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

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15   **Abstract.** Soil erosion severely threatens the soil resource and the sustainability of agriculture. After decades of

16   research this problem persists, despite the fact that adequate technical solutions now exist for most situations. This

17   begs the question as to why soil conservation is not more rapidly and more generally implemented. Studies show

18   that the implementation of soil conservation measures depends on a multitude of factors but it is also clear that

19   rapid change in agricultural systems only happens when a clear economic incentive is present for the farmer.

20   Conservation measures are often more or less cost-neutral which explains why they are often less generally adopted

21   than expected. This needs to be accounted for when developing a strategy on how we may achieve effective soil

22   conservation in the Global South, where agriculture will fundamentally change in the next century. In this paper

23   we argue that smart intensification is a necessary component of such a strategy. Smart intensification will not only

24   allow to make soil conservation more economical, but will also allow to make significant gains in term of soil

25   organic carbon storage, water efficiency and biodiversity, while at the same time lowering the overall erosion risk.

26   While smart intensification as such will not lead to adequate soil conservation, it will facilitate it and, at the same

27   time, allow to offer the farmers of the Global South a more viable future.

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Introduction

30   The terrestrial land surface provides critical services to humanity and this is largely possible because soils are

31   present. Humanity uses ca. 15 million km² of the total Earth's surface as arable farmland (Ramankutty et al., 2008).

32   Besides this, ca. 30 million km² is being used as grazing lands: on all these lands grow plants which are either

33   directly (as food) or indirectly (as feed, fibre or fuel) used by humans for nutrition and a large range of economic

34   activities. Agricultural areas, especially areas used as arable land, have often been selected because they have soils

35   that make them suitable for agriculture. But it is not only the soils on agricultural land that provide humanity with

36   essential services. Also on non-agricultural land soils provide the necessary rooting space for plants, store the

37   water necessary for their growth and provide nutrients in forms that plants can access. Both on agricultural and

38   non-agricultural land soils are host to an important fauna whose diversity is, by some measures, larger than that of

39   its aboveground counterpart (De Deyn and Van der Putten, 2005). Both on agricultural and non-agricultural land

40   soils store massive amounts of organic carbon, the total amount of which (ca. 2500 Gt, Batjes, 1996; Hiederer and

41   Köchyl, 2012) is much larger than the amount of carbon present in the atmosphere (ca. 800 Gt). Importantly,

42   organic carbon storage per unit area is generally much higher on non-agricultural land (Poeplau et al., 2011;

43   Hiederer and Köchyl, 2012). By allowing plants to grow, soils significantly contribute to the terrestrial carbon

44   sink, which removes an amount equal to 30-40% of the carbon annually emitted by humans from the atmosphere

45   (Le Quere et al., 2009). Soils, both those on agricultural and non-agricultural lands, are therefore a vital part of

46   humanity's global life support system, just like the atmosphere and the oceans. An Earth without soils would be

47   fundamentally different from the Earth as we know it and would, in all likelihood, not be able to support human

48   life as we know it.

49   No further arguments should be necessary to protect soils from the different threats posed to them by modern

50   agriculture and other human activities. Yet, as is the case with many other natural resources, soils are under

51   intensive pressure. Organic carbon loss, salinization, compaction and sealing all threaten the functioning of soils

52   to different extents in different areas of the world. One of the most important and perhaps the ultimate threat posed

53   to soils is accelerated erosion due to agricultural disturbance. When soils are used for farming their natural

54   vegetation cover is removed and they are often disturbed by tillage. The result is that, under conventional tillage,

55   erosion rates by water on arable land are, on average, up to two orders of magnitude higher than those observed

56   under natural vegetation. This acceleration creates a major imbalance as soil production is outstripped by soil

57   erosion by a factor 10-100 so that soil is effectively mined (Johnson, 1987; Montgomery, 2007; Vanacker et al.,

58   2007b). Eroded soil is, in many cases, truly lost and cannot be restored (although there are exceptions to this rule),

59   which explains why land prices in areas heavily affected by erosion may remain lower than expected, even when

60   excessive erosion has been halted for several decades (Hornbeck, 2012).

61   It is rather surprising that agricultural soil erosion still is such an important problem. Pre-industrial societies such

62   as the Inca already understood that erosion threatened agricultural productivity and used soil conservation

63   techniques such as terracing for centuries (Krajick, 1998). In France, environmental degradation by excessive

64   water erosion of mountain hillslopes literally ruined the livelihood of entire mountain communities at the end of

65   the 19th century (Robb, 2008). A similar situation developed in Iceland where excessive wind and water erosion

66   forced entire villages to be abandoned in the same period. In both countries overexploitation of the natural

67   environment by subsistence farmers through excessive deforestation and overgrazing were key factors. Both

68   countries responded to this situation: in Iceland the first soil conservation service of the world was founded in

69   1907 (Arnalds, 2005), while France started an extensive programme to restore its mountain environments (RTM)

70   as early as 1860 (Lilin, 1986). In the United States, the Dust Bowl years (1930s) moved the erosion problem high

71   up the political agenda: President Franklin Roosevelt not only erected a Soil Conservation Service but also,

72   famously, said 'A nation that destroys its soils destroys itself' (FAO and ITPS, 2015).

73   One might therefore expect that, by now, detailed information would exist on the status of the global soil resource

74   and the necessary measures would have been taken to stop soil degradation due to human action and/or mitigate

75   the consequences. Yet, this is clearly not the case: recent estimates of human-induced agricultural erosion amount

76   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.,

77   2007; Govers et al., 2014). Measured soil production rates are, on average, ca. 0.036±0.04 mm yr^{-1} (Montgomery,

78   2007) and are even lower on most agricultural soils because agricultural soils have a certain thickness and soil

79   production rates decrease with increasing soil depth (Stockmann et al., 2014). Thus, over all agricultural land

80   (arable and pasture) total soil formation would amount to maximum ca. 2 Gt yr^{-1} which implies that the global soil

81   reservoir is depleted by erosion at a rate which is ca. 20 times higher than the supply rate. Although these numbers

82   are only an approximation (for instance, they do not account for the fact that eroded soil may be re-deposited on

