Integrating Ruminants to Reduce Agriculture's Carbon Footprint

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Summary

To ensure the long-term sustainability and ecological resilience of natural resources, agricultural production needs to be guided by policies and regenerative management protocols that support ecologically healthy and resilient arable and pastoral ecosystems and mitigate anthropogenic greenhouse gas (GHG) emissions. This requires an inclusive assessment of terrestrial and atmospheric impacts from ALL agricultural activities. Merely addressing one component of agriculture, such as methane emissions from ruminants, leads to flawed and misleading conclusions. We outline the magnitude of GHG emissions from key agricultural components and practices that exceed emissions from current domestic ruminant practices alone, and indicate how using conservation-based management in arable and pastoral agro-ecosystems has the potential for reducing GHG emissions through the sustainable use of natural resources. With appropriate regenerative management, ruminants facilitate provision of essential ecosystem services, increase soil carbon sequestration, reduce GHG emissions, and reduce environmental damage caused by many current agricultural practices.

Introduction

For humans to live sustainably, natural resources need to be managed in ways that prevent their depletion and that ensure ecosystem resilience for self-replenishment. Scientific knowledge, modern technology and sophisticated organization have greatly increased the availability of energy, food, water and other biophysical resources. While these changes have substantially elevated most peoples' well-being and material wealth, they have occurred broadly at the expense of natural resources upon which human survival ultimately depends[1].

To ensure long-term delivery of high quality renewable resources, especially those that support human food and water requirements, agricultural production needs to be guided by policies and management protocols that 1) support ecologically healthy and resilient arable and pastoral ecosystems, and 2) mitigate anthropogenic greenhouse gas (GHG) emissions.

Agriculture must address environmental, social, cultural and economic complexity, while also focusing on unintended consequences. Failure to consider such consequences has contributed to the majority of serious ecological problems created by the industrial agriculture era; most notably increased GHG emissions as well as topsoil and soil carbon losses.

In contrast to the deficiencies of many traditional tillage-based cropping and feedlot-based livestock production systems, ecologically sensitive management of ruminants in arable and pastoral agro-ecosystems can positively contribute to critical ecosystem services. These include carbon (C) sequestration, maintenance of stable and productive soils, functional water catchments, delivery of clean water, production of healthy food, protection of critical wildlife habitat, and enhancement of biodiversity[2,3].

Grasslands and savanna ecosystems around the world coevolved with grazing ruminants and fire[4]. Due to their climatic, edaphic or topographic limitations, many of these grazing ecosystems are not suitable for crop or horticultural production for direct human consumption; they can only be used for food and fiber production through the consumption of domestic or wild grazing herbivores. In addition, in many ecosystems that are marginal for cultivation, livestock are used to concentrate fertility near homesteads to produce crops and vegetables that improve human nutrition and that could not otherwise be grown.

Over 1.3 billion people living in such rangeland ecosystems depend, often almost exclusively, on livestock for their food supply and livelihoods, as they have for millennia[5]. Large domesticated animals, notably cattle, are fundamental for many pastoral cultures. In cultures located in more arid ecosystems, sheep and goats are often more important for pastoralists to convert solar energy into food and fiber products because these smaller ruminants are better able than cattle to consume the available vegetation that otherwise provides no nutritional vale to people.

In addition, in many countries that are affected by monetary instability, livestock, predominantly cattle, provide the most secure individual investment option because they are easily identified and managed by individual owners. They can be moved to follow spatially variable rainfall, are a reliable hedge against inflation, and they produce dividends in the form of offspring that can be marketed or retained to build wealth. In many countries, people observe centuries-old cultures and customs that tie them to livestock in ways that have supported their collective health and prosperity.

Recently, some scientists have suggested reductions in global ruminant numbers could make a substantial contribution to climate change mitigation goals and yield important social and environmental co-benefits [6]. However, given that ruminant livestock are such an integral part of agriculture and human culture in many parts of the world, the feasibility of substantially reducing livestock numbers is potentially very challenging[5]. An objective global analysis of the trade-offs for livestock and food production within whole agro-ecosystems is needed, including an assessment of the potential for livestock in re-greening the earth[7].

