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Holistic management

– a critical review of Allan Savory's grazing method

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Summary

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Allan Savory, a biologist from Zimbabwe, is the man behind the concepts of 'holistic grazing' and 'holistic management' and the founder of the Savory Institute. In February 2013, Savory gave a TED talk on the topic "How to fight desertification and reverse climate change". This lecture, both praised and criticized, has been view-ed more than 3.5 million times. In this talk, Savory makes some controversial claims including that two-thirds of the world's land is turning into desert and that holistic grazing can stop desertification and reduce atmospheric carbon dioxide levels to pre-industrial levels in a few decades. This claim seems to be based on an assumption that 2.5 tonnes of C can be sequestrated per ha and year, on 5 billion ha (corresponding to one third of the world's land), continuously for almost 40 years. Following his TED talk, Savory and his grazing method have received considerable attention in many countries.

Holistic grazing builds on the concept of rotational grazing. The underlying assumption is that herbivorous animals can rehabilitate degraded land through grazing and that the world's grasslands and wild herbivores evolved in parallel and thus are interdependent. Further, it is assumed that grazing livestock (e.g., cattle, goats, sheep and camels) can serve as substitutes for wild herbivorous animals, provided that they are managed in a way that mimics 'natural grazing' of wild herbivores. Natural grazing is characterized by large animal flocks moving across large areas as they try to escape predators. To simulate this function in holistic grazing, livestock are packed in large herds and frequently moved between different areas.

Holistic grazing is claimed to increase plant production and the soil's ability to infiltrate and retain water, stop land degradation and improve living and profitability for the herders. Increased pasture plant growth in turn leads to more carbon from the atmosphere being sequestered into the soil.

Central to holistic grazing is holistic management; a framework for decision-making and a planning tool applied primarily to grazing systems. It is based on comprehensive goal-setting focused on the kind of life pastoralists wish to have. Holistic management aims to use locally available resources to reach set goals by continuously monitoring and adjusting operations. Holistic grazing practised within holistic management is thus claimed to be an adaptive and flexible grazing management approach.

A large part of the criticism directed towards Savory is that his claims are not sufficiently backed

up by scientific evidence. The aim of this study is to review some of the scientific support for the claimed effects of holistic grazing and management.

There are relatively few (11) peer-reviewed studies on the effects of holistic grazing that are 'approved' by the Savory Institute, i.e., included in Savory Institute Research Portfolio. These case studies show positive effects of holistic grazing in terms of grassland and livestock productivity and soil conditions over conventional or continuous grazing, but are rather limited in time, number of study sites and analyzed data. Only six of the studies use measurements while five are based on interviews or surveys. Further, the results are partially inconclusive, and the reported effects are in most cases rather small.

Review studies that have compared different grazing systems are few and difficult to perform due to large variability in systems and local conditions. To date, no review study has concluded that holistic grazing is superior to conventional or continuous grazing. One possible reason is that the effects of the holistic framework for decision-making have not been appropriately accounted for in these studies. The claimed benefits of holistic grazing thus appear to be exaggerated and/or lack broad scientific support. Some claims concerning holistic grazing are directly at odds with scientific knowledge, e.g., the causes of land degradation and the relationship between cattle and atmospheric methane concentrations.

It is well-established that continuous excessive grazing with high stocking rates, or uncontrolled grazing, increases the risks of desertification. How-ever, although grazing in most cases result in reduced vegetation growth, under certain conditions (a long evolutionary history of grazing, moderate grazing pressure during short time periods, and low net primary production) grazing can result in increased vegetation growth. It is also well-established that improved grazing management can improve conditions on many degraded lands. Based on this review, holistic grazing could be an example of good grazing management, but nothing suggests that it is better than other well-managed grazing methods.

Improved grazing management on grasslands can store on average approximately 0.35 tonnes of C per ha and year – a rate seven times lower than the rate used by the Savory Institute to support the claim that holistic grazing can reverse climate change. The total carbon storage potential in pastures does not exceed 0.8 tonnes of C per ha and year, or 27 billion tonnes of C globally, according to an estimate in this report based on very optimistic assumptions. 27 billion tonnes of C corresponds to less than 5% of the emissions of carbon since the beginning of the industrial revolution. Holistic grazing can thus not reverse climate change.

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Contents

1. Introduction

Holistic[1] grazing was introduced by Allan Savory, a biologist from Zimbabwe, over 40 years ago. In brief, holistic grazing is a grazing management method based on planned rotational grazing that 'mimics nature' with the aim of sequestering carbon (C) and water in soils and thus increase pasture productivity. Holistic management is a framework for decision-making and a planning tool applied primarily to grazing systems. It is based on comprehensive goal-setting focused on the kind of life pastoralists wish to have. Holistic management aims to use locally available resources to reach set goals by continuous monitoring and adjusting operations (Savory, 2008). Holistic grazing practised within holistic management is thus an adaptive and flexible grazing management approach. Hence it can take many forms, depending on what each individual herder wants to achieve, climate conditions and the availability of local resources.

Allan Savory was born in Zimbabwe in 1935. As a newly trained biologist, he studied the causes of desertification and soil degradation in Africa. Initially, he joined the prevailing theory that overgrazing caused these problems, and as an advisor to the Zimbabwean government he contributed to the shooting of 40,000 elephants (Savory, 2013b). As this drastic measure did not result in the expected outcome, Savory launched the idea that a lack of grazing animals instead caused desertification (Savory, 2008; 2013b). Savory later moved to the US where his grazing concept gained much attention during the 1980s as it was suggested that stocking rates could be doubled or even tripled while improving both range and livestock productivity (Holechek *et al.*, 2000).

In 2009, the Savory Institute was founded with the aim of spreading holistic grazing and management across the world. In February 2013, Savory gave a TED talk on the topic "How to fight desertification and reverse climate change" (Savory, 2013b). This lecture, both praised and criticized, has been viewed more than 3.5 million times (www.ted.com, May 3, 2016). In this talk, Savory makes some controversial claims including that two-thirds of the world's land is turning into desert and that holistic grazing can stop this desertification and reduce atmospheric carbon dioxide levels to pre-industrial levels in a few decades. Following his TED, Savory and his grazing method have received considerable attention in many countries, including countries that do not suffer from desertification.

Savory is still very active in promoting his ideas. In February 2016 he started a blog which at the time of writing this report contains seven blog posts (May, 2016). According to Savory, the blog aims to clarify, simplify and explain his view on holistic management. He especially invites critics to participate in the discussion, who he claims to date has not made any effort to study anything he has written or said.

A large part of the criticism directed towards Savory is that his claims are not sufficiently backed up by scientific evidence. Anecdotal reports and testimonies about the excellence of the method dominate over systematically implemented and independent scientific studies (Briske *et al.*, 2011).

The aim of this study is to review some of the scientific support for the claimed effects of holistic grazing and management. However, this report is not a formal review study due to time and budget limitations. Chapter 2 gives a brief background and description of holistic grazing and management. Chapter 3 reviews in detail the scientific studies brought forward by the Savory Institute and summarizes some studies that have critically examined holistic grazing. Also, the scientific support behind the claims made by Savory is discussed. Chapter 4 reviews the plausibility of the claim that holistic management can reverse climate change. Chapter 5 summarizes the main conclusions of this report.

[1] Holistic means "great", "undivided" from the Greek holos: in a general sense a philosophical approach where the whole is greater than the sum, and no part can be separated from its context.

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2. Background to holistic grazing and management

Grazing management in general

The aim of grazing management is to 1) increase productivity and improve species composition by giving key species some rest, 2) reduce animal selectivity, and 3) ensure more uniform animal distribution (Briske *et al.*, 2008). Several different grazing management techniques exist. Basically, a distinction can be made between continuous grazing and rotational grazing. Continuous grazing means that the animals over a longer period graze in the same (larger) area. Rotational grazing means that the animals are moved around between different smaller areas. Within these two types variation is large. For more information on different grazing systems, see McCosker (2000).

Holistic grazing

Savory's holistic grazing builds on the concept of rotational grazing. The underlying assumption is that the grazing of herbivorous animals can rehabilitate degraded land and that the world's grasslands and wild herbivores evolved in parallel and thus are interdependent (Savory, 2008). It is assumed that grazing livestock (e.g. cattle, goats, sheep and camels) can serve as substitutes for wild ruminants, provided that their management mimics 'natural grazing' of wild herbivores (Savory Institute, 2014b).

'Natural grazing' is characterized by large animal flocks moving across large areas as they try to escape predators. To simulate this function in holistic grazing, livestock are packed in large herds and frequently moved between different areas (Savory, 2008). In general, animals do not graze more than a few days in the same area, followed by some months of rest (Savory, 2013a). In other words, in holistic grazing, the land is exposed to intense grazing pressure and large additions of manure and intense trampling during short periods. This is considered to contribute to more extensive cover of dead plant material on the ground which helps to reduce evapotranspiration and increases accumulation of organic matter in the soil; the breaking of the hard soil crust; germination of seeds and faster turnover of dead plant material. This is in turn considered to result in increased soil humus content (and therefore soil carbon); increased ability of the soil to infiltrate and retain water, and eventually that the plant production increases, and thus increased profitability and quality of life of pastoralists (Savory, 2008; 2013a; 2013b; Savory Institute, 2014b).

Holistic management

Many of the ideas currently associated with Savory were neither new nor original when they were launched by Savory, such as using livestock to mimic the behaviour wild grazers, and using grazing livestock to restore degraded rangelands (Briske *et al.*, 2011). Such as ideas had been proposed already in the 1920s. However, Savory packaged these ideas in a new way and launched the concept of 'holistic management', also called 'holistic resource management', which includes the holistic framework for decision-making (Briske *et al.*, 2011).

On the main web page of the Savory Institute holistic management is explained as"a process of decision-making and planning that gives people the insights and management tools needed to understand nature: resulting in better, more informed decisions that balance key social, environmental, and financial considerations." (http://savory.global/, 19th of May, 2016)

The concept is further detailed in scientific papers (e.g. Savory *et al.*, 1991), books (e.g. Butterfield *et al.*, 2006 and Savory, 1999) and shorter summaries (e.g. Savory, 2011). The description here is a summary based on information published on the


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newly launched blog by Savory (http://savory.global/allanUncensored/Welcome-to-my-new-blog, 17th of May, 2016).

Savory's starting point is that all problems (he mentions drugs, poverty, violence, terrorism, increasing droughts and floods and many other issues) are caused by the application of "reductionist management in a holistically functioning world". The main cause of all problems is, according to Savory, "our inability to address complexity". He goes on to explain what complexity is, making a distinction between complicated systems that are things that we make like radio communications, space vehicles and computers, and complex systems that are things that we manage including organisations and institutions and nature itself. When problems arise within complicated systems these are relatively easy to fix while problems within complex systems, so called 'wicked problems', are difficult to solve as these systems have unintended and changing properties that are difficult to foresee or even recognise.

According to Savory, the genetically-embedded framework for decision making in humans cannot manage complexity, especially not when it comes to the problems of desertification and climate change. In addition, we lack the tools to deal with these challenges as the human toolbox includes only four tools; technology, fire, planting of plants and resting the environment (i.e. modern nature conservation). In this context, Savory highlights the importance of large grazing animals for reversing desertification of grasslands in regions with seasonal rainfall (constituting roughly two thirds of the world's land area). Without animals, aboveground leaves and stems will chemically oxidise instead of biologically decaying, Savory claims[2]. In such conditions, resting land would only increase oxidation and hence the death of perennial grasses i.e., desertification. Hence, the missing tool in the human toolbox is properly managed livestock. These animals should be managed using 'holistic grazing' (described in the next section).