83   agricultural land) they clearly illustrate that we are still far away from a sustainable situation: the rate at which the

84   soil resource is being depleted is, over the longer term, a clear threat to agricultural productivity (FAO and ITPS,

85   2015). The loss of mineral soil is not the only issue: soil erosion also mobilises 23-42 Tg yr^{-1} of nitrogen and 14-

86   26 Tg yr^{-1} of phosphorus (Quinton et al., 2010). These numbers may be compared with the annual application rate

87   of mineral fertilizers, which are ca. 122 Tg yr^{-1} for N and ca. 18 Tg yr^{-1} of mineral P respectively. At 2013 USA

88   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-

89   products/fertilizer-use-and-price.aspx) the annual amount of fertilizers mobilised by soil erosion is equivalent to

90   ca. 35 billion US $ for N and ca. 80 billion US $ for P: this is a significant financial loss, even if one considers that

91   the total global agricultural food production is nowadays valued at ca. 4000 billion US $

92   (http://faostat.fao.org/site/613/DesktopDefault.aspx?PageID=613#ancor). Most of these soil and nutrient losses

93   take place in the hilly and mountain areas in the so-called Global South: a recent scientific appraisal by FAO and

94   the ITPS (the Intergovernmental Technical Panel on Soils) showed that erosion problems are still increasing in

95   Africa, Latin-America and Asia (FAO and ITPS, 2015). The situation is perceived to be improving in Europe and

96   North America (FAO and ITPS, 2015), albeit that also in these regions soil losses are often still above the tolerable

97   level (Verheijen et al., 2009). Thus, it is especially the agriculture in the Global South (Latin America, Africa, the

98   developing nations of Asia and the Middle East), where it is often one of the main economic activities, which

99   suffers excessively from these losses.

100   In this paper we reflect on why, despite these clear facts, effective soil conservation is not yet a done deal and what

101   might be done about this. We argue that there is a need for a novel vision on soil conservation in the Global South,

102   shifting the focus away not only from the technical issues of soil conservation but also away from soil conservation

103   as such. Soil conservation efforts need to be framed into a general vision on how agriculture will develop in the

104   South: this vision needs to account for soil protection, but must also guarantee food security and allow the

105   development of an agricultural system that does provide a sufficient income to farmers. We will first assess

106   possible reasons as to why soils do not yet get the protection they deserve. Thereafter we will discuss the building

107   blocks of a vision on future soil conservation.

108   **The status of soil conservation**

109   **Do we have the necessary data to guide soil conservation?**

110   Investing in the application of soil conservation measures is only meaningful when erosion rates are higher than

111   acceptable. This can most easily be established when erosion rates can reliably be quantified. Quantitative

112   information is indeed available for North America and Europe (Cerdan et al., 2010; NRCS, 2010). However, the

113   quality of our estimates of soil erosion rates by water for other areas on the globe is often poor. Sometimes,

114   estimates are based on a limited number of data which are simply extrapolated to larger areas: this often leads to

115   bias, simply because erosion rates are generally measured at locations where erosion intensity is much higher than

116   average (Boardman, 1998; Cerdan et al., 2010). Also when models are used to make an extrapolation, estimates

117   are often incorrect. This is due to two reasons: (i) the models that are used are often improperly calibrated, i.e.

118   model parameters are set to values that are not appropriate for the location under consideration and (ii) the model

119   parameterization may be correct but the spatial data used to drive the model are inappropriate. A typical example

120   of the latter is when slope lengths are directly derived from a DTM so that the impact of slope breaks such as field

121   borders is not accounted for (e.g. Yang et al., 2003). This can lead to a considerable overestimation of erosion

122   rates (Desmet and Govers, 1996; Cerdan et al., 2010; Quinton et al., 2010). Erroneous predictions do not only

123   make it difficult to identify the most vulnerable areas in which conservation measures are most urgent: they may

124   also invalidate the cost-benefit evaluations of soil conservation programs and lead to disinformation of the general

125   public about the extent and severity of the problem.

126   **Although there is a clear need for better, quantitative data on erosion rates, the lack of such data is not the most**
127   **important explanation as to why excessive soil erosion often still goes unchecked. While it may indeed be difficult to**
128   **quantify erosion rates correctly, it is much easier to identify those areas where intense soil erosion is indeed a problem**
129   **and where action is necessary, whatever the exact erosion rates are. This is, after all, what institutions such as the soil**
130   **conservation services of Iceland and the United States did long before accurate erosion measurements were available.**
131   **Simple visual observations on the presence of rills and gullies or wind deflation areas are clear indications that the**
132   **implementation of conservation measures is necessary (**

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134 Figure 1). Another reason why an exact quantification is not always necessary is that conservation measures
135 generally are not proportional: Their implementation is most often of a yes/no type: one can decide whether or not
136 to implement conservation tillage, but not by how much.

Do we have the necessary technology for soil conservation?