To address the need for a more comprehensive and inclusive assessment of global GHG emissions from agriculture, we outline the magnitude of GHG emissions from key agricultural components and practices that exceed emissions from current domestic ruminant practices alone. We also indicate how domesticated ruminants can be a tool to facilitate the delivery of essential ecosystem services, notably soil C sequestration and GHG emission reduction, as well restoring ecosystems that have been damaged by traditional agricultural practices. We outline the value of using conservation-based grazing management in arable and pastoral agro-ecosystems and the potential for improvements in grazing management to reduce GHG emissions through the regenerative use of natural resources. We further discuss a research framework to facilitate the adoption of management approaches that bridge the gap between the results obtained from single-discipline, reductionist research and effective resource management that reduces the C footprint of current agricultural practices.

Emissions from agricultural sources

An analysis of key elements in the food supply-chain lifecycle indicates that agriculture in general generates substantial levels of non-ruminant related GHG emissions. The production of food to meet global demand comes at a considerable environmental and social cost. Since tillage-based farming began, most agricultural soils have lost 30% to 75% of their original soil organic carbon (SOC) with industrial agriculture accelerating these losses[3]. In some areas, instead of increasing food yields, high input agriculture has led to a decrease in food production due to the environmentally deleterious effects on soils[7]. Importantly, the anthropogenic sources of GHG emissions related to intensive crop production are independent from ruminants and would be produced even if livestock numbers were reduced.

Globally the GHG emissions from livestock production are approximately 14.5% of total anthropogenic emissions (1.97 of 13.6 Gt C yr^{-1}), of which ruminants contribute 11.6 % (1.58 Gt C yr^{-1}) and cattle 9.4 % (1.27 Gt C yr^{-1}) [6,8,9,10]. By contrast, the effects of agricultural soil management contribute about 24.3 % (3.30 Gt C yr^{-1}) to these emissions, with 16.9% (2.30 Gt C yr^{-1}) resulting from arable land management that includes the application of fertilizer, fuels and pesticides. Soil erosion due to tillage and poor grazing practices accounts for an additional 7.4% (1.0 Gt C yr^{-1}) (Table 1). Impacts of agricultural practices on GHG emissions are predicted to increase to meet the growing food demands of a growing global population if production methods persist.

Soil erosion caused by current arable land management contributes directly to increasing GHG emissions[10]. In the USA annual soil losses (1.72 Gt yr^{-1}) are one of the greatest sources of GHGs from agriculture and are greater than the combined yields of corn (*Zea maize*; 0.36 Gt yr^{-1}), beans (*Glycine max*; 0.045 Gt yr^{-1}) and hay (0.146 Gt yr^{-1})[11] . Unless measures are taken to reduce erosion, current agricultural practices are unsustainable and are far greater sources of GHG emissions than ruminant livestock in these agro-ecosystems (Table 1; Figure 1.). Intensification of agriculture continues to increase soil loss and siltation of reservoirs. Under the anaerobic conditions in the anoxic sediment deposits, emissions of CH_4, N_2O, and ammonia (NH_3) from water bodies are 0.8 to 1.2 Gt C yr^{-1} [10], approaching emissions from cattle at 1.27 Gt C yr^{-1} [6]. The N_2O and CH_4 emissions alone emitted from the disturbance of continued tillage and erosion of SOC from clay and silt clay loam soils have been one of the primary sources of GHG emissions, accounting for a large percentage of all GHG emissions produced by modern civilization[10, 12].

In North America the Mississippi River watershed covers 43% of the lower 48 states of the USA and Canada, and contains approximately 40,000 dams capturing 225-270 million tons (Mt) of sediment (dry mass) annually[13], demonstrating there is significant soil erosion still occurring despite reduced tillage[12]. This deposition of organic rich SOC produces anaerobic conditions in water bodies resulting in CH_4 and N_2O emissions and is further exacerbated by increasing quantities of nitrogenous fertilizer running off from croplands[14].

Additionally, use of tillage, inorganic fertilizers and biocides have reduced soil surface cover and decimated soil microbial communities, which control 90% of soil ecosystem function, thereby compromising the physical, chemical and biological soil properties[15,16,17,18,19,20]. These practices have also led to nutrient losses via erosion, reduced nutrient concentrations in the remaining soil and reduced nutrient availability to plants[3].