Savory goes on to describe the need for a 'holistic context', or reasons for our actions, which cater for both social and economic complexity. Savory admits in his blog that the concept of holistic context has been murky and confusing in the two first version of his book but that the coming edi-

[2] Savory admits in blogpost 4 that this is not valid for humid regions like much of Europe.

tion, to be released later this year (i.e., 2016), will provide a clearer and more applicable description. Savory does not describe in his blog what a holistic context is but provides the following example of a simple generic holistic context:

"We want stable families living peaceful lives in prosperity and physical security while free to pursue our own spiritual or religious beliefs. Adequate nutritious food and clean water. Enjoying good education and health in balanced lives with time for family, friends, and community and leisure for cultural and other pursuits. All to be ensured, for many generations to come, on a foundation of regenerating soils and biologically diverse communities on Earth's land and in her rivers, lakes, and oceans." (http://savory.global/allanUncensored/managing-complexity, 17th of May 2016)

The holistic management framework then provides a set of seven context-checking questions to help guide difficult decisions. For simpler decisions on the other hand, "we intuitively begin to know if they are in line with our holistic context". Savory compares this to riding a bicycle; the more one tries to explain how it is done, the harder it gets.

New idea: holistic grazing can reverse climate change

In parallel to climate change attracting great attention during the last decade, Savory launched the idea that holistic grazing, apart from restoring degraded land and improving the livelihoods of herders, can storage such large amounts of carbon in the soils that atmospheric carbon dioxide levels can drop to pre-industrial levels in a few decades (Savory, 2008; 2013b; Savory Institute, 2013a). This claim, further evaluated in Chapter 4, gained considerable attention after Savory's appearance at TED in February 2013.

Savory's activities and organisations today

The main vision of Savory's current activities is to "to promote large-scale restoration of the world's grasslands through Holistic Management" (http://savory.global/, 19th of May, 2016). Three organisations have been set up to reach this mission:

- The Savory Institute is the main organisation which is devoted to developing tools, informing policy, increasing public awareness, coordinating research and cultivating relationships with partners, i.e. the Savory Institute works with development and marketing of the Savory concepts. The Savory Institute has nine employees and is governed by a board with five members, including Savory himself.

- The Savory Network is a global network of regional 'Hubs' and 'Accredited Professionals'. A Hub is a self-sustained entity which provides training and implementation support of holistic management in the local region. Currently there are 18 established hubs in five continents and 16 hub candidates. The goal is to establish 100 hubs by 2025 to influence the management of 1 billion hectares of land i.e. 1/5 of all grasslands globally. An Accredited Professional provides training and support in holistic management to hubs, ranchers, consumers, government agencies, NGO etc. To become an Accredited Professional one has to complete training in holistic management, provide evidence of practical experience and pay an annual fee of $399.

- The Savory Platform provides training and support for land managers and farmers. It contains a wide range of online courses priced at $99. It also sells books and resources for carrying out holistic management e.g. monitoring sheets and different templates. An online software platform is also available for holistic management planning and evaluation (annual cost $599).

Holistic Management International (HMI) is another organisation which aims at "A world where sustainable agricultural communities flourish through the practice of Holistic Management" (http://holisticmanagement.org/). HMI and the Savory Institute both use the same model of holistic management but differ in businesses model (Stephanie von Ancken, HMI, pers. comm.).

3. Scientific studies of holistic grazing

Savory admits that scientific studies of holistic grazing are lacking, and offers two explanations: 1) practicing ranchers and pastoralists cannot easily publish their findings in scientific journals, and 2) complex systems (involving interactions between animals, humans and nature in time and space) cannot fully be understood using scientific 'reductionist' methods (Savory, 2013a). However, upon requests to present the available scientific studies, the Savory Institute in 2013 published a so-called research portfolio consisting of a collection of articles and reports (Savory Institute, 2013c). The portfolio was updated in 2014 (Savory Institute, 2014a).

Chapter 3.1 reviews the material included in the research portfolios. Chapter 3.2 summarizes the main findings and conclusions from a selection of relevant studies that were not included in the research portfolios. Chapter 3.3 derives some conclusions based on this literature review. Chapter 3.4 discusses why scientific studies of holistic grazing often fail to confirm the positive effects that many practitioners apparently experience.

3.1 Review of the research portfolios of the Savory Institute

The two research portfolios published by the Savory Institute (Savory Institute, 2013c, 2104a) contain in total 40 unique publications of both scientific and non-scientific character. The selection criteria for inclusion in the research portfolios are unclear. Fourteen of these publications are original research studies published in peer-reviewed journals that compare the effects of holistic grazing (or similar grazing regimes) with other grazing systems and/or no grazing. The rest of the material are either literature reviews, non-peer reviewed reports, concept notes, reports containing more of 'testimonies', or studies that do not specifically address holistic grazing.

The fourteen peer-reviewed studies were selected for closer examination in this report. Three papers were however excluded; McCosker (2000) appeared to contain a small selection of positive results from different farms selected for unclear reasons, while Joyce (2000) and Sparke (2000) report of personal experiences associated with the transition from conventional to holistic grazing on only two farms.

The remaining eleven studies are from four countries (Mexico, Australia, Canada and USA), and published between 1995 and 2013. They vary in scope from a single farm up to a survey of over 1,700 farmers (Table 3.1). The methodology for data collection is field measurements or interviews/survey; approximately half of the studies use the former and half of studies the latter. It should be noted that in terms of the effects of soil and vegetation, field measurements are more reliable than interviews. It should also be noted that longer measurement series from larger areas or more test sites generally increase the quality of the data, since spatio-temporal variations are evened out. Based on this, it is clear from Table 3.1 that the scientific evidence included in the Savory research portfolio is rather limited; only six of the eleven studies have collected data through field measurements. The largest number of farms included is fourteen and the longest time period is three years.

Table 3.2 shows the research focus of the eleven studies reviewed here, divided into general themes. Most studies have dealt with land and soil-related parameters, vegetation and pasture production as well as aspects related to the adaptability and values. Least explored is the impact on biodiversity.

The main findings from the eleven peer-reviewed studies of holistic grazing reviewed in this report

	Methodology for data collection
Alfaro-Arguello *et al.* (2010)	Interviews with 25 farmers
Earl & Jones (1996)	Field measurements on three farms during three years
Ferguson *et al.* (2013)	Interviews with 25 farmers, field measurements on 14 farms during one year
Manley *et al.* (1995)	Field measurements on one farm during one year
McLachlan & Yestrau (2009)	Questionnaire answered by >1700 farmers
Richards & Lawrence (2009)	Interviews with farmers from 25 farms
Sanjari *et al.* (2008)	Field measurements on one farm during six years
Sherren *et al.* (2012)	Interviews with 25 farmers centered around photos
Stinner *et al.* (1997)	Interviews with 25 farmers (deep interviews with three)
Teague *et al.* (2011)	Field measurements on nine farms during one year
Weber & Gokhale (2011)	Field measurements on three farms during three years

Table 3.1 Methodology for data collection in the eleven peer-reviewed studies of holistic grazing reviewed in this report.

are summarised briefly in the following sections. For more information, please refer to the original sources.

Alfaro-Arguello et al. (2010)

Alfaro-Arguello *et al.* (2010) reported that seven practitioners of holistic grazing in Chiapas, Mexico, had twice as high emergy sustainability index as their conventional colleagues in the same area (18 farmers). A re-evaluation of the same material concluded that the index was only marginally higher (Ferguson *et al.*, 2013). This index is calculated based on the total resources needed to produce a product, and is considered to measure sustainability.

Earl and Jones (1996)

Earl and Jones (1996) studied the vegetation on three farms in Australia and reported that the basal diameters, relative frequency and contribution to dry weight of the most desirable and palatable species at each site remained constant or increased under holistic grazing (called cell grazing in this paper), while declining significantly under continuous grazing. The inverse was true for the least palatable components of the pasture, which declined significantly under holistic grazing but did not change much under continuous grazing. Percentage ground cover was significantly higher after two years of holistic grazing than under continuous grazing.

Ferguson et al. (2013)

Ferguson *et al.* (2013) studied holistic and conventional cattle ranching in the seasonally dry tropics of Chiapas, Mexico. When comparing seven holistically managed farms with 18 conventional farms, they found higher soil respiration, deeper topsoil, increased earthworm presence, more tightly closed herbaceous canopies (all $p<0.05$), and marginally higher forage availability ($p=0.053$) in holistically managed farms. However, they did not find any significant differences in soil compaction, soil chemistry and pasture tree cover between farms.

	Soil	Water	Vegetation and pasture productvity	Biodiversity	Livestock production including economy	Adaptation, values and quality of life	Integrated indicators
Alfaro-Arguello *et al.* (2010)					X		X
Earl & Jones (1996)			X				
Ferguson *et al.* (2013)	X		X		X		X
Manley *et al.* (1995)	X						
McLachlan & Yestrau (2009)						X	
Richards & Lawrence (2009)						X	
Sanjari *et al.* (2008)	X						
Sherren *et al.* (2012)						X	
Stinner *et al.* (1997)				X	X	X	
Teague *et al.* (2011)	X	X	X				
Weber & Gokhale (2011)		X	X				

Table 3.2 Research focus of the eleven peer-reviewed studies of holistic grazing reviewed in this report. Author names in bold indicate that studies have applied field-measurements as a method of data collection.

They also found that holistic ranchers had 2.5 times higher milk productivity (measured as litre per ha pasture per year), as well as lower cow mortality (1 vs. 5%) and calf mortality (2 vs. 7%) compared to their conventional colleagues. On average, holistically managed farms had considerably higher profitability (measured both as profit per ha, and net ranch profit) than conventional farms, but the differences were not statistically significant, due to large variations between individual farms.

Further, they found that holistically managed farms had statistically significantly denser vegetation on the pastures (measured both as ground-level gaps and herbaceous canopy gaps) compared to farms with conventional grazing. Forage availability was on average 46% higher on holistic pastures than on conventional pastures, but due to large variations over time, this difference was not statistically significant. With regard to the composition of plant species on pastures no statistically significant difference between holistic and conventional farms was found.

In addition to these parameters an 'Organic Conversion Index' was calculated based on the standards for organic production, combining economic, social, technological and environmental indicators. Data were collected through semi-structured interviews and field observations. This index was considerably higher for holistic farms than for conventional farms.

Manley et al. (1995)

Manley *et al.* (1995) studied rangeland soil carbon and nitrogen content between five different grazing systems, including holistic grazing and no grazing, on one farm in Wyoming, USA. The different grazing systems had been implemented eleven years before measurements began. The study found that grazing had positive effects compared with no grazing, but no significant differences between the grazing systems were found. Grazed land had statistically significantly higher levels of carbon and nitrogen in the upper 30 cm compared to land not grazed, but the difference was relatively small and concentrated to the top 8 cm of the soil.

McLachlan & Yestrau (2009)

McLachlan & Yestrau (2009) conducted a survey of 315 practitioners of holistic grazing and 1470 conventional herders in Canada regarding how they had been affected by bovine spongiform encephalopathy (BSE, mad cow disease) and their view of the future. They concluded that practitioners of holistic grazing had a more optimistic view on, and confidence in their ability to cope and adapt to the effects of BSE, than their conventional colleagues.

