007), also the tools that societies have at their disposal vary greatly.

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. As a result erosion rates in North

America have gone down considerably over the last decade 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., 2015)

These approach is, at present, not possible in most countries of the Global South. Here, the baseline data that are necessary to develop such a sophisticated soil conservation policy system are lacking, making it hard to identify the farmers and areas requiring the most urgent action. Even if such data would be available, many governments in the Global South would not be able to implement a soil conservation do not dispose of 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 change the face of agriculture in the South for good over the next decades and which should be accounted for when developing a vision on soil conservation in the 21st century.

In most areas where soils are most seriously threatened, the human population will continue to grow strongly in the next decades. In the next decades, the world population will continue to grow but the locus of population growth will shift though, 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/, Gerland et al., 2014; Lutz and KC, 2010). Africa is a different matter altogether: in sub-Saharan Africa, where the demographic transition started only after the second World War 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 % in 2100, while 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, 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 (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 their 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. The average farm worker is

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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) and that rural populations are indeed rapidly aging, both in the developing and in the developed world.

It is not overly optimistic to expect that, while population growth continues, at the same time *these populations will gain in purchase power.* While it is definitely true that 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. 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 USD (2015) in 2004 to 550 USD in 2015 (http://data.worldbank.org/country/ethiopia).

The combined impact of these tendencies will clearly lead to an increased demand for food. Apart from this, the nature of the demand will shift as diets will shift away from a diet largely based on cereals towards a more varied (but not necessarily healthier) food palate in which meat will have a larger share than is currently the case. Global estimates therefore often predict that global food production (in terms of kcal) will more or less double in the first half of the 21st century (e.g. (Tilman et al., 2011) As (relatively) more people will live in cities, there will be relatively less 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 have to rely on markets to obtain the food it needs and this will change traditional tropical smallholder farmer beyond recognition. 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 context

A key point is, of course, that more food will have to be produced in the Global South. Two contrasting pathways can be followed to meet the expected increase in food demand. 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). Here, the so-called Green Revolution led to a dramatic rise in agricultural yields through the combination of new 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 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 0.978 billion to 1.53 billion in Eastern Asia and from 1.055 billion to 2.20 billion in 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. 291 million ha of agricultural land is in use in Africa, but there is still another 400 million ha of land on the continent that is suitable (good) of 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.

Such a strategy may, at first sight, be attractive from the point of view of soil conservation. One might indeed argue that a further areal extension 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 intensification and aiming at area extension may therefore seem attractive to avoid excessive soil degradation as traditional farming methods can be maintained and optimised to be as environmentally friendly as possible. Many organisations that are working 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 African agriculture in particular and tropical smallholder farming in general do need judicious intensification for soil conservation to become successful. Furthermore, what might be call smart intensification would allow to reap additional environmental benefits that may be lost when a less-intensive development path is chosen. In other words, smart intensification will make tropical farming more eco-efficient and hence more sustainable.

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 flatter land is preferred over steeper land for obvious reasons (Bakker et al., 2005; Van Rompaey et al., 2001). 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. 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 amount of erosion per unit of crop yield will therefore necessarily increase when area expansion is preferred over intensification (Figure 1).

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 increase.

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. 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 is in Africa 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 (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 (Mueller et al., 2012; Sanchez, 2010; Twomlow et al., 2010).

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 to (i) return nutrients and carbon to the soil and (ii) reduce the soil erosion risk. Such strategies are likely to be more successful when more residue per unit of area is available.

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 findings do indeed suggest that some gains are indeed possible, most studies report modest gains at best. Under conservation tillage, reported average sequestration rates are between 0 and 0.14 Mg C ha^{-1} yr^{-1} in Canada (VandenBygaart et al., 2010) and 0.12 Mg C ha^{-1} yr^{-1} in 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 are very small. (Table 2) These findings contrasts with the observation that carbon inventories on natural (or undisturbed) land are generally much higher than those observed on arable land (Poeplau et al., 2011). 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 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 inventories may increase with increasing agricultural yields, provided that the residual biomass is adequately managed (Minasny et al., 2012; VandenBygaart et al., 2010): this, in turn, will reduce the erosion and degradation risk (Torri and Poesen, 1997). Thus, again intensification will allow to preserver more carbon then areal extension (Figure 1).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 between 1960 and 2005 (Burney et al., 2010).

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 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 stragegy would not be beneficial for biodiversity at a larger scale: indeed, the biodiversity gained on agricultural land is in most cases not sufficient to compensate for the additional biodiversity loss due to agricultural land expansion (Phalan et al., 2011). 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 1). Sparing will not always be the best strategy as this will invariably depend on local conditions: for instance, wildlife-friendly agriculture is the best solution in the buffer zones around wildlife reserves.

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 (Doll et al., 2009). As the amount of available water will not 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 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.

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

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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). Again, the transition from a subsistence to a market-oriented system will almost inevitably be 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 need to be developed everywhere such conflicts occur.

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: consequently actions at a certain locations will necessarily have implications at other locations. Agricultural systems are also subject to constant change as they respond to changes in population numbers, population spreading, 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 most 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 carbon storage, biodiversity and water availability. It is therefore no surprise that, when considering these other angles, people have reached similar conclusions, stating that agriculture in the Global South and particularly in Africa needs to intensify.