In addition to the negative impacts on arable agro-ecosystems there is considerable degradation of rangelands that comprise approximately 40% of the global land surface area (excluding Greenland and Antarctica). As rangeland ecosystems constitute approximately 25% of potential C sequestration in global soils[22] their degradation contributes to increased emissions of GHGs and decline in ecosystem services and increased desertification.

Historically, many rangelands have been subjected to increasingly heavy continuous grazing (CG) by livestock. This grazing approach, which allows sustained access to plants that cannot recover between grazing events, has been documented as contributing to serious ecological impacts including depletion of root biomass and carbohydrate reserves in selectively grazed plants and reduction in above ground biomass productivity[7,23]. Other negative effects of such grazing management include impoverished herbaceous plant communities, more bare ground, lower SOC reserves, and more soil erosion and compaction.

At landscape scales these changes have contributed to reduced surface water infiltration, increased runoff and downstream flooding, and reductions in water quality[7,23]. As with tillage agriculture, the sediment from eroded soils emits CH_4 and other GHG gases when organic matter including SOC in sediments enters anaerobic waterways. As the health of the land declines so too does the health of the livestock and people who depend on it for their livelihoods.

We propose that the alternative to reducing ruminant livestock, is using new regenerative management measures to replace current arable and livestock management practices to mitigate climate change. Such alternate management options[3] include: 1) using cover crops in conjunction with row crops; 2) diversifying annual cropping systems and including legumes, perennial crops and forages in rotations; 3) using organic soil amendments such as cover crops, manure and biofertilizers; 4) reducing N-fertilizer use and changing the type of fertilizer used (e.g. legumes, controlled-release and nanoenhanced fertilizers), and use of nitrification inhibitors; 5) improving grazing management, converting marginal and degraded cropland to permanent pasture and forests, and restoring wetlands; 6) changing plough tillage to no-till (NT) cropping and using precision agriculture to moderate the rate and time of agrochemicals and water when and where they are needed[24]; 7) applying biotic fertilizer formulations that feed the soil microbial systems and improve mycorrhizal function, potentially resulting in less N and P runoff and ground water losses[25].

Livestock as part of the solution

Ruminants in rangelands or cultivated forage agro-ecosystems are overwhelmingly beneficial when they are appropriately managed[3,23]. Grazing ungulates play key ecological roles in grasslands and savannas and can contribute positively to numerous ecosystem services. These potentially beneficial effects include increased water infiltration into soils that improves water catchment functionality, greater biodiversity that increases ecosystem stability and resilience, and improved carbon sequestration that mitigates GHG emissions[26]. However, many grassland ecosystems have been degraded through unsustainable livestock production practices. Restoring the functionality and resilience of these degraded ecosystems requires the replacement of such unsustainable practices with regenerative grazing management practices. When domestic ruminants are managed in a way that restores and enhances grassland ecosystem function, increased carbon stocks in the soil will lead to larger and more diverse populations of soil microbes, which in turn increase carbon sequestration, including CH_4 oxidation[15,23]. With livestock management focused on building soil health, grazing animals can lead to carbon negative budgets with more C entering the soil than is emitted indirectly or via ruminant emissions [7].

Most current most agro-industrial crop production systems are dominated by summer row crops, like corn and soybeans, which are planted annually and grow for only part of the year. The consequence of annual tillage is that for a significant part of the year the soil is without above ground plant matter to stem surface runoff and erosion and without active roots to filter surface water percolating through the soil profile. Additionally, as noted above, current agricultural practices are far greater sources of GHGs than ruminant livestock in these agro-ecosystems. By contrast, in pre- industrial agricultural systems maintained permanent ground cover through the rotation of forage and row crop mixes, cover crops, legumes to increase soil fertility, and grazing livestock accelerated nutrient cycling through the consumption and decomposition of residual above ground biomass. This combination of crop rotation with livestock grazing enhanced soil function and health.

Sowing winter crops into permanent summer growing pastures, and using crop rotation systems with forage crops and grazing animals have been shown to lead to the reduction or elimination of the damaging effects of current arable land management, including soil erosion, loss of SOC and elevated GHG emissions, especially where soil erosion potential is moderate to high.