Richards & Lawrence (2009)

Richards & Lawrence (2009) studied adaptation and change in rangelands of Queensland, Australia. Based on interviews with 49 farmers from 25 farms, they concluded that holistic grazing (called cell grazing in this paper) require farmers to adapt ideologically and culturally, and that women seem to have a more prominent role in the business, compared to what is customary on conventional farms. Although the causalities are not fully understood, interviewed farmers reported that they had started practicing holistic grazing for reasons related to lifestyle and ecological factors, as well as efficiency in beef production.

Sanjari et al. (2008)

Sanjari *et al.* (2008) compared continuous and time-controlled grazing systems (which the authors state is synonymous to holistic grazing; quote: "a system of flexible, high-intensity, short period grazing followed by a long period of rest") on one farm in Australia, and found that time-controlled grazing led to a statistically significant increase in ground-litter accumulation compared to continuous grazing. The content of soil organic carbon and nitrogen increased in holistic grazing during the period 2001 – 2006 but this increase was not statistically significant. During the same period, the change of soil organic carbon and nitrogen did not increase at all under continuous grazing.

Sherren et al. (2012)

Sherren *et al.* (2012) found, in an interview with 25 Australian pastoralists, that practitioners of holistic grazing had a different mentality and approach than their conventional colleagues and to a greater extent valued heterogeneity, biodiversity and resilience. This was interpreted as an indication that the practitioners of holistic grazing increasingly applied systems thinking, and were better positioned to adapt to changing circumstances, compared to their conventional counterparts. This study has been criticized for drawing too far-reaching conclusions based on their results, see Briske *et al.* (2014).

Stinner et al. (1997)

Stinner *et al.* (1997) interviewed 25 holistic grazing practitioners in the US that had converted from conventional grazing. Of these, 80% perceived increased profitability since they started to use holistic management. On one farm where quantitative data was collected, not profit per hectare had increased by more than a factor 5 between 1990 and 1995. On another farm where quantitative data was collected, costs per kilo of produced beef had decreased by 50% between 1983 and 1991. It is not known, and not discussed in the paper, to what extent these results are representative of holistic ranchers at large.

The same study reported that all interviewed ranchers considered biodiversity to be important for

Soil depth, cm	Heavy continuous	Light continuous	Multi-paddock (= holistic grazing)	Graze exclosure (=no grazing)
0 – 15	3.76[b]	5.24[a]	5.72[a]	5.62[a]
15 – 30	2.45[b]	3.55[a]	4.00[a]	4.01[a]
30 – 60	1.49[a]	2.09[a]	2.48[a]	2.63[a]
60 – 90	1.78[a]	1.67[a]	2.00[a]	2.34[a]
Average 0 – 90	2.49[c]	3.24[b]	3.61[a]	3.59[a]

Table 3.3 Soil organic matter content (%) for different grazing systems, results from Teague et al. (2011). Different letters indicate that the results are statistically different (p <0.05). The stocking density in multi-paddock grazing is the same as in "Light continuous".

the farm sustainability, while only 9% had thought about biodiversity in the context of their operations before conversion to holistic grazing. Also, 95% perceived increases in biodiversity on their farms (mainly with respect to plants) since they started using holistic management. Furthermore, the study found that 91% of farmers experienced an improvement in quality of life after they converted to holistic grazing. In addition, all farmers said they saw signs of positive changes in ecosystem processes e.g. hydrological and nutrient cycling. These results were however not validated with measured data.

Teague et al. (2011)

Teague *et al.* (2011) compared the effects of four different grazing systems on vegetation, soil biota and soil chemical, physical and hydrological properties in tall grass prairie in Texas, USA. The land where the samples were taken had been managed with the same grazing systems for at least nine years before measurements began.

With regard to soil organic matter, they found that land grazed holistically (called multi-paddock grazing in this paper) had statistically significantly higher content of soil organic matter compared to land grazed continuously, when then average content in the top 90 cm of the soil was calculated (Table 3.3). However, there was no statistical difference in soil organic matter content between multi-paddock grazing, light continuous grazing and graze exclosure in the separate layers of soil, see Table 3.3.

With regard to soil chemical properties, they found higher content of magnesium, calcium and sodium, and higher cation exchange capacity in soils grazed holistically compared to continuous grazing (heavy and light), and that grazed lands had lower levels of nitrogen than lands not grazed (all results are statistically significant).

Furthermore, they found that grazed lands had lower penetration resistance, higher soil moisture (% water) and lower sediment loss (g per m^2) compared to land with heavy continuous grazing (all results are statistically significant). However, they did not find any differences between holistic and light continuous grazing for these parameters.

With regard to soil biota, Teague *et al.* (2011) found that land grazed holistically had higher ratio of soil fungi and bacteria than the other systems, which was considered to contribute to better water holding capacity and nutrient availability.

With regard to infiltration capacity, they found no statistically significant differences in the soil's ability to infiltrate water between holistic grazing, light continuous grazing and graze exclosure. They also found no differences in soil bulk density, water runoff (cm per ha) or soil potassium, manganese, copper, phosphorus, zinc and iron between holistic and heavy continuous grazing (all results were statistically significant).

With regard to vegetation, Teague *et al.* (2011) found that the share of bare ground was statistically

	2006	2007	2008
Simulated holistic planned grazing	23.3[a]	44.1[a]	45.8[a]
Rest-rotation grazing	19.7[b]	34.8[b]	34.7[b]
No grazing (total rest)	19.2[b]	31.9[b]	29.8[c]

Table 3.4 Mean volumetric-water content (%) 2006 - 2008 from pastures managed in three different ways, results from Weber & Gokhale (2011). Different letters indicate statistically different results (p<0.001) when comparing the results within years[3].

significantly lower on pastures with holistic grazing compared to pastures with heavy continuous grazing (1 vs. 30%; however, no difference between holistic grazing and light continuous grazing pastures). Further, they found 18 and 74% higher standing crop biomass for holistic grazing compared to light and heavy continuous grazing, respectively (measured as kg biomass per ha above ground at peak standing crop; statistically significant differences). Notably, however, they found no difference in standing crop biomass between holistic pastures and land that was not grazed at all.

Weber & Gokhale (2011)

Weber & Gokhale (2011) studied the effect of grazing on soil-water content in semiarid rangelands of southeast Idaho. Based on continuous measurements between 2006 and 2008, they found that soil moisture (measured as volumetric-water content) was higher in holistic grazing (called simulated holistic planned grazing in this paper) compared with rest-rotation grazing and no grazing (Table 3.4). In holistic grazing, cattle grazed at high density (66 animal units (AU) per 11 ha, corresponding to 36 animal units days (AUD) per ha) for a short period of time (6 days) during the first week of June each year (2006–2008). In rest-rotation, cattle grazed at low density (300 AU per 1467 ha, corresponding to 6 AUD per ha) for a longer period of time (30 days) during the month of May each year.

They also found that the percentage litter cover was higher under simulated holistic planned grazing (36 AUD per ha) compared with rest-rotation grazing (6 AUG per ha) two years out of three. However, no difference in vegetation (percentage shrub cover) was found between the two grazing systems.

3.2 Studies not included in the research portfolios of the Savory Institute

The studies reviewed above are selected by the Savory Institute and one may suspect that more critical studies might have been excluded as well as studies that show less favourable results of holistic grazing and management.

Here, two review studies that were omitted from Savory's research portfolio are summarised as well as a critical evaluation of Savory's claims and a more recent study on holistic grazing and carbon sequestration in South Africa. It should be noted that systematic review studies are complicated by terminology (McCosker, 2000; Teague *et al.*, 2013; Briske *et al.*, 2011). A wide range of terms are used; rapid rotation, time-controlled, holistic grazing, planned grazing, prescribed grazing, management-intensive grazing, rest–rotation, deferred rotation, high frequency–short duration, season-long, intensive short-duration, multi-paddock, Savory grazing and cell grazing. There is no clear definition what the different terms actually mean, sometimes different terms are used for the same system or the same term is used for different systems (Briske *et al.*, 2011). An overview of different grazing systems and how they relate to holistic grazing is given in McCosker (2000).

Review by Briske et al. (2008)

Briske *et al.* (2008) reviewed more than 40 studies, mostly from the US and Africa, which compared continuous grazing and different types of rotatio-

[3] Taken from the text in Weber & Gokhale (2011) as we suspect a mistake in the table in that paper (all letters were an a).

nal grazing systems with regard to plant production/standing crop, livestock production per head and livestock production per land area.

With regard to plant production/standing crop, 19 out of 23 studies found no difference between rotational and continuous grazing (when all studies of different stocking rates were combined). Three studies reported higher plant production for rotational grazing and one study reported higher plant production for continuous grazing (Fig. 3.1).

With regard to livestock production per head, 19 of 38 studies found no differences between rotational and continuous grazing (when all studies of different stocking rates were combined). Three studies reported higher livestock production per head for rotational grazing and 16 studies reported higher livestock production per head for continuous grazing (Fig. 3.1).

With regard to livestock production per land area, 16 out of 32 studies found no differences between rotational and continuous grazing (when all studies of different stocking rates were combined). Five studies reported higher livestock production per land area for rotational grazing and 11 studies reported higher livestock production per land area for continuous grazing (Fig. 3.1).

Based on these results, Briske *et al.* (2008) concluded that rotational grazing is not superior to continuous grazing with respect to the studied parameters. They also noted that stocking rates and climate, rather than grazing system, are the factors with largest effect on vegetation and livestock productivity.

Review by Holechek et al. (2000)

Holechek *et al.* (2000) reviewed 13 North American studies published between 1982 and 1999 (unclear how these were selected) that compared continuous grazing with so-called short-duration grazing, considered equivalent to holistic grazing in this paper.

The role of hoof action in increasing the soil's ability to infiltrate water was the most studied aspect in the reviewed studies. Holechek *et al.* (2000) found that a large number of animals on a small

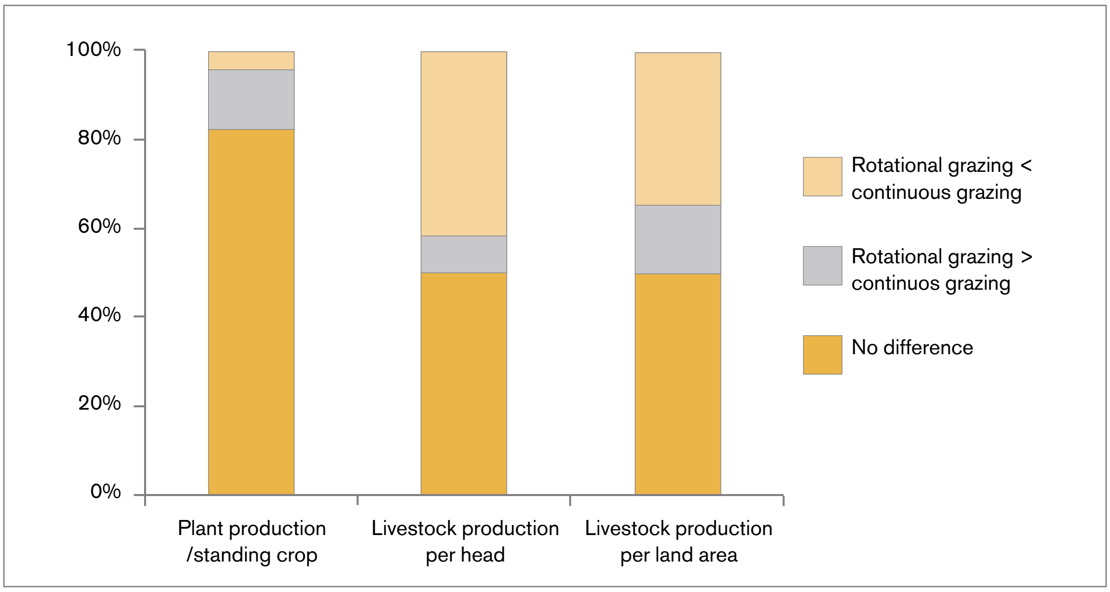

Fig. 3.1 Comparison of continuous grazing and different types of rotational grazing systems with regard to plant and livestock productivity per head and land area, for all stocking-rates. Results from the review by Briske et al. (2008), in which results are further differentiated with regard to stocking-rates.