138 There is no doubt that soil conservation technology has matured over the last decades: we now have the tools to
139 effectively reduce erosion rates to acceptable levels in many, if not all, agricultural systems. Conservation tillage
140 is the tool of choice in many areas, especially in the Americas. This is hardly surprising: erosion plot research has
141 consistently shown that water erosion rates under conservation tillage are reduced by one to two orders of
142 magnitude in comparison to conventional systems (Montgomery, 2007; Leys et al., 2010). Moreover, the
143 effectiveness of conservation tillage as calculated by plot studies is likely to be underestimated: for various reasons
144 the effectiveness of conservation does increase if the slope length increases (Leys et al., 2010). As a consequence,
145 water erosion rates under conservation tillage on moderate slopes are generally very low (< 1 t ha y) and often
146 comparable to those occurring under natural vegetation (Montgomery, 2007). Conservation tillage may also be
147 used to drastically control wind erosion not only because residue cover does reduce the shear stress to which soil
148 particles are exposed but also because the presence of residue helps to keep the surface soil layer moist, thereby
149 increasing its shear strength.
150 Conservation tillage is not always the best tool. It may be difficult or impossible to apply with certain crops, such
151 as potatoes grown on ridges, and/or difficult to introduce into specific agricultural systems as it may affect the
152 overall workload or the gender balance of the workload (Giller et al., 2009). It may also not be sufficient to
153 implement conservation tillage as processes such as gully erosion may not be effectively controlled and may in
154 some cases even be enhanced by conservation tillage as the latter is much more effective in reducing erosion than
155 in reducing surface runoff (Leys et al., 2010). However, also in such cases technological solutions do exist: they
156 can consist of infrastructural measures such as stone bunds and terrace building in combination or vegetation
157 measures such as grassed waterways, but also proper land use allocation can make a significant difference. Water
158 and wind erosion rates can often be reduced to acceptable levels through the use of such measures in combination
159 with modifications of tillage techniques and crop rotations (Sterk, 2003; Valentin et al., 2008; Nyssen et al., 2009).
160 Not only arable land can be affected by excessive erosion. Grazing lands may suffer from a drastic reduction in
161 vegetation cover due to overgrazing and compaction, again resulting in excessive water and/or wind erosion with
162 rates up to two orders of magnitude higher than those observed under natural conditions (Vanacker et al., 2007b).
163 Reduction of grazing pressure (at least in a first stage) and the introduction of controlled grazing are key strategies
164 (i) to restore the vegetation cover and (ii) to allow these lands to become productive again so that they can be
165 sustainably used (Mekuria et al., 2007). Such measures can be further supported by the planting of trees (Sendzimir
166 et al., 2011). Reforestation may also be a solution as it reduces erosion rates to near-natural levels but it has evident
167 implications for the type of agriculture that can be supported (Vanacker et al., 2007b). Thus, as is the case on
168 arable land, the key to erosion reduction on grasslands is in most cases the maintenance or restoration of a good
169 vegetation cover, possibly supported by technical measures.
170 Erosion in agricultural areas is often not directly related to agricultural activities but also to the infrastructure
171 related to these activities such as roads and field boundaries. Unpaved roads on sloping surfaces are not only
172 important sources of sediment in many agricultural areas (Rijsdijk et al., 2007; Vanacker et al., 2007a) but also in

173 cities (Imwangana et al., 2015). Water is often concentrated at field boundaries therebyleading to gully formation
174 (Poesen et al., 2003). Again, the necessary technological know-how to control such erosion phenomena is
175 available: check dams, better water drainage infrastructure, the implementation of field buffer zones and a better
176 landscape organisation all help to reduce sediment production on road networks and in built-up areas.

177 Why then is soil conservation not more generally adopted?

178 Thus, neither the lack of conservation technology nor the lack of data on the erosion hazard can fully explain why
179 efficient soil conservation measures are still not implemented on most agricultural land, especially in the Global
180 South. It has indeed long been clear that several factors other than (the lack of) scientific knowledge or data hamper
181 the adoption of conservation tillage. These factors include the training level of the farmer, the farm size and work
182 organisation as well as access to information. However, a thorough analysis by Knowler and Bradshaw (2007)
183 showed that the effect of these variables was often ambiguous (when different studies are compared) and that few,
184 if any, variables showed a consistent effect. One might conclude from this that changing farming practices must
185 be inherently difficult, as our understanding of controlling factors is relatively poor and many barriers to the
186 adoption of novel technology need to be overcome. This is not only a problem in the Global South: also in Europe
187 the adoption of conservation tillage is slow in many countries due to a multitude of factors, including the fact that
188 soil tillage is deeply rooted in the culture of many farmers (Lahmar, 2010).
189 Clearly, farming systems are, to some extent, 'locked in': they rely on well-tried technology, division of labour
190 and crop types and are therefore difficult to change. There are, nevertheless, also cases where farming systems
191 change rapidly and conservation technology is quickly adopted. Once the necessary technology was available,
192 conservation tillage spread very rapidly through most of Argentina and Brazil: in Argentina, it took ca. 20 years
193 (from 1990 to 2010) to bring ca. 80% of the arable land under no-till (Peiretti and Dumanski, 2014), thereby
194 effectively halting excessive soil erosion on most of the arable land of the country. In Brazil, more than 25 million
195 ha of land was under no-tillage in 2006, whereas the technique was virtually unused before 1990 (Derpsch et al.,
196 2010). Rapid changes in agricultural systems are not limited to the adoption of conservation tillage. When
197 subsistence farmers in remote areas gain access to profitable markets, very rapid changes can occur, even in areas
198 where existing technology is poor: such changes can have very negative effects in terms of soil degradation rates
199 as a switch to cash cropping may introduce crops to which a much higher erosion risk is associated (Valentin et
200 al., 2008). Thus, while cultural and technological barriers to change certainly do exist, farmers are most certainly
201 capable of rapid change. Whether such rapid change occurs critically depends on whether farmers think change
202 will bring them a personal gain.
203 This is where the problem lies. Under some conditions, the adoption of conservation technology is indeed clearly
204 economically beneficial to the farmer: this appears to be true for large farming operations in (sub-) tropical regions
205 growing cash crops such as soy beans (Peiretti and Dumanski, 2014). But in most other cases the direct benefits
206 of the implementation of conservation agriculture and/or other soil conservation measures are small, if they exist
207 at all. This appears to be the case for both large-scale mechanised agriculture in the temperate zone as well as for
208 marginal hillslope farming in developing countries (Knowler et al., 2001). In both scenarios, potential savings are
209 offset by additional costs: in mechanized systems the cost of machinery and agrochemicals offsets savings in fuel
210 costs (Zentner et al., 1996; Janosky et al., 2002) while in traditional hillslope farming extra work hours are needed
211 to maintain conservation structures and some land has to be sacrificed to implement these structures, thereby

212 reducing overall yields (Nyssen et al., 2007; Quang et al., 2014). Importantly and contrary to common belief, crop

213 yields do not rise significantly in conservation systems if no additional inputs are provided: this is true for advanced

214 technological systems (Van den Putte et al., 2010; Pittelkow et al., 2015) as well as for tropical smallholder farming

215 (Brouder and Gomez-Macpherson, 2014). As a consequence, farmers often do not have direct incentives to

216 implement soil conservation measures and change becomes difficult to implement.