Achieving the same positive soil health results in pasture and rangeland-based livestock production systems as in mixed rotational cropping-livestock systems requires a change in land management practice. Emerging research suggests that non-conventional grazing management on cultivated pastures and rangeland might at a minimum reduce the GHG footprint, and at best, turn livestock management practices into a tool to improve local ecosystems, economies, and even human health. Moreover, ruminant production entirely from pastures has been done most effectively, efficiently and economically achieved using appropriate regenerative grazing management [3,7,23,27,30]. Therefore, in agro-ecosystems, replacing erosion hazard cropping systems with permanent pastures using improved grazing management can significantly reduce erosion, especially where slopes are significant and soil texture is compromised.

Producing grass-finished beef obviates the need for finishing animals on corn-based feeds. This dietary switch also reduces the C footprint of ruminant production because of the elimination of soil GHG emissions resulting from corn production and associated soil erosion. Therefore, beef production without corn inputs has the potential to reduce fossil fuel inputs, GHG emissions and soil erosion, and to improve ecological health and resilience of the land as well as human health. With the increasing recognition that grass-fed and grass-finished beef is better for the environment and for human health[28], there has been a rapid increase in demand for such beef [5] with many large consumers of such beef placing increasing emphasis on sustainable beef production.

On rangelands, use of regenerative high density (RHD) grazing management has been demonstrated globally to be capable of reversing degradation processes associated with the widespread practice of continuous grazing at high stocking rates[23,27,29,30]. Regenerative high density management involves using a goal-oriented, proactive, multi-paddock grazing strategy focused on restoring the ecological function and productivity of degraded grasslands. The approach involves using single herd multi-paddock management with short periods of grazing in any given area and proactively adjusting post-grazing forage residuals, recovery periods and other management elements as biophysical conditions change[23,27,29]. RHD has been successfully applied in areas with annual rainfall ranging from 250 mm to 1,500 mm.

Such grazing management has resulted in increasing forage productivity, restoration of preferred herbaceous species that were reduced or eliminated by previous grazing practices, and increased SOC and soil fertility, water holding capacity and economic profitability for ranchers[23,30]. Data presented by Teague et al.[30] of “across the fence” comparisons in semi-arid rangelands of Texas, where RHD was applied to areas previously degraded through prolonged continuous grazing, enable us to calculate an average carbon of 30 t C ha $^{-1}$ more carbon sequestration over a decade in RHD compared to commonly practiced heavy continuous grazing (Table 2). Based on this research, RHD grazing management led to higher herbaceous plant cover, plant productivity and SOC and, thereby, provided carbon sinks that far exceed the production of GHGs from the grazing ruminants; it also reduced bare ground, erosion, and non-livestock related GHG emissions and improved hydrological processes[26]. Where regenerative grazing has been applied in semi-arid and arid lands for some time, ephemeral streams have re-perennialized and biodiversity has recovered to varying degrees [33]; soil building C_3 and C_4 grasses, nitrogen fixing native leguminous plant species, and even pollinators have come back.

Most cattle produced in “developed” world countries from conventionally grazed rangelands and forage-based grazing systems are finished for the marketplace on high starch, grain-based feeds. Proponents of this finishing method claim that, compared to grass-finished beef production, intensification of production through the use of grain-based feeds results in lower GHG emissions per kilogram beef produced because it reduces the overall production time to slaughter. However, this may not be the case when the full GHG emissions associated with the production of grain-based feeds and associated soil erosion are taken into consideration. Not accounting for substantial GHG emissions resulting from crop production greatly underestimates GHG output from feedlot-based beef production. Suitable modification of agro-ecosystem production systems and conversion to RHD-based grass-finished livestock would increase the provisioning of other ecological benefits[26].

Therefore, widespread conversion of livestock-purposed cropland to a rotation with perennial pasture or rangeland, such as the integrated crop and pasture Australian ley farming systems[34], would be the most advantageous option to reduce overall crop and livestock-associated GHG emissions. At a minimum, policy changes are needed to incentivize farmers to implement no-till agriculture, more diverse rotations, more perennial forages and greater bio-diversity in the form of cover crops between rotations. Such policies would lead to an expansion of mixed agronomic systems that facilitate the reintroduction of grazing animals as an element of integrated food production versus the government incentivized monoculture systems seen today.