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area reduced infiltration and increased erosion, contradictory to Savory's claim. They did not find any study that showed any benefits of hoof action on range soils.

With regard to forage production, there was 'little difference' between short-duration grazing and continuous grazing at the same stocking rate, based on results from six studies. It is not clear what is meant by 'little difference".

With regard to vegetation (plant succession and range conditions), there was no significant differences between different grazing systems. The most complete study of vegetation under different grazing systems (Manley *et al.* 1997, conducted during 13 years) showed no significant differences with regard to bare ground and vegetation composition; these were primarily affected by stocking rate rather than grazing system.

With regard to livestock productivity, Holechek *et al.* (2000) found small or no differences between short-duration grazing and continuous grazing in 9 of 10 studies when stocking-rates were the same, and significant difference in only one study, which reported 11-20% lower live weight gains of yearling cattle under short-duration grazing compared to continuous grazing.

With regard to financial returns, short-duration grazing was not found to have any financial advantage over continuous grazing.

Based on these results, Holechek *et al.* (2000) rejected the hypothesis that short-duration grazing is superior to continuous grazing. Holechek *et al.* (2000) also summarized the main findings from two reviews of more than 50 studies on short-duration grazing from the African continent (Skovlin, 1987; O'Reagain & Turner, 1992). According to Holechek *et al.* (2000), these review studies came to very similar conclusions, namely that (selected conclusions): 1) there are no large differences between continuous and short-rotation grazing with regard to range conditions and livestock production, 2) grazing intensity is the most important factor determining long-term effects on vegetation, livestock and financial returns, 3) a large number of animals packed together lower water infiltration and increase erosion and 4) continuous grazing at moderate intensity does not result in rangeland degradation.

Review by Carter et al. (2014)

A literature review by Carter *et al.* (2014) examined five claims made by Savory, focusing on western grasslands of North America.

Firstly, Carter *et al.* (2014) describes that western North America's grasslands have not adapted to the grazing of wild ruminants as there was no major presence of grazing animals in these ecosystems historically. This contradicts Savory's claim that all grasslands evolved in parallel with large herds of grazing animals.

Secondly, Savory's claim that grass withers and die if not grazed was examined. Carter *et al.* (2014) conclude that grasses, especially bunchgrasses, are more likely to die if they are overgrazed, rather than not grazed. Further, these grasses protects soils and harvests water, and that their removal may result in simplification of plant communities, establishment of woody vegetation or invasive species.

Thirdly, Carter *et al.* (2014) concludes that the natural vegetation of the plains in western North America develop normally in the absence of grazing, contrary to the assumption that grasses die if not grazed.

Fourthly, Savory's claim concerning the need for 'hoof action' to break up soil crusts (which Savory calls 'the cancer' of grasslands) is examined. According to Savory, broken soil crusts would increase infiltration, plant seeds, and incorporate plant material, manure, and urine into the soil. Carter *et al.* (2014) write that soils in arid and semiarid grasslands indeed have biological crusts that consist of bacteria, algae, mosses, and lichens and that these are essential elements of these ecosystems that help to stabilize soils, increase soil organic matter and nutrient content, absorb dew during dry periods, and fix nitrogen. Carter *et al.* (2014) found no benefits of hoof action. On the contrary, they found a number of adverse effects as a result of broken crusts including increased erosion and soil compaction and reduced fertility and water infiltration.

Finally, Carter *et al.* (2014) concludes that cattle cause significant emissions of greenhouse gases, and that holistic grazing, as it involves animals, cannot reverse climate change. However, no mass balance calculation or other quantitative support for this argumentation is given.

Study by Chaplot et al. (2016)

A recently published study (Chaplot *et al.*, 2016) assessed the ability of grassland managed with high density and short-duration grazing to sequester atmospheric C into soils of rangelands in South Africa with different levels of degradation. This management system was compared to 1) livestock exclosure, 2) livestock exclosure with topsoil tillage, 3) livestock exclosure with NPK fertilization and 4) annual burning in combination with traditional grazing, as control. 540 soil samples were collected from the top 5 cm of the soil. After two years, topsoil carbon stocks were significantly larger for livestock exclosure with NPK fertilization and for the short-duration grazing system (average of 33.4 ± 0.5 and 12.4 ± 2.1 g C m^2 year-1, respectively). Burning reduced SOC stocks by 3.6 ± 3.0 g C m^2 year-1, while no significant results were found for livestock exclosure and livestock exclosure with topsoil tillage.

Chaplot *et al.* (2016) acknowledge that the increase in soil carbon stocks in either fertilized grassland or as a result of grazing is likely the application of nutrients to the soils which increase biomass production and hence cause larger input of carbon to soils. Chaplot *et al.* (2016) also highlights hoof action as an important mechanism; the trampling of the animals breaks impermeable crusts often found on bare soil; fattens the grass and puts dead plant material in contact with decomposer bacteria and invertebrates in the soil, which is in line with Savory's claim.

3.3 Why do scientific studies fail to confirm the positive effects that many practitioners testify?

Based on the material reviewed here, there is only indicative evidence for the general superiority of holistic grazing over other grazing systems or no grazing. There is definitely not enough evidence to support broad generalizations concerning the performance of holistic grazing in different conditions. In addition, it is not clear what causes the positive outcomes in holistic grazing; nutrient input to depleted soils, high stocking densities over short periods of time, the adaptive management, the commitment and expectations of ranchers, or other factors.

The review of the research portfolio of the Savory Institute shows that there are a number of scientific studies that show that different types of rotational grazing systems performs better than conventional continuous grazing or no grazing, in a number of aspects. It appears that under certain circumstances practitioners of holistic grazing achieve better results than their conventional counterparts. Results from the few existing review studies do not, however, conclusively confirm these positive findings. Further, it should be noted that the studies included in the research portfolio are relatively limited in time, space and amount of analysed data. To some extent results point in different directions and the changes are in most cases relatively small.

Whether rotational or continuous grazing is superior has been debated since the early 1950s, i.e., before Savory launched his ideas (Briske *et al.*, 2011). In recent decades, proponents of holistic grazing have showcased a number of studies with good results and a range of 'testimonies', while critics have argued that the available evidence is not enough to draw any reliable or general conclusions.

Even with the best intentions, relevant comparisons between different grazing systems are difficult to design due to the large variability in a wide range of ecological and managerial factors, e.g. rainfall, vegetation structure, composition and productivity, prior land use, livestock characteristics, and the commitment, abilities and ambitions of ranchers (Briske *et al.*, 2008). Managerial variability is seldom recognised and documented which makes comparisons between grazing systems difficult as differences in e.g., productivity is heavily influenced by management.

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The role of the practitioners themselves for the results achieved has not yet been studied. But it has been shown that practitioners of holistic grazing more often apply a systems approach than their conventional colleagues, and that they have a different mentality and to a greater extent value heterogeneity, biodiversity, resilience and adaptation (Sherren *et al.*, 2012). It has also been reported that holistic grazing and management requires ideological and cultural adaptation, and that women seem to have a more prominent role in the management (Richards & Lawrence, 2009). Thus, a special type of people seem to use holistic grazing and management, or the method itself helps to develop special characteristics. Many practitioners undergo training in the holistic framework for decision-making that aims to improve efficiency and help them reach targets. It is likely that these farmers have a special drive and ambition to change and improve their businesses, and that they in fact improve as a result of the training. Such factors could possibly partly explain the positive experiences and results that many farmers testify.

The conclusion that holistic grazing is not superior to continuous grazing is often attributed to the reviews by Holechek *et al.* (2000) and Briske *et al.* (2008), but Savory and others reject these publications and claims that none of them actually refers to 'real' holistic grazing (Itzkan, 2011; Itzkan, 2014; Teague *et al.*, 2008; Teague *et al.*, 2013; Savory, 2013a; Gill, 2009). Savory emphasizes in several publications that holistic management is not the same as short-duration grazing and that the adaptive part of holistic management (i.e. the holistic framework for decision-making) is crucial.

Teague *et al.* (2008) also stresses that the holistic framework for decision-making is such a central part of the method that it cannot be ignored, and that systems that do not include this dimension cannot be considered to represent "real" holistic grazing. In a later study, Teague *et al.* (2013) note that only three studies in the review by Briske *et al.* (2008) actually applied adaptive management, while the other 38 studies were fixed constellations without the flexibility or customization.

Briske *et al.* (2011) admit that most of the studies reviewed in 2008 had deliberately been standardized (i.e., management flexibility had been removed) in order to study the effects of selected parameters. Hence, one of the most important cornerstones of holistic grazing was excluded, namely the holistic framework for decision-making with its continuous adjustment to achieve targets. Briske *et al.* (2011) suggested that the omission of this component probably partially explained the 'gap' between the effects reported by practitioners and the results from scientific studies.

Carter *et al.* (2014) also acknowledges this explanation and argues that the claimed positive effects of holistic grazing probably can be attributed to the actual execution of the method, including its adaptive management, rather than to its basic characteristics in terms of stocking densities or frequency of movement. In line with this, Sherren *et al.* (2012) suggest that the holistic framework for decision-making, the systems perspective and planning methods practitioners are trained in and apply, are key components to the success many practitioners experience, rather than the grazing system in itself. That could explain why studies that exclude this dimension are unable to demonstrate any significant differences compared with conventional methods. Briske *et al.* (2008) also points to a possible psychological effect, as the expectations on holistic grazing have been very high, at least in the US, where more or less fantastic stories about the effects of the method flourished during a period.

Briske *et al.* (2011) and Teague *et al.* (2013) both highlight the need for studies that take into account that holistic grazing is an adaptive and flexible system that integrates biophysical and social components. Such studies could provide more fair evaluations of the method and possibly better capture the potential positive effects. Teague *et al.* (2013) suggested in line with this, a possible alternative hypothesis, namely (briefly): 'holistic grazing can be superior to continuous grazing, when it is carried out to achieve as good results as possible at the farm level.' Such a hypothesis is however problematic since it is difficult to refute and hard to test.

4. Can holistic grazing reverse climate change?

It has been claimed that soils managed with holistic grazing can storage such large amounts of carbon (C) that atmospheric carbon dioxide levels can drop to pre-industrial levels in a few decades (Savory, 2008; Savory Institute, 2013a; Savory, 2013a). This claim has encountered strong criticism from scientists; see e.g. Briske *et al.* (2013; 2014) and Carter *et al.* (2014).