Clearly, intensification brings risks. 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 (Foley et al., 2011). However, the environmental benefits of judicious mineral fertilizer use will far outweigh their potential negative impacts (Tilman et al., 2011).

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

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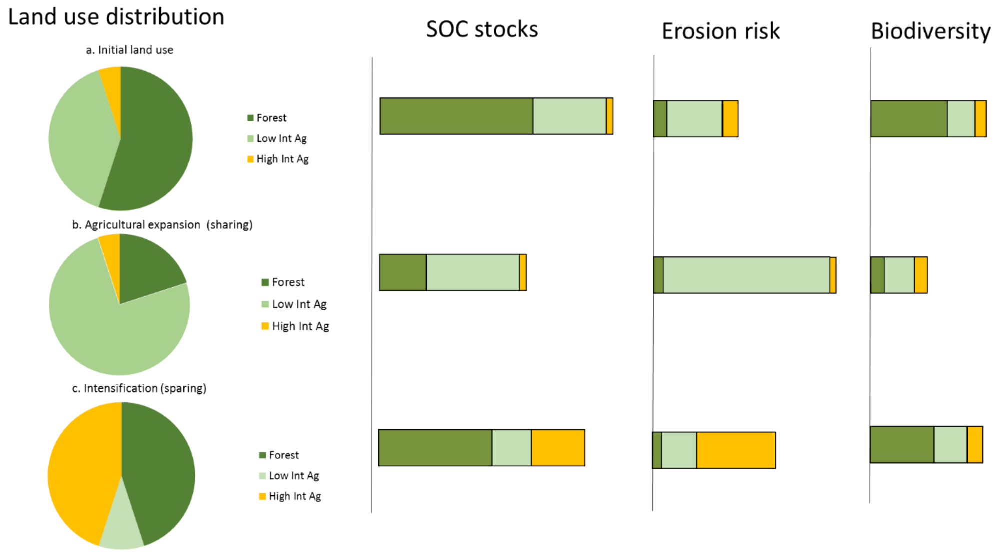

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636 *Figure 1* The effects of an increase of agricultural production through intensification (sparing) vs.
637 agricultural expansion (sharing) on soil organic carbon storsks, erosion risks and biodiveristy.
638 Intensification is, at the landscape scale, beneficial for all aspects.

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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)

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Reference	Location	System	SOC sequestration rate (Mg C ha^{-1} yr^{-1})	Sampling depth	Comment
(Lenka et al., 2012)	Eastern India	Various techniques to reclaim degraded land	0	0-0.3m	Reclamation led to significant SOC storage (2-3 Mg C ha^{-1} yr^{-1}, but presence of trees did not help
(Veum et al., 2011)	Missouri, claypan region	No-till vs. grass filter strips vs. agroforestry filter strips, 10 yrs	0	NA	No significant differences in total SOC between systems
(Salazar et al., 2011)	Chile, Mediterranean zone	Agroforestry in combination with water harvesting vs. other systems, 12 yrs	0	NA	No significant differences in total SOC between systems
(Peichl et al., 2006)	Southern Ontario, Canada	Tree-based intercropping (poplars), 13 yrs	ca. 1	NA	Significant SOC increase under poplars
(Peichl et al., 2006)	Southern Ontario, Canada	Tree-based intercropping (spruce), 13 yrs	0	NA	Spruce did not lead to any SOC enhancement
(Sharrow and Ismail, 2004)	Western Oregon, USA	Agroforests vs. pastures, 10 yrs	0		No significant difference in SOC content
(Oelbermann et al., 2004)	Canada	Alley cropping, 10 yrs	0	0-0.2	No significant differences in SOC stocks
(Oelbermann, 2002)	Costa Rica	Alley cropping, 10 yrs	0	0-0.2	No significant differences in SOC stocks
(Oelbermann, 2002)	Costa Rica	Alley cropping, 19 yrs	0.25	0-0.2	Same tree as study above (*E. poeppigiana*) but longer monitoring time
(Oelbermann, 2002)	Costa Rica	Alley cropping, 10 yrs	1.1	0-0.2	*G. Sepium trees*
(Oelbermann, 2002)	Costa Rica	Alley cropping, 19 yrs	0.42	0-0.2	*G. Sepium trees*

(Schroth et al., 2002)	Amazonia	Multistrata system, 7 yrs	0.45	0-0.15	
(Chander et al., 1998)	India	Alley cropping, 13 yrs	0	0-0.15	*Dalbergia sissco*
(Mazzarino et al., 1993)	Costa Rica	Alley cropping, 10 yrs	0.47	0-0.1	*E. poeppignia*
(Mazzarino et al., 1993)	Costa Rica	Alley cropping, 10 yrs	0.44	0-0.1	*G. Sepium*
(Haggar, 1990)	Costa Rica	Alley cropping, 6 yrs	0.81	0-0.2	*E. poeppigiana*
(Haggar, 1990)	Costa Rica	Alley cropping, 6 yrs	0.2	0-0.2	*G. Sepium*
(Diels et al., 2004)	Ibadan, Nigeria	Alley cropping, 16 yrs	0.12	0.4	No net gain in SOC: decrease in SOC was less rapid under alley cropping *(L. leucocephala* and *Senna siamea)* in comparison to treeless systems

Table 2 Soil organic sequestration rates under agroforestry systems (Govers et al., 2013b)

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