Finally, we contend that ruminant-based enteric methane emissions are immaterial in the overall C footprint of grass-finished beef cattle production solely *from grassland*. Data from the Northern Plains[2] report modest annual SOC sequestration rates with conventional continuously grazing management of -0.618 tons CO_{2equiv} ha^{-1} yr^{-1} for heavy stocking and -0.783 tons CO_{2equiv} ha^{-1} yr^{-1} for moderate stocking. Overall enteric methane was reported to be 0.484 and 0.176 tons CO_{2equiv} ha^{-1} yr^{-1}, respectively, indicating a negative GHG balance for both conventionally grazed systems. However, as noted previously, improved RHD grazing management results in a ten year SOC sequestration rate of 30 tons C ha^{-1} *more* than that of heavy continuous grazing[30]. With respect to global warming potential, SOC is clearly the larger determinant in the C footprint of beef production from a forage base managed to maximize C sequestration.

Alternative net greenhouse gas emission scenarios

We postulate five scenarios for land management changes to reduce and ultimately reverse GHG emissions associated with crop and livestock production (Table 2, Table 3, Figure 2). These scenarios are based on crop and livestock production in the 48 contiguous states of the USA.

- Scenario 1 represents the estimated total C emissions from soil erosion loss, current fertilizer and ploughing practices for crop production, corn-finished livestock production and current continuous grazing management. It most closely resembles the substantial carbon footprint of the current agricultural practices.

- Scenario 2 represents the reduction of ruminants by 50% from the current situation as proposed by Riddle et al.[6]. It has only a modest impact on total C emissions from all agricultural actives.

- Scenario 3, 4 and 5 represent adoption of best conservation management practices in both cropping and grazing on 25%, 50% and 100%, respectively, of land used in the USA crop and livestock production. These conservation management practices include zero till and arable rotations with minimal inorganic fertilizer use in arable production; and grass-fed and grass-finished beef production using RHD grazing management. The application of these practices in integrated crop and livestock production systems to just 25% of the land they occupy results in substantially more net C emission reduction than reducing livestock by 50%. Applying them to greater portions of agricultural production land results in increasingly negative net C emissions with application to all agricultural land potentially providing a significant C sink to offset non-agricultural emissions.

These five scenarios are speculative because of a paucity of data. However, they do represent an inclusive assessment of possible terrestrial and atmospheric impacts resulting from all agricultural activities in the USA. They also provide a set of testable hypotheses that could direct future long-term (at least 10 years) systems-based research at the operating scale. To date such research has been lacking due to funding and other constraints. These constraints have led to a plethora of short-term and small-scale crop and livestock production research, the results of which frequently bear no resemblance to the performance of best management practices across the whole-systems operating scale[23]. The principle reason for this disconnect is the lack of capacity for short-term and small-scale research to address land management lag effects, and both spatial and temporal heterogeneity of soils, vegetation and livestock impact, and precipitation patterns at operational scales.

Development and adoption of regenerative management

To effect management changes that will lead to a more sustainable future it is vital to create government agricultural policies that encourage the adoption of regenerative GHG neutral, or possibly GHG negative, agricultural practices. Such policy changes must reward producers for adopting and maintaining environmentally sustainable management practices for both crop and livestock production and discourage the use of land management practices that require high energy inputs and irrigation, and that degrade soils, reduce biodiversity and increase GHG emissions.

To operationalize such policies, it is equally vital that leaders in farming and ranching communities across the world actively participate in developing workable solutions and adaptive practices for food production ecologically suited to local biophysical conditions [5]. Leading environmentally conscious farm and ranch managers are demonstrating how it is possible to achieve desired environmental goals while simultaneously improving livelihoods.

Knowledge gained from reductionist science does not translate automatically into producing desirable results from arable or pastoral agro-ecosystems, especially across regions or at watershed scales [23,35]. To be meaningful small-scale reductionist research should be combined with complementary whole-systems research. To achieve this it is imperative to work in collaboration with farmers and ranchers who obtain superior economic returns in different ecological and cultural settings while simultaneously improving the biophysical conditions of their environments [35]. Finally, working to educate drivers of change, from policy-makers to the farming community, is essential to overcome the complexity associated with GHG emissions and overall pollution associated with ruminant livestock and crop production.