217 One may argue that benefits should not only be considered at the level of the individual farmer, but also at the

218 societal level, where soil conservation may generate co-benefits. Often carbon storage and biodiversity protection

219 under conservation systems are mentioned as important ecosystem services for which farmers could be paid.

220 Research in the last decade has consistently shown that carbon storage gains in conservation systems are lower

221 than was anticipated two decades ago and is generally well below 1 t C ha^{-1} yr^{-1} ((Oorts et al., 2007; Angers and

222 Eriksen-Hamel, 2008; Christopher et al., 2009; Eagle et al., 2012; Govers et al., 2013). Furthermore, paying

223 farmers to store carbon would only be viable at much higher carbon prices than the current market prices, which

224 are around 10-15 USD ton^{-1} (Grace et al., 2012; Govers et al., 2013). Paying farmers at current market prices can

225 only generate a relatively small economic benefit for the farmer and prices would have to rise significantly for soil

226 carbon storage to become an important element on the farmers' balance sheet. On the other hand, soil conservation

227 generally has a positive impact on (soil) biodiversity on the farm land as soils are less frequently disturbed (Mader

228 et al., 2002; Verbruggen et al., 2010). Where agriculture is interspersed with densely populated areas, additional

229 co-benefits may consist of a reduction of flooding and/or siltation of sewage systems and water treatment plants,

230 which are important problems in many areas in Europe (Boardman et al., 1994). These benefits, however, are

231 difficult to convert to financial income for the farmer. This is not only because the economic value of increased

232 biodiversity on farmland is difficult to quantify but also because such on-farm benefits in biodiversity have to be

233 weighed against possible off-farm losses (see below). The reduction in flooding risk, on the other hand, will

234 generally not be considered as a benefit by society but rather as damage repair: the problems were caused by

235 agriculture in the first place.

236 **The way forward**

237 How then should we proceed to stimulate a more rapid adoption of soil conservation measures to protect the

238 world's soil resource? The answer to this question will obviously depend on the characteristics of the local agro-

239 ecological system. Agricultural systems show a large variety so that not only the factors impeding the adoption of

240 conservation tillage vary locally (Knowler and Bradshaw, 2007) but also the tools that societies have at their

241 disposal to reduce it.

242 Western societies with highly developed information systems tackle the problem by a policy combining regulation

243 (e.g. by forbidding the cultivation of certain crops on land that is very erosion-prone) and subsidies or

244 compensations in combination with well-guided campaigns to inform farmers on the potential benefits and risks

245 for themselves as well as for the broader society. Such combined approaches do have demonstrable success in

246 various parts of Europe and North America where farmers are not only well trained and highly specialized but also

247 depend to a large extent on subsidies, giving the administrations the necessary financial leverage to stimulate or

248 even coerce farmers (Napier et al., 1990). As a result erosion rates in North America have gone down considerably

249 over the last decades and are still declining (Kok et al., 2009). One may therefore assume that in these societies

250 erosion rates can be reduced to tolerable levels provided that the necessary policies are maintained and/or

251 strengthened. Countries having a strong central government that can impose decisions on land use and soil
252 conservation, as is the case in China, can successfully reduce erosion: the excessive erosion rates on the Chinese
253 Loess Plateau were strongly reduced through massive government programs implementing erosion control
254 measures (Chen et al., 2007; Zhao et al., 2016)

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

263 *In many areas where soils are most seriously threatened, the human population will continue to grow strongly.* In
264 the next decades, the locus of world population growth will shift in an unprecedented manner. Population growth
265 in the North has stopped and many regions in the Global South will follow suit in the next decades: Asia is expected
266 to reach its maximum population around 2050. China's population will peak around 2030 and that of India no later
267 than 2070. Latin America will follow around 2060 (http://esa.un.org/unpd/wpp/, Lutz and KC, 2010; Gerland et
268 al., 2014). Sub-Saharan Africa is a different matter: here the demographic transition started only after the Second
269 World War and the population will continue to grow rapidly during most of the 21st century. As a result of these
270 diverging tendencies the distribution of the world's population will have changed beyond recognition in 2100:
271 Europe's share in the global population will have fallen from its maximum of ca. 22 % in 1950 down to ca. 6 %
272 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/).

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

287 It is not overly optimistic to expect that, while population growth continues, at the same time *these populations*
288 *will gain in purchase power.* While incomes in southern Asia and especially sub-Saharan Africa are nowadays
289 much smaller than those in the North, their growth rates are, fortunately, much bigger. For example, Ethiopia's
290 economy has, over the last decade, consistently been growing at 8 to 10% per year, leading to a rise of the per

291   capita Gross National Income from 110 US $ (2015 dollars) in 2004 to 550 US $ in 2015
292   (http://data.worldbank.org/country/ethiopia).

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

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

305   **Soil conservation in a changing global context**

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

309   Both pathways are, in principle, possible: until present, Africa has followed the first path. Over the last five
310   decades, the increasing food demand of African populations has mainly been met by increasing the area used for
311   farming, while yields per unit of surface area remained stable and very low (Henao and Baanante, 2006). This
312   evolution sharply contrasts with the one observed in most parts of Asia: here agricultural production was mainly
313   increased through intensification (Henao and Baanante, 2006). In Asia, the Green Revolution led to a dramatic
314   rise in agricultural yields through the combination of new crop varieties, better farming technology and the
315   increased use of fertilizers. As a consequence, Asia now manages to feed its population much better than it did in
316   1970: the amount of available kcal per person rose from ca. 2000 kcal to ca. 2400 kcal (South Asia) or even 3000
317   kcal (East Asia) in 2005 (Alexandratos and Bruinsma, 2012) despite the fact that the amount of land used for
318   agriculture did only marginally increase (Henao and Baanante, 2006) and despite the fact that the population in
319   these regions increased from 0.98 billion to 1.53 billion (East Asia) and from 1.06 billion to 2.20 billion (South
320   Asia) over the same period (http://esa.un.org/unpd/wpp/).