The controversial claim appears to be based on a calculation in a report issued by the Savory Institute, "Restoring the climate through capture and storage of soil carbon through holistic planned grazing" (Savory Institute, 2013a), in which it is assumed that 2.5 tonnes of C can be sequestrated per ha and year, on 5 billion ha (corresponding to one third of the world's land), continuously for almost 40 years. A calculation shows that: 2.5 tonnes of C / ha / year × 5 billion ha × 40 years = 500 billion tonnes of C. This amount corresponds fairly well to the total emissions of carbon since the beginning of the industrial revolution, which amount to 555 billion tonnes of C (see Appendix 1). However, the assumptions on which this calculation is based are presented without support or references and appear to be speculation[4].

A report by Seth Itzkan[5] (2014), published on the website of the Savory Institute, has afterwards tried to compensate for the apparent lack of scientific rigor. Itzkan estimates the carbon sequestration rate to 1-2.4 tonnes of C per ha and year, over 3.5 billion ha, during 25 years, which yields a total of 88-210 billion tonnes of sequestrated C. The upper sequestration rate is based on visual inspections of before-and-after photographs by Itzkan himself. It is unclear what the lower sequestration rate is based on.

It should be emphasized that Itzkan's report has not undergone scientific peer-review and that visual inspections or 'before-and-after' photographs are not a scientifically acceptable methods to accurately evaluate changes in soil carbon (see Chapter 4.2). For these reasons, this report is not further discussed here.

4.1 Land degradation – a global problem

A large part of the world's (potential) pastures are located in dry climate areas. The main limiting factor to plant growth in drylands is water availability (del Grosso *et al.*, 2008). The drylands of the world amount to 3.5 to 6.3 billion ha (26-47% of the world's land area), depending on land classification system (for more information see Lal, 2001 and Appendix 2).

In his TED-talk (at 2.30), Savory claimed that about two-thirds of the world's land area is desertifying (Savory, 2013b), equivalent to about 9 billion ha. This estimate appears to be based on visual inspections of satellite photos of the Earth, where areas appear as either brown or green. It can be noted that recent research analyzing satellite images has shown that semi-arid land areas actually became greener in the period 1981-2007 (Fensholt *et al.* 2012). The savory.global homepage presents a more modest estimate of global degradation (Table 4.1), which is in the upper range of other estimates. According to the United Nations Convention to

[4] It is stated in the report issued by the Savory Institute (Savory Institute, 2013a) that this estimate is uncertain, but these uncertainties seem to have been largely overlooked in ensuing communications concerning the ability of holistic grazing to mitigate climate change.

[5] Seth Itzkan presented his own TED talk in 2012 on the topic holistic grazing and carbon sequestration in soil, entitled "Reversing global warming with livestock?". This speech can be seen as the precursor of Savory's TED talk, in 2013. Itzkan's speech has not gained the same amount of attention as Savory's TED talk.

Combat Desertification (UNCCD) desertification is defined as land degradation in arid, semi-arid and dry sub-humid areas (UNCCD, 2012). Literature estimates of land degradation vary from 0.6 to 3.6 billion ha, depending on estimation method and the type of land and the degree of degradation considered (see Table 4.1 and Appendix 3).

In other words, Savory's claim at the TED-talk concerning the amount of land affected by degradation seems to be greatly exaggerated. It is clear, however, that land degradation is a major problem in many parts of the world, and that climate change and increasing pressure on many types on land to deliver products and services, adds to this problem. Within holistic grazing, lack of grazing animals is considered to cause land degradation (Weber & Horst, 2011). According to the UNCCD, the causes of land degradation are complex and site-specific, and generally a combination of anthropogenic forces and climate, and rather a result of too much than too little, grazing (UNCCD, 2012).

To prevent degradation it is important to prevent soil erosion, preserve vegetation and its protective functions, and adapt the grazing pressure to the capacity of the land. The adaptive part of holistic grazing could be positive in this regard if used to prevent degradation. According to the UNCCD (2012), it is more cost effective and practical to prevent further degradation, than trying to restore already degraded land.

4.2 Soil carbon sequestration

Soil carbon sequestration refers to the uptake of carbon dioxide from the atmosphere through photosynthesis, storage in the soil in the form of organic carbon and dead organic matter, and the conversion of organic carbon to more stable forms of humus that are less susceptible to degradation (Lal, 2004a).

Estimate and brief explanation	Reference
Two-thirds of the world's land area is desertifying (corresponding to about 9billion ha, assuming Savory refers to the world's ice-free land area).	Savory (2013b, at 2:30).
70% of the world's grasslands have been degraded (grasslands make up 1/3 of the world's land area). This estimate corresponds to roughly 3.1 billion ha degraded globally (calculated here based on the world's ice-free land area).	http://savory.global/ (accessed June 1, 2016)
10-20% of the world's drylands are degraded, corresponding to 0.6 to 1.2 billion ha globally (6.1 billion ha are classified as drylands).	Millennium Ecosystem Assessment (MA, 2005).
20-35% of the world's permanent pastures are degraded, corresponding to 0.7 to 1.2 billion ha globally (3.5 billion ha are classified as permanent pastures).	Food and Agriculture Organization of the United Nations, FAO (Conant, 2010).
Land degradation caused by human activity affect 2 billion ha worldwide. Land degradation on permanent pastures affect 0.68 billion ha (21% of the total pasture areas).	Oldeman (1992).
24% of the global land area has been degraded between 1981 and 2003, corresponding to 3.6 billion ha. An additional 12 million ha becomes degraded annually.	UNCCD (2012).

Table 4.1 Different estimates of land degradation.

Terrestrial ecosystems have historically lost large amounts of carbon

Soils hold large amounts of carbon. Temperate grasslands and tropical savannas occupy 3.5 billion ha and store more than 600 billion tonnes of C, of which nearly 87% in the soil, see Appendix 2.

Land degradation in drylands result in losses of carbon from soils and vegetation (Lal, 2001; 2003). Smith (2004a) estimated that soils globally (not just grasslands) historically have lost between 40 and 90 billion tonnes of C, as a result of cultivation and other disturbances. Since the beginning of the industrial revolution, terrestrial ecosystems (also including vegetation) have lost around 30 billion tonnes of C, according to the latest report by the Intergovernmental Panel on Climate Change, IPCC (see Appendix 1). Lal (2001) estimated that land degradation alone may have caused losses of 19-29 billion tonnes of C historically from drylands.

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The fact that large quantities of carbon have historically been lost from terrestrial ecosystems implies that these ecosystems have a large potential to re-sequester carbon. This potential is however not large enough to reverse climate change. Even if all carbon historically lost from soils globally (using the highest estimate from above: 90 billion tonnes of C) could be re-sequestered, it would not cover more than 16% of total emissions of carbon since the beginning of the industrial revolution (see Appendix 1), and not change the fact that a variety of measures are needed to tackle climate change.

Grazing can have positive effects on vegetation growth

It is well-established that continuous excessive grazing with high stocking rates, or uncontrolled grazing, increases the risks of desertification, since grazing reduces the vegetation cover that protects the soil from erosion (Conant & Paustian, 2002; Conant, 2010; MA, 2005; Lal, 2001; UNCCD, 2012: Oldeman, 1992; Milchunas & Lauenroth, 1993). Oldeman (1992) reported that overgrazing is the main cause of land degradation globally, with 680 million ha affected (corresponding to 4.5% of the world's land area).

However, grazing per se does not necessarily have negative effects on natural ecosystems. A review of 97 studies with comparative data from 236 locations worldwide examined the effects of grazing on vegetation growth (net primary production above ground) (Milchunas & Lauenroth, 1993), and found that although grazing in most cases resulted in reduced vegetation growth, there were cases in which grazing resulted in increased vegetation growth: those cases were characterized by a long evolutionary history of grazing, moderate grazing intensity during short time periods, and low net primary production. It could be in such systems that holistic grazing and other similar grazing regimes could play an important role.

How much carbon can the soil store, and what measures can increase the soil carbon sequestration?

Scientifically published studies report that soil carbon sequestration in grasslands rates vary between 0.03 and 1 tonne of C per ha and year, depending

Reference	Data values	Comments
Carbon sequestration rates (tonnes of C per ha and year)		
Smith *et al.* 2008	0.03 / 0.22	As a result of improved grazing, fertilization and improved fire management on grasslands; average values for dry / humid climate zone.
Smith *et al.* 2008	0.42 – 0.76	As a result of manure application on grasslands.
Ogle *et al.* 2004	0.1 – 0.9	As a result of improved management practices including fertilization, irrigation and introduction of legumes on managed grasslands in the US.
Conant & Paustian, 2002	0.05 – 0.69	As a result of changing from intensive to moderate grazing in overgrazed grasslands.
Conant *et al.* 2001	0.54	As a result of improved management practices on grasslands, see Table 4.3.
Conant *et al.* 2001	0.35	As a result of improved grazing on grasslands, see Table 4.3.
Soussana *et al.* 2007	1	European grasslands with different management. Has been criticized for being unreasonably high, see Chapter 4.2.
Global carbon sequestration rates (billion tonnes of C per year) – summed over area		
Petri *et al.* 2010	0.5	Global grasslands, the top 30 cm of the soil.
Lal, 2004a	0.9 ± 0.3	All land (including cropland) as a results of improved management of permanent cropland and measures aimed at preventing degradation of pastures and grasslands.
Lal, 2001	0.9 – 1.9	Global drylands, as a result of measures aimed at preventing land degradation and for restoring degraded land.
Global carbon sequestration potentials (billions tonnes of C) – summed over area and time		
This report	26.5	See Chapter 4.3.
Lal, 2001	12 – 18	Global drylands, as a result of measures aimed at preventing land degradation and for restoring degraded land, during a period of 25-50 years.
Lal, 2004a	30 – 60	All types of land (including cropland) as a results of improved management of permanent cropland and measures aimed at preventing degradation of pastures and grasslands, during a period of 25-50 years.

Table 4.2 Selection of studies on carbon sequestration potentials in land, globally and/or regionally. For an extended version of Table 4.2 with more information, see Appendix 6.

on type of land, land use and treatment (Table 4.2). Under certain conditions and for special treatments, even higher rates have been measured, see e.g. Aguilera *et al.* (2013).

It has been estimated that globally, 0.5-1.9 billion tonnes of C could be sequestered in the soil, per year (Table 4.2). The upper limit corresponds to approximately 20% of current annual emissions of carbon (see Appendix 1). Therefore, even if this upper limit was achieved, the atmospheric carbon dioxide levels would not decrease, but only increase a bit more slowly. Smith (2004a) estimated that soils could sequester at most about one-third of the current yearly increase in atmospheric CO_2-carbon, for a limited period of time (20-50 years).

Globally, it has been estimated 12-60 billion tonnes of C could be sequestered during a period of 25-50 years (Table 4.2). This can be compared to the 555 ± 85 billion tonnes of C emitted since the beginning of the industrial revolution (Appendix 1), and the nearly 500 billion tonnes of C the Savory Institute claims to be able to sequester and store. This shows that the global soil carbon sequestration potential is not large enough to reverse climate change, and that the sequestration claims of the Savory Institute are gravely exaggerated.