Conclusions

Soil is a depletable resource, but it does not have to be depleted to produce food for human consumption. Using cropping and grazing practices that do not compromise but rather build SOC levels and soil microbial communities and functions and that minimize soil erosion, can result in soils being a net sink for GHGs rather than a major source of GHGs as is currently the case. Effective soil management provides the greatest potential for achieving sustainable use of agricultural land in an environment with rapidly changing, uncertain and variable climate. Ruminant livestock are an important tool for the goal of regenerative agriculture. With appropriate grazing management, ruminant livestock can increase C sequestered in the soil to more than offset their GHG emissions, and can support and improve other essential ecosystem services while maintaining or enhancing the ability of local populations to sustain livelihoods. Affected ecosystem services include water infiltration, nutrient cycling, soil building, carbon sequestration, biodiversity, and wildlife habitat. Our assessment suggests that managing to restore higher levels of SOC globally within food production systems will reduce the C footprint of agriculture much more than reducing domesticated ruminant numbers in an effort to reduce enteric GHG emissions. Integrating livestock into mixed agricultural systems and improving grazing management to increase SOC and soil quality enhances resilience of soil and agroecosystems to climate change and extreme events.

The key is to change current unsustainable high-input agricultural practices to regenerative practices that enhance ecosystem resilience. A primary challenge is how to increase the scale of adoption of land management practices that have been documented to have a positive effect on soil health. In this regard, it is essential that scientists partner with environmentally progressive managers to convert experimental results into sound environmental, social and economic results on managed landscapes at scales that will provide regional and global benefits. Rather than reducing ruminants and incentivizing destructive agricultural land use through the provision of price subsidies, developing agricultural practices and policies that focus on increasing soil carbon and that lead to greater adoption by land managers is essential to creating a robust, resilient and regenerative global food production system.

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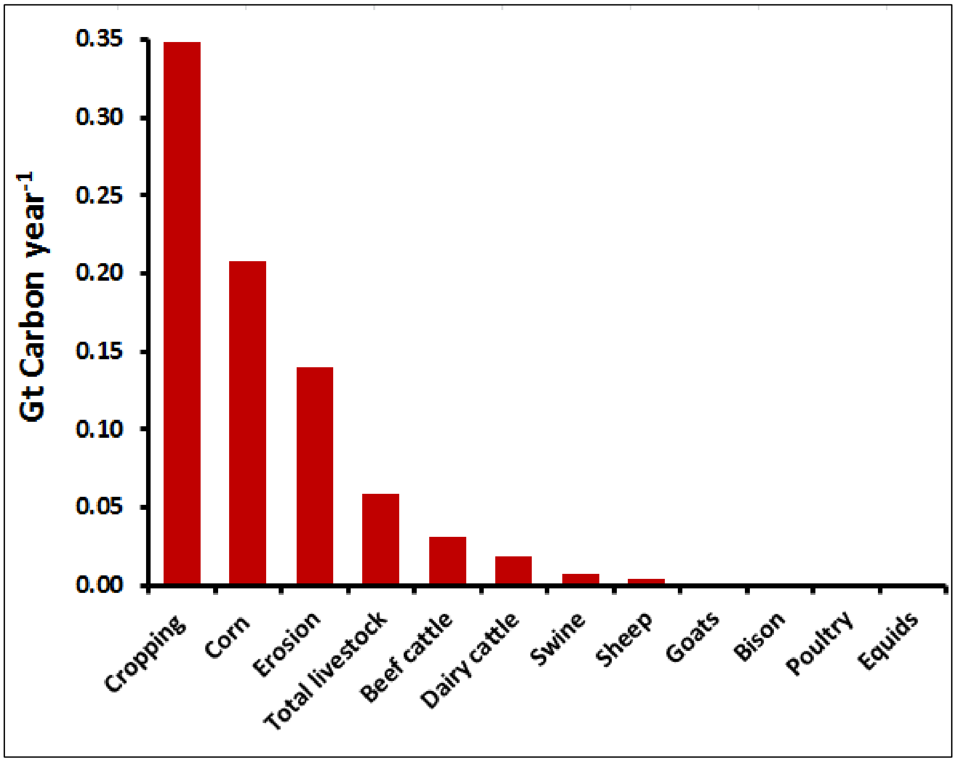
Figure captions