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

328   An extension strategy may, at first sight, be attractive from the point of view of soil conservation. One might
329   indeed argue that this would be based on agricultural technology that has been in use for decades, and may
330   therefore be best suited to increase agricultural production without causing excessive soil degradation. Indeed, the
331   occurrence of erosion in mechanised, intensive agricultural systems is often attributed to the loss of traditional soil
332   conservation methods (Bocco, 1991). Averting intensification and aiming at area extension may therefore seem a
333   suitable solution to avoid excessive soil degradation as traditional farming methods can be maintained and
334   optimised to be as environmentally friendly as possible. Many organisations do indeed stress environmental
335   protection and sustainability as key issues to be addressed in the further development of African agriculture and
336   explicitly state that Africa should indeed follow a path different from the Asian Green Revolution (De Schutter,
337   2011).

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

356

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

367 Increasing agricultural production in Africa through areal extension alone would therefore imply that overall soil

368 losses would increase much more rapidly than agricultural production would. If, on the other hand agricultural

369 yields on good agricultural land would be improved, it may be possible to set aside some of the marginal land that

370 is currently used for arable farming. The somewhat counterintuitive result of this will be that, even if erosion rates

371 on the arable land that remains in production would increase due to intensification, the overall soil loss (at the

372 landscape scale) would still decrease (Figure 3).

373 *Smart intensification will conserve soil carbon which will, on its turn, reduce erosion risks.* Over the last decades,

374 a significant body of scientific literature has emerged on the potential of agricultural land to store additional soil

375 organic carbon through the use of appropriate management techniques. While studies do suggest that some gains

376 are indeed possible, most studies report modest gains at best. Reported average sequestration rates under

377 conservation tillage in Canada are between 0 and 0.14 t C ha^{-1} yr^{-1} in Canada (VandenBygaart et al., 2010) while

378 an average sequestration rate of 0.12 t C ha^{-1} yr^{-1} has been calculated for the USA (Eagle et al., 2012). In a study

379 covering 12 study sites in three Midwestern states of the USA Christopher et al. (2009) did not find any significant

380 increase in soil organic carbon storage under no-till in real farming conditions. Experimental studies also showed

381 that under agroforestry gains in soil organic carbon are small, with an average of 0.25 t C ha^{-1} yr^{-1} (Govers et al.,

382 2013). These findings contrast not only with claims in the literature (Ramachandran Nair et al., 2009), but also

383 with the observation that soil carbon stocks on natural (or undisturbed) land are generally much higher (often more

384 than three times higher) than those observed on arable land (e.g. Poeplau et al., 2011; Hiederer and Köchyl, 2012).

385 The latter is related to two main factors: (i) biomass is not removed from natural land, which results in larger

386 organic carbon inputs and (ii) these lands are not mechanically disturbed which reduces carbon respiration rates.

387 Thus, more soil carbon will be conserved when the extent of agricultural land is reduced and more land is preserved

388 under or restored towards natural conditions. An additional beneficial effect of the latter is that soil organic carbon

389 stocks may increase on agricultural land with increasing agricultural yields, provided that the residual biomass is

390 adequately managed (VandenBygaart et al., 2010; Minasny et al., 2012): this, in turn, will reduce the erosion and

391 degradation risk (Torri and Poesen, 1997). Thus, intensification will allow to preserve more carbon then areal

392 extension (Figure 3, Figure 5).The fact that intensification is beneficial for soil carbon conservation has also been

393 demonstrated at the global level: agricultural intensification has allowed to avoid ca. 161 Gt of carbon emissions

394 from the soil to the atmosphere between 1960 and 2005 (Burney et al., 2010).

395 *Smart intensification will help to make agriculture in the South more water-efficient.* Agriculture is by far the

396 largest global consumptive user of blue water (water extracted from rivers and groundwater): at the global scale,

397 over 80% of all consumptive water use is related to agricultural activities (e.g. Doll et al., 2009). As the amount

398 of available water will not significantly increase in the future, a more efficient water use is a prerequisite to increase

399 agricultural production in the South. Less productive systems are often more water-intensive, i.e. more units of

400 water are needed for each unit of crop that is produced. Striving towards higher yields will remedy this problem

401 as it allows to increase the amount of crop produced per unit of water (Rockström et al., 2007). Higher yields are

402 therefore a means to increase water conservation and to make sure that more water is available for the functioning

403 of non-agricultural ecosystems. Clearly, the realisation of this potential requires other measures as well such as a

404 realistic pricing of water and water use monitoring in areas where water scarcity is a problem so that inefficient

405   use of this scarce resource can be prevented. Again, the implementation of such systems will be far more efficient

406   in high-yield systems as the return per unit of capital cost will be higher.

407   *Smart intensification is beneficial for biodiversity at the landscape scale.* Environments where intensive

408   agriculture is dominant are often very poor in terms of biodiversity. One might therefore suggest that, in order to

409   preserve biodiversity, one should avoid intensification and maintain a certain biodiversity on agricultural lands.

410   Again, such a strategy would necessarily imply that more land would be needed to produce the same amount of

411   agricultural goods. Recent studies have consistently shown that such a strategy is not beneficial for biodiversity at

412   a larger scale: the biodiversity gained on agricultural land is, in general, not sufficient to compensate for the

413   additional biodiversity loss due to agricultural land expansion (e.g. Phalan et al., 2011b; De Beenhouwer et al.,

414   2013; Schneider et al., 2014). Thus, land sparing and concentrating intensive agriculture on designated areas is

415   generally a better strategy than land sharing with low-intensity agriculture that will occupy a much larger fraction

416   of the available land (Figure 5). Sparing will not always be the best strategy as this will depend on local conditions:

417   for instance, wildlife-friendly agriculture may be the best solution in the buffer zones around wildlife reserves.