Most studies of the long-term soil carbon sequestration potentials are based on computer models (Jones, 2010), but there are also experimental field studies. Soussana *et al.* (2007) measured fluxes of greenhouse gases (carbon dioxide, nitrous oxide and methane) in nine European grassland sites with different management (rotational grazing, continuous grazing and mowing) during a period of two years. Based on these measurements, they estimated the average soil carbon sequestration rate to around 1 tonne of C per ha and year. It can be noted that this sequestration rate equals the lower limit reported by Itzkan (2014) (see above). It should further be noted that Soussana *et al.* (2007) has been criticized for overestimating the soil carbon sequestration rate, since it is based on indirect, flux measurements and not direct measurements of soil C change (Smith, 2014)[6]. Among other things, Smith (2014) mentioned that experimental data from long-term studies of soil carbon stocks in grasslands are not available to support such high sequestration rates. For example, Schrumpf *et al.* (2011) reviewed nine studies that had measured soil organic carbon content in European grasslands over 10-50 years, and found no clear trend: increases, decreases as well as stable conditions were reported. In another study, Bellamy *et al.* (2005) reviewed experimental soil carbon data from grasslands in England and Wales with different types of management, collected 1978-2003, and found virtually no change in grassland SOC stocks, apart from small decreases in upland grass and moorland SOC content over time.

Further, Smith (2014) concluded that if 1 tonne of C per ha and year were indeed sequestered, it may not be a result of current management practices, but could reflect land use changes many decades earlier. It can take up to 100 years from a land use change, until a new soil carbon equilibrium is reached (see Appendix 5 for more information). It is possible that many European grasslands are situated on former croplands, and still act as carbon sinks because equilibriums have not yet been reached. It should also be noted that Soussana *et al.* (2007) studied well-managed and high-yielding European grasslands, which means that these results cannot easily be transferred to drylands.

Improved management, e.g. grazing, can increase soil carbon storage potential

It is well-established that improved management practices can be beneficial for the soil's capacity to store carbon, especially in land that has previously been, or is, mismanaged and thus depleted of soil carbon (IPCC, 2007; Jones, 2010).

Some management measures identified in scientific studies as having the potential to increase carbon storages in grasslands and pastures are: improved grazing management, improved fire management that reduce the frequency or extent of fires, fertilization including manure application, irrigation

[6] It may be added that when the nitrous oxide from soils and methane from grazing livestock were included in the analysis, uptake and emissions were of the same order of magnitude, and the production systems roughly carbon neutral.

and introduction of legumes, earthworms and improved grass species with better protective properties (for more information, see Appendix 6). The IPCC (2007, p. 508) also acknowledges that improved grazing management can increase carbon sequestration (as well as reduce losses) in pastures. It should be noted that "improved grazing management" implicitly relate to a reference scenario in which traditional, often abusive, management practices dominate.

Grazing per se, however, does not necessarily result in higher soil carbon content, compared to grazing exclosure. A review by Milchunas & Lauenroth (1993) of 97 studies with comparative data from 236 locations worldwide examined the effects of grazing on soil organic matter content but found no correlation (there were approximately equal number of positive and negative results).

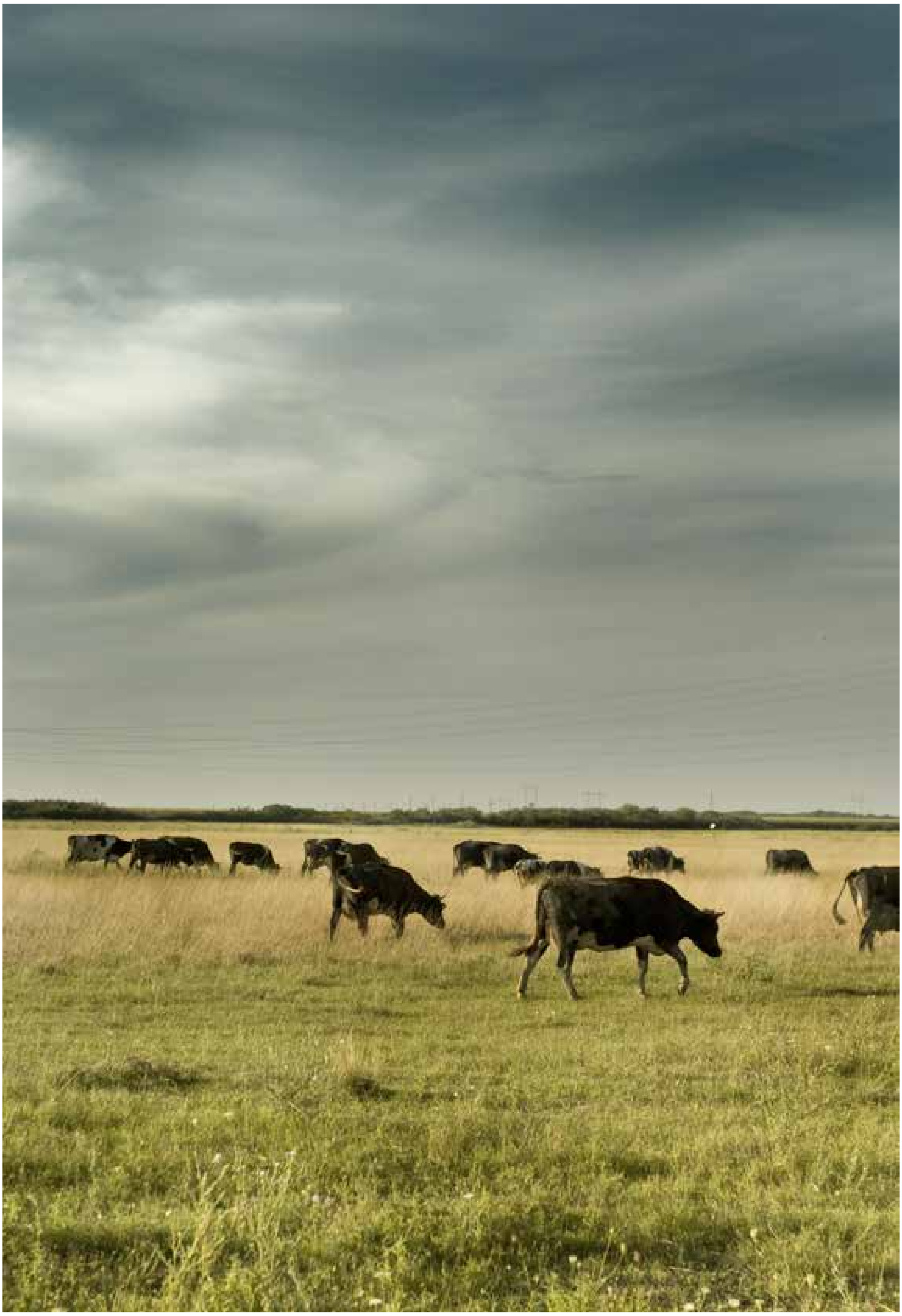
An extensive review concerning effects on soil carbon as a result of grassland management and conversion into grassland was conducted by Conant *et al.* (2001)[7]. This study reviewed data from 115 studies world-wide, comprising over 300 data points and found that carbon sequestration rates varied between 0.11-3.04 tonnes of C per ha and year, with an average value of 0.54 tonnes of C per ha and year (Table 4.3). Increases in soil carbon content were mainly concentrated to the top 10 cm of the soil, and generally decreased with depth (studies measured soil C changes to different depths). Sequestration rates were highest during the first 40 years after implementing a management change. It is important to note that carbon cannot be sequestered in the soil with the same rate year after year, as is sometimes assumed (for more information concerning time scales associated with soil carbon sequestration, see Appendix 5).

For 'improved grazing', Conant *et al.* (2010) found an average carbon sequestration rate of 0.35 tonnes of C per ha and year, based on 45 data points (Table 4.3). This is seven times lower than the 2.5 tonnes of C per ha and year reported by the Savory Institute (Savory Institute, 2013a). A majority (65%) of these studies were from areas with a long evolutionary history of grazing and relatively low productivity (Conant *et al.* 2010) – factors that in combination with moderate grazing have been shown to favor plant production (Milchunas & Lauenroth, 1993). It is therefore likely that the observed increases in carbon sequestration in many of

[7] More information about the reviewed studies can be found in Appendix A of Conant *et al.* (2001): http://www.esapubs.org/archive/appl/A011/005/appendix-A.htm (accessed June 1, 2016)

Management	Number of data points	Carbon sequestration rate (tonnes of C per ha and year)
Irrigation	2	0.11
Fertilization	42	0.30
Improved grazing	45	0.35
Conversion: native to pasture	42	0.35
Conversion: cultivation to pasture	23	1.01
Introduction of legumes	6	0.75
Earthworm introduction	2	2.35
Improved grass species	5	3.04
All types	167	0.54

Table 4.3 Carbon sequestration rates and number of data points by type of management change (source: Conant et al. 2001).



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these cases were due to increased plant production (Conant *et al.* 2001). In fact, study sites without a long evolutionary history of grazing lost carbon a result of grazing, by almost 2% per year (Conant *et al.* 2001).

Some measures identified in the review by Conant *et al.* (2001) resulted in carbon sequestration rates in the same order of magnitude as reported by the Savory Institute, e.g. 3 tonnes of C per ha and year as a results of improved grass species (Table 4.3). Such high sequestration rates should be considered maximum values that can be achieved in fertile soils with favorable climate conditions, and not average values that are representative for a variety of soil and climate conditions.

Smith (2014) stressed that the amount of soil carbon that can potentially be lost by far exceed the amount of carbon that can potentially be sequestered (and that it is easier to deplete, than to sequester, carbon). Therefore, although management measures with the potential to increase carbon sequestration rates exists, Smith (2014) argued that efforts should primarily aim to prevent further land degradation and preserve existing soil carbon stocks, rather than try to sequester additional carbon.

Numerous measurements during long time are needed in order to study soil carbon changes

Correlating changes in soil carbon content with management practices, such as grazing, is challenging due to varying conditions in terms of soil, climate and vegetation, as well as differences in the implementation of management practices, concerning e.g., grazing intensities and herd sizes (Jones, 2010; Follett *et al.*, 2001). Also, changes in soil carbon content are typically small compared to background levels, which poses a challenge when it comes to measuring (Smith, 2004b; Dungait *et al.*, 2012).

In order to produce reliable results, a large number of soil samples taken during a long period of time are usually required (Smith, 2004b). Schrumpf *et al.* (2011) reported that it could take up to 15 years to detect statistically significant changes in soil carbon if 100 soil samples from the top 10 cm of soil were regularly collected and analyzed. This means it takes even longer to detect statistically significant changes if fewer soil samples are collected. Studies based on a small number of soil samples and/or measurements during short periods of time should therefore be considered highly uncertain (including all forms of "visual inspections"). It should also be noted that the knowledge underpinning soil carbon models has changed a lot over the past decade, and is still evolving (see, e.g., Dungait *et al.* 2012), which further indicate the involved uncertainties.