Figure 1. Estimated US greenhouse gas emissions for 2012 from total crop production, corn, total livestock and livestock by class (EPA 2013 [32]), and soil erosion (Lal 2003 [10])

Figure 2. Hypothetical North American net greenhouse gas emission scenarios for: 1) current agriculture; 2) current agriculture with 50% current ruminants; 3) 25% conservation cropping and regenerative high density (RHD) grazing with current numbers of ruminants; 4) 50% conservation cropping and regenerative high density (RHD) grazing with current numbers of ruminants; and 5) 100% conservation cropping and RHD grazing with current numbers of ruminants



Gt Carbon year-1
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Cropping
Corn
Erosion
Total livestock
Beef cattle
Dairy cattle
Swine
Sheep
Goats
Bison
Poultry
Equids

Fig 1.

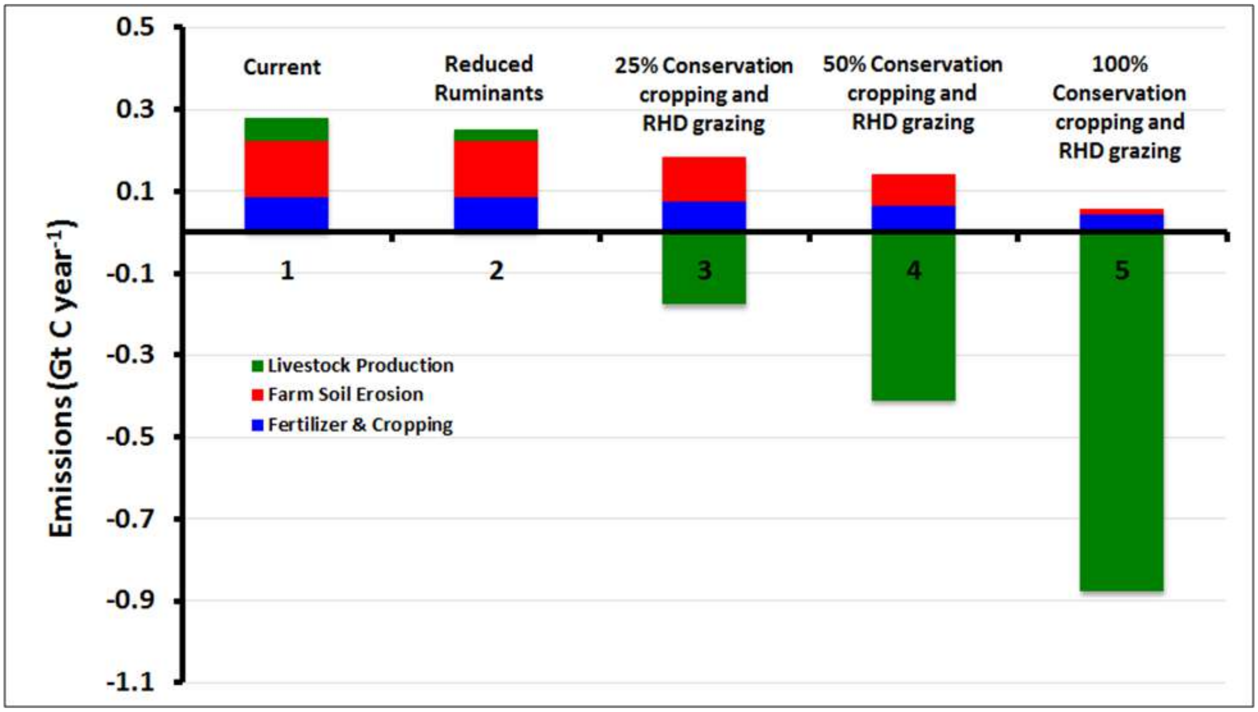

0.5
0.3
0.1
-0.1
-0.3
-0.5
-0.7
-0.9
-1.1
Emissions (Gt C year-1)
Current
Reduced Ruminants
25% Conservation cropping and RHD grazing
50% Conservation cropping and RHD grazing
100% Conservation cropping and RHD grazing
1
2
3
4
5
Livestock Production
Farm Soil Erosion
Fertilizer & Cropping

Fig 2.