418   *Smart intensification will increase the added value of the land used for agricultural production and hence make*

419   *the implementation of conservation measures economically sound.* Clearly the economic value of a good such as

420   arable land depends on the economic return that can be gained from the use of it. Intensification will allow to

421   increase these returns. This is especially true for sub-Saharan Africa where yields are still abysmally low

422   (Neumann et al., 2010). While there are many reasons for this, a key factor is that African soils are chronically

423   underfertilized (Henao and Baanante, 2006; Keating et al., 2010). The amount of fertilizer used per unit of surface

424   are of agricultural land in Africa is only 10% of what is being used in Europe or the United States: the consequence

425   is that, in many cases, the nutrient balance of many African agricultural systems is negative, i.e. more nutrients are

426   removed through harvesting than there are supplied by fertilization (Smaling et al., 1993; Henao and Baanante,

427   2006). This negative balance is further aggravated by soil erosion, which annually mobilises more nutrients than

428   are applied in sub-Saharan Africa (Quinton et al., 2010). Even a modest increase in fertilizer use may therefore

429   allow to significantly boost agricultural yields in sub-Saharan Africa, at least if this increase would be accompanied

430   by other measures such as the introduction of high-yield varieties and the necessary training for the farmers

431   (Sanchez, 2010; Twomlow et al., 2010; Mueller et al., 2012).

432   Higher agricultural yields will increase the added value that may be produced per unit of agricultural land and

433   hence its value. A consequence of this is that the economic stimulus to implement conservation measures on this

434   land will increase as land will become a more precious resource. Furthermore, intensification will also reduce the

435   overall conservation investment that has to be made as the acreage that needs to be treated will be smaller which

436   will allow to concentrate the available resources on a smaller area. Finally, many conservation strategies are based

437   on the use of crop residue (i) to return nutrients and carbon to the soil and (ii) to reduce the soil erosion risk. Such

438   strategies are likely to be more successful when more residue per unit of area is available. Case studies have

439   repeatedly shown that the mechanisms described above can indeed lead to more effective soil conservation under

440   increasing intensification and population pressure (e.g. Tiffen et al., 1994; Boyd and Slaymaker, 2000)

441   *Smart intensification will help to create the market opportunities needed for sustainable agriculture.* The dramatic

442   increase in population that will occur in the South over the next century, in combination with rapid urbanisation

443   and economic growth, make the transition towards a market-oriented agriculture inevitable. This is not a bad thing:

444 all too often we have a far too rosy view on the potential of subsistence agriculture. The truth is that subsistence

445 farming does not generate the necessary financial means for the farmers to get out of poverty, although

446 improvements in agricultural technology may contribute to increased food security (Harris and Orr, 2014). Only

447 when farmers have access to markets they can generate an income that allows them to fully participate in society

448 so that they can not only benefit from the material perks of modern life but also provide a high quality education

449 to their children and the necessary health care to those who need it: soil conservation as such cannot achieve this

450 (Posthumus and Stroosnijder, 2010). Case studies support that a symbiosis between the development of a market-

451 oriented agriculture and soil conservation is indeed likely as market access provides farmers with the economic

452 incentives to implement soil conservation measures (Boyd and Slaymaker, 2000). Again, the transition from a

453 subsistence to a market-oriented system will almost inevitably have to be accompanied by intensification as the

454 latter will allow a better return on both capital and input investment.

455 *Smart intensification will not be sufficient to achieve adequate soil conservation (but it will help).* The points raised

456 above illustrate that adequate soil conservation is much more likely to be achieved if more intensive agricultural

457 systems are developed in the Global South as the economic and environmental stimuli to implement soil

458 conservation measures will be much larger. Yet, the experiences in Europe and Northern America illustrate that

459 this may not be sufficient to achieve adequate soil conservation and that government stimulation (through financial

460 measures) and/or coercion may be necessary to further reduce soil degradation. It is, however, the magnitude of

461 such efforts and their effectiveness that should be considered. The societal efforts and costs that will be needed to

462 achieve adequate soil conservation will be far smaller when less land is used for agriculture as much less land will

463 need treatment. Furthermore, one may also imagine that efforts to convince farmers to adopt conservation

464 measures will be more successful in an intensive, market-oriented agricultural system as they will, generally, be

465 more open to changes and both governments and other stakeholders will have more leverage in discussions on

466 how the agricultural system needs to be organised. This is, obviously, no guarantee for success as potential direct

467 financial benefits may seduce the stakeholders to neglect the necessary investments to achieve long-term

468 sustainability. The latter is a problem that occurs everywhere where environmental and economic concerns conflict

469 and, while general principles to resolve such problems have been formulated (Ostrom, 2009), specific policies to

470 deal with this conflict will depend on local conditions.

471 **Conclusions**

472 All too often, soil conservation is discussed in isolation, whereby much attention is given to the effectiveness of

473 technical solutions in reducing excessive soil and water losses at a given location. Agriculture, however, is a system

474 wherein lateral connections at different scales are very important: actions at a specific location will necessarily

475 have implications at other locations. Agricultural systems are also subject to constant change as they respond to

476 changes in population numbers, population distribution, economic wealth and cultural preferences. A coherent

477 vision on the development of soil conservation in 21st century needs to account for this context and needs to

478 consider both the spatial and temporal dynamics of agricultural systems.

479 While it is certainly true that conservation technology can be further developed other considerations may be more

480 important for the successful implementation of soil conservation programs. In our view, smart intensification is an

481 essential ingredient of any strategy seeking efficient soil conservation while at the same time meeting the growing

482　food demands of a strongly increasing, more urbanised global population. Smart intensification will help to reduce
483　the land surface area exposed to a high soil degradation risk while it will, at the same time, increase the return on
484　the soil conservation measures that will still be necessary. Smart intensification will also allow to reap additional
485　environmental benefits in terms of soil organic carbon storage, biodiversity and water availability. It will also be
486　directly beneficial to the farmer, allowing her/him to produce food for more people and to achieve an acceptable
487　income. It is therefore no surprise that, when considering these other angles, other researchers have reached similar
488　conclusions, stating that agriculture in the Global South and particularly in Africa needs to intensify and that the
489　exclusive focus on smallholders as engines for growth needs to change (Collier and Dercon, 2009).