4.3 How much carbon can be stored in pastures?

A simple calculation, based on very optimistic assumptions, is presented. This calculation estimates the carbon storage potential in pastures and is used to evaluate the claim that holistic grazing can reverse climate change. Assume that (the reasonableness of these assumptions are discussed further below):

1. holistic grazing is introduced on 1 billion ha worldwide, in line with the goal of the Savory Institute;
2. plant growth measured as net primary production (NPP) above and below ground is 3.8 tonnes of C per ha and year before holistic grazing is introduced (see Appendix 4);
3. plant growth in the form of NPP is doubled as a result of holistic grazing;
4. 10% of the NPP is sequestered in the soil year 1, and
5. the soil carbon sequestration rate declines linearly from 10% of the NPP year 1, to 2% during the first 50 years, and from 2% of the NPP to 0% during the next 50 years.

Based on these (combined) very optimistic assumptions (see below), 0.76 tonnes of C is sequestered per ha year 1 (= 3.8 tonnes of C / ha / year × 2 × 10%). Assuming that holistic grazing is introduced on 1 billion ha, this rates correspond to 0.76 billion tonnes of sequestrated C. Note that these values fit relatively well with values reported in scientific studies (Table 4.2). Despite optimistic assumptions, 0.76 billion tonnes of C correspond to less than 10% of current annual emissions, which exceed 10 billion tonnes of C, see Appendix 1. After year 1, the carbon sequestration rate declines (while anthropogenic C emissions are increasing).

During 100 years, the total carbon storage potential amounts to 26.5 billion tonnes of C (which also fits relatively well with values reported in scientific studies, see Table 4.2). This amount corresponds to less than 5% of the total emissions of carbon since the beginning of the industrial revolution (555 billion tonnes of C, see Appendix 1). Although efforts to reverse climate change are not primarily focused on offsetting historic emissions, but rather reducing current emissions, this comparison clearly shows that holistic grazing cannot reverse climate change, since it cannot even offset 5% of historic emissions.

How reasonable are the assumptions in the above calculation?

1. 1 billion ha managed holistically is the goal of the Savory Institute. This corresponds to 1/15 of the world's total land surface (see Appendix 1). Currently, 15 million ha are managed holistically (Savory Institute, 2014b). To increase this area by a factor 67 is of course a huge challenge. The Food and Agriculture Organization of the United Nations (Conant, 2010) has estimated that 5-10% of the global grazing lands could be placed under carbon sequestration management by 2020, if proper policies, incentives and training programs are implemented. This corresponds to 175-350 million ha. Therefore, 1 billion ha managed with holistic grazing is an extremely optimistic assumption.
2. An initial NPP of 3.8 tonnes of C per ha and year corresponds to the higher estimate of del Grosso *et al.* (2008), and refer to savannas, see Appendix 4. Grasslands have significantly lower NPP (1.7 tonnes of C per ha and year). If holistic grazing were to be introduced large scale, it is likely that the average NPP would be lower than assumed here. Therefore, this assumption is considered optimistic.
3. A doubling of plant productivity: the world's grasslands and savannas are situated in areas where the vegetation growth is limited by precipitation and temperature (del Grosso *et al.* 2008); factors a specific grazing method cannot change. None of the studies included in the research portfolio of the Savory Institute (see Chapter 3.1) support a doubling of plant productivity. Therefore, this assumption is considered very optimistic.
4. 10% of the NPP sequestrated in the soil year 1 is considered a relatively optimistic estimate.
5. Soil carbon sequestration is a slow process, in which the sequestration rate is highest immediately after a management change, after which it declines as the soil carbon stocks become saturated and a new equilibrium is reached, see Appendix 5. Jones (2010) and Smith (2014) report that it can take up to 100 years from a land use change until a new equilibrium is reached. Lal (2001) suggested that, for practical calculations, it is enough to account for the soil carbon sequestration that takes place during the first 25-50 years after a land use change, after which sequestration rates generally are too low to be important. Based on this, it is reasonable, and relatively optimistic, to assume that carbon is being added to the soil continuously for 100 years. It is reasonable to assume that the sequestration rate declines, as the carbon stocks become saturated, see e.g., Smith (2014). Although carbon sequestration in reality is a non-linear process, a linear approximation was considered a reasonable simplification for the purpose of this calculation.

4.4 The Savory Institute's view on emissions of methane from cattle

The Savory Institute has published a report, "An exploration of methane and properly managed livestock through holistic management", which deals with emissions of methane from cattle (Savory Institute, 2013b). This report suggests that there is probably no correlation between emissions of methane from cattle, and the (rising) atmospheric concentration of methane, based on similar claims made in a report by the International Atomic Energy Agency (IAEA, 2008), and an idea of 'very large' ruminant populations on Earth in historic times without the atmospheric methane concentration being affected. These claims and ideas are addressed here.

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Lack of correlation between emissions of methane from cattle, and the (rising) atmospheric concentration of methane is completely at odds with the available scientific knowledge. Of the total greenhouse gas emissions from the global livestock sector, methane from enteric fermentation of ruminants account for 39% - of which cattle account for three-quarters (Gerber *et al.*, 2013). Lassey (2007) showed that the increasing concentration of methane in the atmosphere can largely be attributed to the world's increasing livestock population. For more information, see Appendix 7.

The idea that ruminant populations have historically been 'very large' appears to be pure speculation. Available estimate indicate that the global population of wild ruminants has decreased during the past 500 years, but if both domestic and wild ruminants are considered (cattle, buffaloes, horses and wild ruminants), the population has increased by more than a factor 6 during the past 500 years. During the same period, the number of cattle alone increased by more than a factor of 20. For more information, see Appendix 8.

Last but not least, it is important that emissions of methane from cattle are accounted for when assessing the total climate impacts of livestock production systems. It is likely that the emissions of methane outweigh any positive effects associated with increased soil carbon storage as a result of improved grazing management.

5. Conclusions

- There are relatively few (11) peer-reviewed studies on the effects of holistic grazing that are 'approved' by the Savory Institute, i.e., included in Savory Institute Research Portfolio. These case studies show positive effects of holistic grazing in terms of grassland and livestock productivity and soil conditions over conventional or continuous grazing, but are rather limited in time, number of study sites and analyzed data. Only six of the studies use measurements while five are based on interviews or surveys. Further, the results are partially inconclusive, and the reported effects are in most cases rather small.

- Review studies that have compared different grazing systems are few and difficult to perform due to large variability in systems and local conditions. To date, no review study has been able to demonstrate that holistic grazing is superior to conventional or continuous grazing. One possible reason is that the effects of the holistic framework for decision-making have not been appropriately accounted for in these studies. The claimed benefits of the method thus appear to be exaggerated and/or lack broad scientific support.

- Some claims concerning holistic grazing are directly at odds with scientific knowledge, e.g. the causes of land degradation and the relationship between cattle and atmospheric methane concentrations.

- It is well-established that continuous excessive grazing with high stocking rates, or uncontrolled grazing, increases the risks of desertification. However, although grazing in most cases result in reduced vegetation growth, under certain conditions (a long evolutionary history of grazing, moderate grazing pressure during short time periods, and low net primary production) grazing can result in increased vegetation growth.

- Improved grazing management can improve conditions on many degraded lands. Based on this review, holistic grazing could be an example of good grazing management, but nothing suggests that it is better than other well-managed grazing methods.

- Improved grazing management on grasslands can store on average approximately 0.35 tonnes of C per ha and year – a rate seven times lower than the rate used by the Savory Institute to support the claim that holistic grazing can reverse climate change.

- The total carbon storage potential in pastures does not exceed 0.8 tonnes of C per ha and year, or 27 billion tonnes of C globally, according to an estimate in this report based on very optimistic assumptions. 27 billion tonnes of C corresponds to less than 5% of the emissions of carbon since the beginning of the industrial revolution. Holistic grazing can thus not reverse climate change.

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Appendices

Appendix 1. Anthropogenic carbon emissions

Human activities since the beginning of the industrial revolution (~ 1750) have emitted 555 ± 85 billion tonnes of C, of which 68% from fossil fuel burning and cement production, and 32% from land use change, mainly deforestation, but also, e.g., conversion of grasslands to croplands (IPCC, 2013).

Emissions from fossil fuel burning and cement production averaged 7.8 billion tonnes of C per year between 2000 and 2009, with an annual increase of 3.2% (IPCC, 2013). In 2011, emissions from fossil fuel burning and cement production reached 9.5 billion tonnes of C per year (IPCC, 2013). Net emissions from land use change have been estimated to 1.1 billion tonnes of C per year between 2000 and 2009 (IPCC, 2013). Combined, emissions from fossil fuel burning, cement production and land use change thus currently exceed 10 billion tonnes of C annually.

Of the 555 billion tonnes of C emitted since 1750, 43% (240 ± 10 billion tonnes of C) has accumulated in the atmosphere (and thus contributed to the enhanced greenhouse effect), 28% (155 ± 30 billion tonnes of C) has been absorbed by the ocean, and 29% (160 ± 90 billion tonnes of C) has been absorbed by terrestrial ecosystems (IPCC, 2013).

Terrestrial ecosystems function both as a source and sink of carbon. Based on the latest report by the IPCC, terrestrial ecosystems have probably been a net source since the beginning of the industrial revolution when balancing losses from soil and vegetation associated with land use change and carbon sequestration in mainly forests. This net source has been estimated to 30 billion tonnes of C, but the uncertainties are large; ± 45 billion tonnes of C, which means terrestrial ecosystems may instead have been a net sink (IPCC, 2013).

Lal (2004b) reports that land use changes during pre-industrial times (7,800 years) have caused losses of 320 billion tonnes of C from terrestrial ecosystems, and an additional 136 ± 5 billion tonnes of C since the beginning of the industrial revolution.

Appendix 2. Land areas, and carbon stocks in soil and vegetation

Biome	Area (billion ha)	Global carbon stock (billion tonnes of C)		Soil carbon stocks (tonnes of C per ha) calculated
		Vegetation	Soil (depth of 1 m)	
Tropical forests	1.76	212	216	123
Temperate forests	1.04	59	100	96
Boreal forests	1.37	88	471	344
Tropical savannas	**2.25**	**66**	**264**	**117**
Temperate grasslands	**1.25**	**9**	**295**	**236**
Deserts and semideserts	4.55	8	191	42
Tundra	0.95	6	121	127
Wetlands	0.35	15	225	643
Croplands	1.6	3	128	80
Total	15.12	466	2011	133

Table A1. Extensions and carbon stocks in vegetation and soil down to a depth of 1 meter, for different biomes (vegetation zones).

Drylands

Drylands are areas where water availability limits plant growth (del Grosso *et al.*, 2008), and characterized by low and irregular rainfall; large variation between day and night temperatures and soils with low organic matter content (UNCCD, 2012). Globally, drylands support 50% of the world's livestock and are home to more than 2 billion people (UNCCD, 2012).

Drylands cover 3.5 to 6.3 billion ha (26-47% of the world's land area), depending on classification system (for an overview, refer to Lal, 2001). For example, the United Nations Environment Programme uses a climate-based classification system, according to which 6.1 billion ha (41% of the global ice-free land area) are classified as dryland (MA, 2005).

Appendix 3. Desertification and land degradation

Land degradation in drylands result in losses of carbon from soils and vegetation (Lal, 2001; 2003). According to the UNCCD[8] (2012), desertification is defined as 'land degradation in arid, semi-arid and sub-humid areas', and may be caused by various factors, such as climatic variations and human activities. Desertification is not the same as loss of land to deserts through movement of sand dunes, however, desert-like conditions are often created as a results of land degradation in drylands (UNCCD, 2012). Land degradation is defined as a reduction or loss of biological or economic productivity in dry areas (MA, 2005).