Table 1. Estimates of global sources of GHG emissions related to agricultural soil management including cropping practices, soil erosion compared to that of livestock

Parameter	Gt C yr^{-1}	% of Human caused emissions	% of Total livestock emissions	Source
Total human caused emissions	13.57			[6]
Soil management (fertilizer, cropping)	2.30	16.9	116.8	[8,9]
Soil erosion	1.00	7.4	50.7	[10]
Total soil management	3.30	24.3	167.5	
Cattle	1.27	9.4	64.5	[6]
Total ruminants	1.58	11.6	80.2	[6]
Total Livestock	1.97	14.5	100.0	[6]

Table 2. Differential properties of soil due to grazing management[30]

Carbon		Heavy Continuous				Regenerative High Density			
Depth	Layer thickness	Soil Organic Carbon	Bulk Density	Carbon Density	Total Carbon Storage	Soil Organic Carbon	Bulk Density	Carbon Density	Total Carbon Storage
(cm)	(m)	Wt. %	g cm^{-3}	t $(ha*m)^{-1}$	t ha^{-1}	Wt. %	g cm^{-3}	t $(ha*m)^{-1}$	t ha^{-1}
0-15	0.15	2.18	1.06	231.2	34.7	3.32	0.91	301.9	45.3
15-30	0.15	1.42		150.6	22.6	2.32		211.1	31.7
30-60	0.30	0.86		91.6	27.5	1.44		130.9	39.3
60-90	0.30	1.03		109.4	32.8	1.16		105.6	31.7
					117.6				147.9

Water & Runoff									
		Ring Infiltrometer	Runoff	Sediment Loss	Soil Moisture	Ring Infiltro meter	Runoff	Sediment Loss	Soil Moisture
		cm hr^{-1}	cm/h	g m^{-2}	(Vol %)	cm hr^{-1}	cm h^{-1}	g m^{-2}	(Vol %)
		4.0	2.0	18.0	15.0	7.0	1.4	4.0	25.0

Table 3. Estimates of North American greenhouse gas emissions due to current cropping and grazing management, current cropping with reduced ruminants compared to using conservation cropping and regenerative, high-density grazing with current levels of ruminants

Parameter	Source	Scenario 1. Business as usual	Scenario 2. Reduce ruminants 50%	Scenario 3. 25% Conservation cropping and RHD grazing	Scenario 4. 50% Conservation cropping and RHD grazing	Scenario 5. 100% Conservation cropping and RHD grazing
		Gt C ha^{-1} yr^{-1}				
Fertilizer + cropping	[8,9]	0.083	0.083	0.073	0.062	0.041
Soil erosion	[10]	0.14	0.14	0.109	0.077	0.014
Livestock production	[6,8]	0.056	0.028	0.056	0.056	0.056
RHD grazing impact ***	[4,30,31]	0	0	-0.234	-0.468	-0.935
Net livestock		0.056	0.028	-0.142	-0.339	-0.734
Total		0.279	0.251	-0.040	-0.200	-0.679

** Scenarios 3 through 5 assume stated % of land under conservation cropping and grazing with the remainder applying usual practices

*** -3.0 t C ha^{-1} yr^{-1} [4,29] for 263 mil ha [31]

Table4. Abbreviations

Abbreviation	Name
Gt C yr^{-1}	Giga tonnes Carbon per year
GHG	Greenhouse gas
Gt $CO_{2\ equiv}$ yr^{-1}	Giga tons carbon dioxide equivalents per year
SOC	Soil organic carbon
CG	Continuous grazing
RHD	Regenerative High Density grazing
N	Nitrogen
P	Phosphorous
CH_4	Methane
N_2O	Nitrous oxide
CO_2	Carbon dioxide
NT	No-till
C_3 grasses	Cool season grasses
C_4 grasses	Warm season grasses
ha	Hectare