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

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

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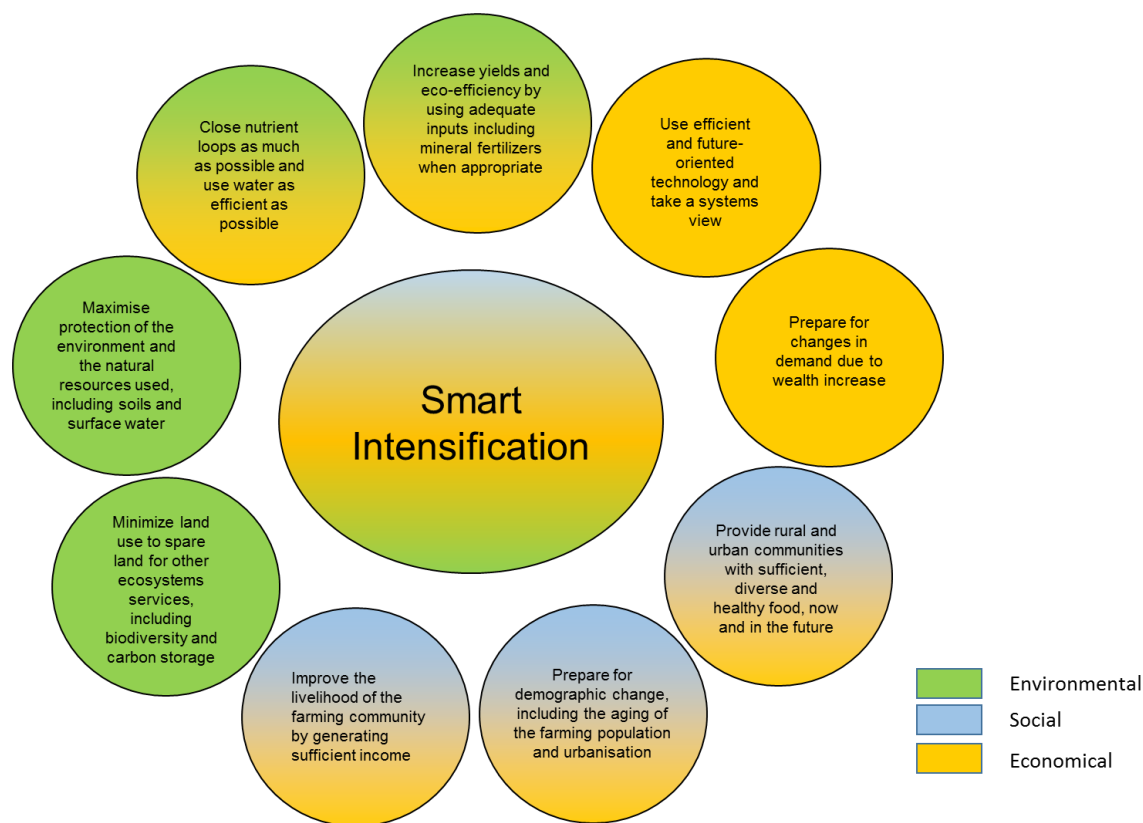755   13, 4735-4750, 2016.
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759 **Figure 1. The presence of a dense network of rills and of significant deposition at the footslope (here in Huldenberg,**
760 **Belgium in July 2006) is a such sufficient proof for excessive soil erosion (in this case erosion exceeded 100 t ha^{-1} in a**
761 **single event)**

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Figure 2 Different aspects of smart agricultural intensification. Colouring refers to main reason as to why each aspect is important.
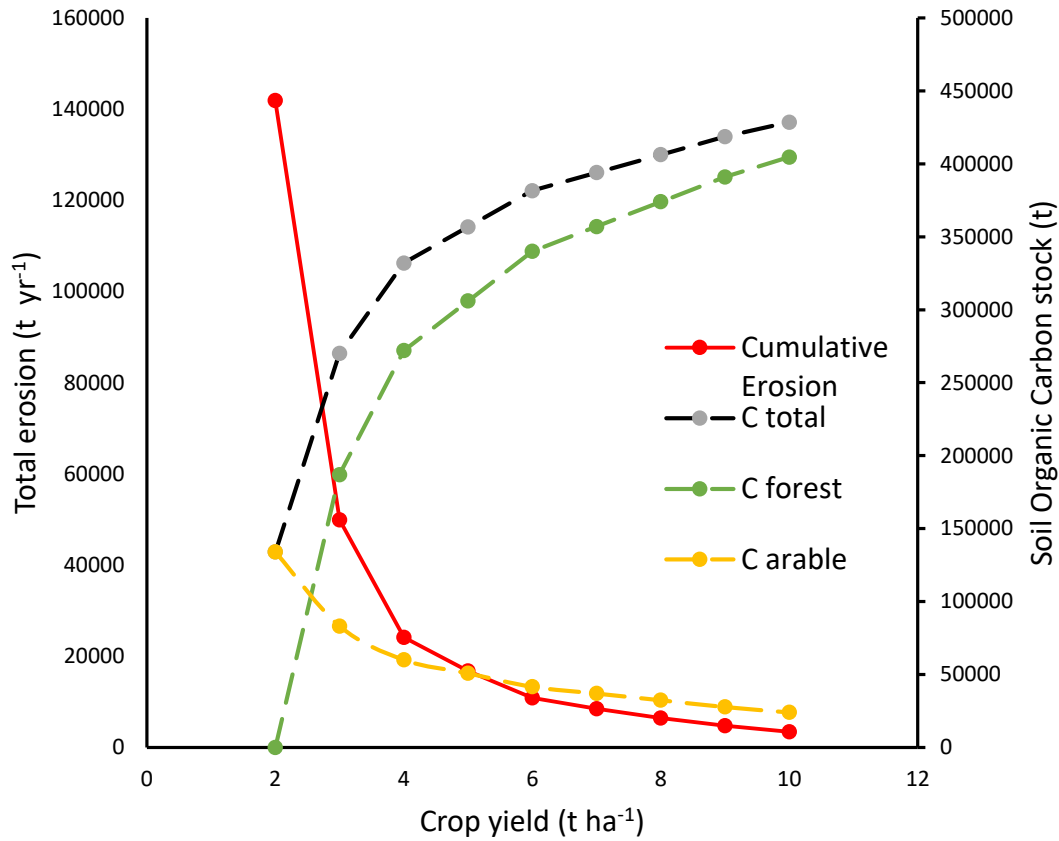
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Figure 3 Modelled total erosion (t, yr⁻¹ left axis) and soil organic carbon stocks (t, right axis) vs. crop yield per ha for a hypothetical test area of 2900 ha and assuming a total cereal production of 5000 ton. We assumed that slope gradients (sin θ) 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: $P=1-(\sin\theta)^{0.5}$. Erosion (E, t ha⁻¹ yr⁻¹) is assumed to vary with slope gradient according to the slope function derived by Nearing (1997): $E \sim -1.5+17/[1+\exp(2.3-6.1 \sin\theta)]$, and an erosion rate of 10 t ha⁻¹ yr⁻¹ is assumed on a 0.09 slope. Soil organic carbon stocks per unit area are assumed to be 40 t ha⁻¹ on arable land and 170 t ha⁻¹ under forest (Poeplau et al., 2011). The total soil organic carbon stock (C total) in the area strongly increases with increasing crop yield because the gain in soil organic carbon stocks on forested land (C forest) is much more important than the loss on arable land (C arable).