Estimates of the amount of land affected by land degradation vary depending on estimation method and the type of land and the degree of degradation considered. The Millennium Ecosystem Assessment (MA, 2005) estimated that 10-20% of the world's drylands are degraded, corresponding to 0.6 to 1.2 billion ha globally.

The Food and Agriculture Organization of the United Nations (Conant, 2010) estimated that 20-35% the world's permanent pastures are degraded, corresponding to 0.7 to 1.2 billion ha globally (according to the FAO, 3.5 billion ha are classified as permanent pastures).

UNCCD (2012) estimated that 24% of the global land area has been degraded between 1981 and 2003, corresponding to 3.6 billion ha, and that an additional 12 million ha become degraded annually.

Oldeman (1992) estimated that land degradation caused by human activity amounts to 2 billion ha worldwide, and that land degradation on permanent pastures amounts to 0.68 billion ha (21% of the total pasture areas).

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[8] United Nations Convention to Combat Desertification.

Appendix 4. Biomass production potential on grazing lands

Net primary production (NPP) is the difference between CO_2 fixed by photosynthesis and CO_2 lost to autotrophic respiration (del Grosso *et al.*, 2008). The NPP can be viewed as an indicator of biomass production. The majority of the world's potential grazing lands are situated in areas where precipitation is the main limiting factor to vegetation growth, followed by temperature (del Grosso *et al.*, 2008). Table A2 shows the NPP above and below ground in grasslands and savannas (i.e. also in the roots).

Biome	Net primary production above and below ground (tonnes of C per ha and year)
Grasslands	1.7
Savanna	3.8

Table A2. Net primary production above and below ground in grasslands and savannas (own calculations based on data in Table 2 in del Grosso et al. 2008).

Appendix 5. Time scales associated with soil carbon sequestration

The capacity of soil to store carbon is finite and determined by a range of factors such as soil type (e.g. the content of organic matter and clay), climate and type of land use. A change in land use can result in a higher or lower carbon storage potential (or similar). Soil carbon sequestration is a slow non-linear process, in which the sequestration rate is highest immediately after a change in management, after which it declines as the soil carbon stocks become saturated and a new equilibrium is reached (Jones, 2010; Smith, 2014, Powlson *et al.*, 2011).

Jones (2010) reports that it usually takes between 20 and 100 years before a new equilibrium is reached, after a management change is introduced. Smith (2014) also noted that it can take up to 100 years before an equilibrium is reached. Lal (2001) suggested that, for practical calculations, it is enough to account for the soil carbon sequestration that takes place during the first 25-50 years after a land use change, after which sequestration rates are generally too low to be important.

Appendix 6. Extended version of Table 4.2

Reference	Data values	Comments
Carbon sequestration rates (tonnes of C per ha and year)		
Smith *et al.* 2008	0.03 / 0.22	As a result of improved grazing, fertilization and improved fire management on grasslands; average values for dry / humid climate zone.
Smith *et al.* 2008	0.42 – 0.76	As a result of manure application on grasslands. The range is associated with varying regional conditions. In general, sequestration rates are higher in humid regions than in dry.
Ogle *et al.* 2004	0.1 – 0.9	As a result of introduction of one or several improved management practices on managed grasslands in the US, including, among others, fertilization, irrigation and introduction of legumes. Sequestration rates are estimated based on results from 49 individual studies on the connection between management and soil carbon and a sequestration period of 20 years.
Conant & Paustian, 2002	0.05 – 0.69	As a result of changing from intensive to moderate grazing in overgrazed grass-land sites. The range indicate potentials in different regions.
Conant *et al.* 2001	0.54	As a result of improved management practices on grasslands. Average value based on 167 data points (see Table 4.3).
Conant *et al.* 2001	0.35	As a result of improved grazing on grasslands. Average value based on 45 data points (see Table 4.3).
Soussana *et al.* 2007	1	European grassland sites with different management (rotational grazing, continuous grazing and mowing). Based on flux measurements during two full years of carbon dioxide, nitrous oxide and methane. Has been criticized for being unreasonably high, see Chapter 4.2.
Global carbon sequestration rates (billion tonnes of C per year) – summed over area		
Petri *et al.* 2010	0.5	Grasslands of the world (31% of the global land area), the top 30 cm of the soil. Calculated based on GIS data on land cover and land use, degree of land degradation and soil and climate conditions. Highest potential in warm, humid and boreal regions, and lowest potential in desert regions.
Lal, 2004a	0.9 ± 0.3	All types of land (including cropland) as a result of improved management of permanent cropland and measures aimed at preventing degradation in pastures and grasslands, based on a literature review. Highest potential in degraded lands, followed by croplands, pastures and forested land / perennial crops.
Lal, 2001	0.9 – 1.9	Drylands of the world, during 25-50 years, as a result of measures aimed at preventing land degradation and for restoring degraded land, such as introduction of plant species with better protective properties, more effective water management, irrigation, fertilization, and controlled, non-excessive grazing. Based on the assumption that two-thirds of what has historically been lost can be retrieved.
Global carbon sequestration potentials (billions tonnes of C) – summed over area and time		
Estimate in this report	26.5	See Chapter 4.3.
Lal, 2001	12 – 18	Drylands of the world, as a result of measures aimed at preventing land degradation and measures for restoring degraded land, such as introduction of plant species with better protective properties, more effective water management, irrigation, fertilization, and controlled, non-excessive grazing. Could be achieved during a period of 25-50 years. Based on the assumption that two-thirds of what has historically been lost can be retrieved.
Lal, 2004a	30 – 60	All types of land (including cropland) as a results of improved management of permanent cropland and measures aimed at preventing degradation of pastures and grasslands, based on a literature review. Could be achieved during a period of 25-50 years. Highest potential in degraded lands, followed by croplands, pastures and forested land / perennial crops.

Appendix 7. Anthropogenic emissions of methane

Since the beginning of the industrial revolution, the concentration of methane in the atmosphere has increased from 722 to 1803 ppb (IPCC, 2013). In the 1980s, the growth rate slowed down, and almost ceased by the end of the 1990s. The fact that the atmospheric methane concentration almost stabilized, while global livestock populations increased (see Appendix 8), has been misinterpreted as lack of correlation between these two variables: this idea was proposed in a report by the International Atomic Energy Agency (IAEA), in 2008. The explanation was that the emissions of methane, which remained relatively stable at around 550 million tonnes per year for nearly three decades, were basically offset by decay (IPCC, 2013). Hence, the atmospheric concentration of methane was stabilizing. Since 2007, the atmospheric concentration of methane has however continued to increase again (IPCC, 2013).

Natural sources, mainly various types of wetlands, accounted for 35-50% of total methane emissions during 2000-2009. The remaining portion (50-65%) came from anthropogenic sources, of which enteric fermentation of ruminants accounted for about a quarter (IPCC, 2013). Enteric fermentation is a process in which microorganisms in the rumen of ruminant animals break down cellulose and produce methane (Lassey, 2007).

Methane emissions from cattle vary with type and amount of feed: grass result in higher emissions than protein-rich feed-stuff, such as grain, because grass contains more cellulose (Crutzen *et al.*, 1986). The FAO has estimated that the global livestock sector accounts for 14.5% of anthropogenic greenhouse gas emission (Gerber *et al.*, 2013). Of the total greenhouse gas emissions from the global livestock sector, methane from enteric fermentation of ruminants account for 39% - of which cattle account for three-quarters (Gerber *et al.*, 2013). That methane from enteric fermentation affects the climate has been known for a long time (Johnson & Johnson, 1995; Moss *et al.*, 2000). Lassey (2007) showed that the increasing concentration of methane in the atmosphere can largely be attributed to the world's increasing livestock population. Methane emissions from enteric fermentation of cattle are at least 15 times higher than methane emissions from the global population of wild ruminants (own estimate based on IPCC, 2013, pp. 507 and Crutzen *et al.* 1986).

As a greenhouse gas, methane is 34 times more powerful than carbon dioxide, measured over 100 years, including climate–carbon feedbacks (IPCC, 2013; Table 8.7).

Appendix 8. Ruminant populations over time

The global population of domestic ruminant livestock currently exceeds 3.8 billion animals, of which 1.5 billion cattle, and 2.3 billion sheep, goats, horses and buffaloes (FAOSTAT). Sheep, goats, horses and buffaloes causes lower per-animal, as well as total, methane emissions than cattle (Crutzen *et al.*, 1986; Gerber *et al.*, 2013). By comparison, in 1900, there were around 1.4 billion livestock animals (cattle, sheep, goats, horses and buffaloes, according to the HYDE database). The global population of cattle, buffaloes and horses in the Middle Ages (around year 1500) has been estimated to 130 million animals, based on Subak (1994), no data are available for sheep and goats.

Concerning wild ruminants, the global population in present times has been estimated to 75 million animals (Hackmann & Spain, 2010). In historic times, the population in North America pre-European settlement (Hristov, 2012), and in Africa around the year 1500 (elephant, wildebeest and giraffe, based on Subak, 1994) has been estimated to 165 million animals in total.

These estimates suggest that the global population of large ruminants (cattle, buffaloes, horses and wild ruminants combined) increased by more than a factor 6 during the past 500 years. During the same period, the number of cattle alone increased by more than a factor of 20. At present, the global population of domestic ruminants is approximately 50 times larger than the global population of wild ruminants.

Appendix 9. Links to further reading

- Monbiot, G. Eat more meat and save the world: the latest implausible farming miracle. Aug 4, 2014. http://www.theguardian.com/environment/georgemonbiot/2014/aug/04/eat-more-meat-and-save-the-world-the-latest-implausible-farming-miracle

- Maughan, P. Allan Savory gives a popular and very misleading TED talk. March 18, 2013. http://www.thewildlifenews.com/2013/03/18/alan-savory-gives-a-popular-and-very-misleading-ted-talk/

- Merberg, A. Cows Against Climate Change: The Dodgy Science Behind the TED Talk. March 11, 2013. http://www.inexactchange.org/blog/2013/03/11/cows-against-climate-change/

- Online discussion forum where A. Savory participates, initiated by C. Kruger, Nov 20, 2012, http://csanr.wsu.edu/savory1/

- McWilliams, J. E. All sizzle and no steak: Why Allan Savory's TED talk about how cattle can reverse global warming is dead wrong. April 22, 2013. http://www.slate.com/articles/life/food/2013/04/allan_savory_s_ted_talk_is_wrong_and_the_benefits_of_holistic_grazing_have.single.html#

- West, J.; Briske, D. D. Cows, Carbon and the Anthropocene: Commentary on Savory TED Video. Nov 4, 2013. http://www.realclimate.org/index.php/archives/2013/11/cows-carbon-and-the-anthropocene-commentary-on-savory-ted-video/

- Grazing the Grasslands - and Allan Savory's TED Talk. Nov 24, 2013. http://tmousecmouse.blogspot.se/2013/11/grazing-grasslands-and-allan-savorys.html

- Hadley (1999) The wild life of Allan Savory. Article in the Range Magazine. http://www.rangemagazine.com/archives/stories/fall99/allan_savory.htm

Allan Savory is the man behind holistic grazing and the founder of the Savory Institute. Savory claims that holistic grazing can stop desertification and reduce atmospheric carbon dioxide levels to pre-industrial levels in a few decades. In this report, we review the literature on holistic grazing in order to evaluate the scientific support behind these statements.

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