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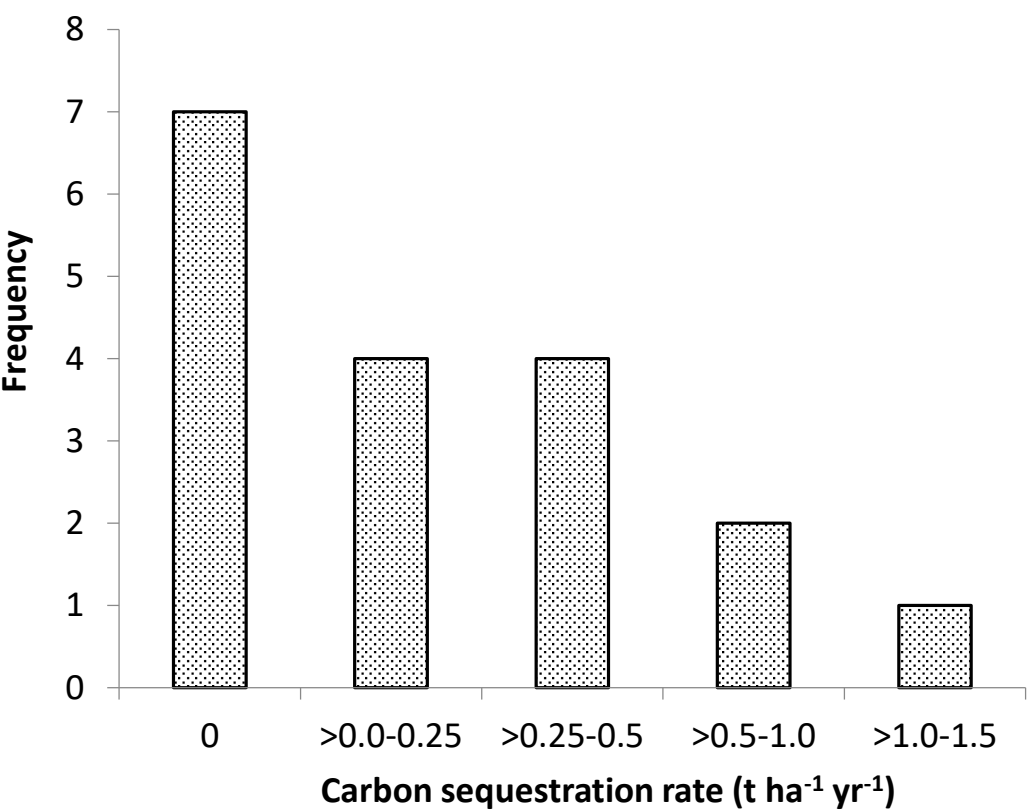
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784 **Figure 4 Frequency distribution of experimentally observed carbon sequestration rates under agroforestry. Data from**
785 **18 paired field studies in both (sub-)tropical and temperate climates (details and references of studies in (Govers et al.,**
786 **2013)). The average soil organic carbon sequestration rate reported over all 18 studies is 0.25±0.33 t ha^{-1} yr^{-1}.**
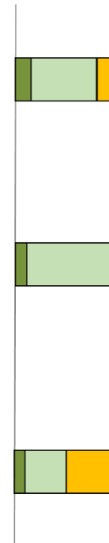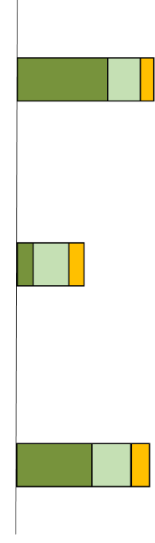
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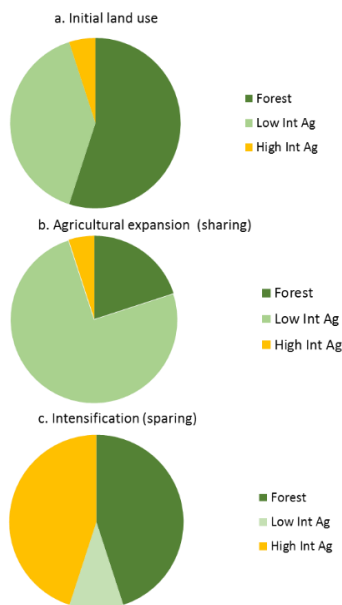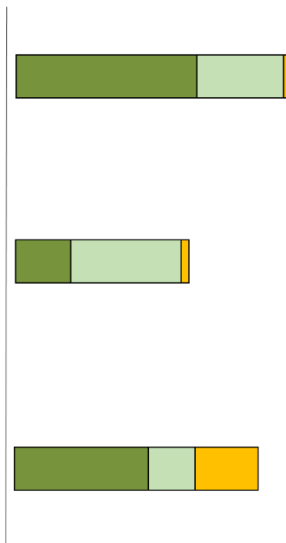
Figure 5 Semi-quantitative illustration of the effects of a significant increase of agricultural production through smart intensification (sparing land) vs. agricultural expansion (sharing land) on soil organic carbon stocks, the erosion risk and biodiversity. We assume that in a given area the required 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, at the landscape scale, of the impact of these alternatives according to current scientific insights. Smart intensification is beneficial with respect to 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 biodiversity because 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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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

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

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