제 6 주 제

미국에 있어 지구온실가스 감소를 위한 초지의 역할

Carbon Sequestration and Greenhouse Gases Mitigation in Forage/Grassland Systems in the USA

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지구의 온실가스 효과(Greenhouse gas effect)라는 것은 장파장을 지닌 빛에너지가 지구표면에서 대기권 및 우주공간으로 반사되지 못하고 지구온실가스, 특히 CO_2, CH_4, 그리고 N_2O에 흡수되어 지구표면이 더워지는 현상을 말한다. 지구의 온난화 현상(Global warming)은 점점 증가하고 있으며 세계의 모든 나라들이 이러한 현상을 늦추지 않는 이상 지구의 온도는 더욱 상승할 전망이다. 이러한 온실가스의 상당수 원인은 우리 인류가 만들어 낸 결과이기도 하다.

일반적으로 6가지 온실가스는 water vapor, carbon dioxide, methane, nitrous oxide, 그리고 ozone인데 그 중에 가장 문제가 되는 대표적인 온실가스는 carbon dioxide, methane, 그리고 nitrous oxide이다. 이러한 온실가스 등의 주원인을 살펴보면 carbon dioxide는 화석연료의 연소, methane은 매립지, 폐수처리, 반추위 발효, 또는 액상분뇨처리, 그리고 nitrous oxide는 주로 화학질소비료 및 가축분뇨에 기인하고 있다. 지난 세기 동안 얼마만큼의 온실가스가 증가했는가를 살펴보면, CO_2는 80ppm, CH_4는 800ppb, 그리고 N_2O는 30ppm 이 각각 증가했으며 앞으로도 계속 증가 추세에 있다.

그렇다면 이러한 지구 온실가스 감소를 위한 미국에서의 초지 축산 · 낙농의 역할은 무엇인가? 농업은 사실 온실가스의 원인 제공(source)과 원인 해결(sink)의 역할을 동시에 할 수 있으며 어떻게 관리하느냐에 따라 sink도 될 수 있고 source도 될 수 있다. 2003년 미국 환경청(EPA, Environmental Protection Agency)의 보고서에 의하면 농업활동이 미국 전체 온실가스 생산의 약 9%를 차지한다고 보고하였다. 그렇다면 어떤 관리체계 및 방법을 통해 이러한 주요 온실가스의 감소를 가져올 수 있는가? 먼저 이산화탄소의 예를 들어보도록 하겠다. 초지농업에서 이산화탄소를 줄일 수 있는 방법은 지구 중에 있는 CO_2를 최대로 이용하거나 토양 중에 탄소를 최대로 저장(Carbon sequestration)하는 방법이다. 또 다른 방법은 화석연료의 사용을 줄이거나 다른 bio-energy로 대체하는 방법 등이 있다. 초지 토양의 탄소 성분을 증가하는 것은 곧 토양유기물(Soil organic matter)을 증가시키는 것인데 이러한 방법에는 불경운(no-till), 퇴비이용, 윤환방목(rotational grazing), 다양한 작물체계 도입, 또는 우수한 품종 사용 등이 있다. 근래에는 bio-energy 또는 bio-fuel crop 개발에 많은 연구가 진행 중에 있으며 특히 switchgrass(남방형 목초의 일종)의 열에너지 효율이 옥수수의 에탄올보다도 높은 것으로 보고되어 있다.

Methane을 줄이는 방법으로는 고품질의 목초제공, 윤환방목, 반추위 소화시간을 줄이기 위한 사료개발, 기

름첨가제(canola 또는 coconut), 특수반추 미생물개발, crop residue 연소의 감소, 그리고 메탄가스 digester 이용 등이 있다.

Nitrous oxide는 지구온난화 잠재력(Global Warming Potential)이 이산화탄소보다 100년 기간에 걸쳐 310배나 높은 것으로 나와 있어 N_2O를 줄이려는 노력이 유럽에서는 이미 많이 진행되었으며 미국과 캐나다에서도 근래에 많은 연구가 진행 중에 있다. Nitrous oxide를 줄이는 방법으로는 Pre-sidedress nitrate test(PSNT), 질소질비료 및 가축분뇨의 분할시용, 보호작물(cover crops) 이용, 두과목초 사용, 가을이나 겨울 기간동안 휴경지에 가축분뇨 시용금지, 석회시용, 그리고 토양질소성분, 가축분뇨 질소성분 및 목초의 양분 요구량에 근거하여 가축분뇨 및 질소비료 시용 등이 있다.

결론적으로 초지농업은 지구 온실가스 감소 및 지구온난화 방지에 큰 역할을 담당할 수 있으며, 보다 장기적인 계획과 포괄적인 접근방법으로 토양의 탄소 저장 및 지구온실가스 감소 노력을 동시에 진행하여야 할 것이다.

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Outline of Presentation

- Carbon Sequestration
- Greenhouse Effect and Greenhouse Gases
- Greenhouse Gases and Grassland
- Bio-Energy crop (i.e., switchgrass)
- Strategies to Reduce the Greenhouse Gases
- Summary and Conclusion

What is carbon sequestration?

Carbon sequestration is defined as a tool of storing carbon into the plants and the soil from the atmosphere.

The amount of C that will be stored depends heavily on good soil management and appropriate land use.

Carbon Sequestration In Agricultural Systems
Why The Current Interest in C Sequestration?

Concern: *Over the past century, the Earth's surface temperature has warmed by 0.5 °C*

- Global shifts in vegetation or ecological zones
- Impacts of potential global climate change

Carbon Sequestration In Agricultural Systems
The Role of Agriculture

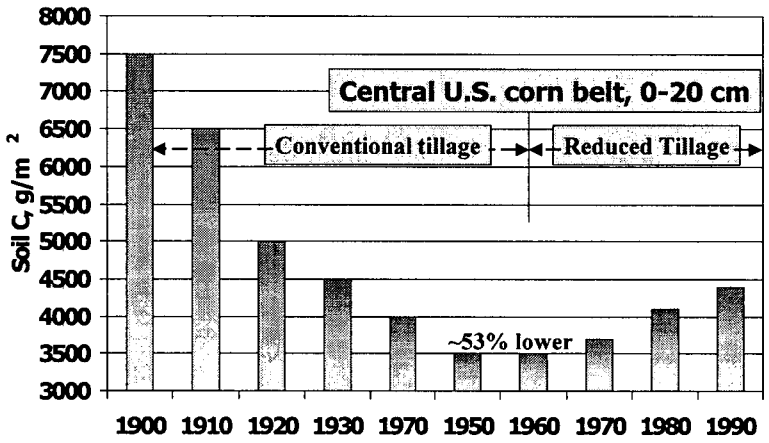
Agriculture plays and has played a major role as a source of greenhouse gas emissions,

But, agriculture can also be a major sink for C sequestration.

Carbon Sequestration In Agricultural Systems
The Role of Agriculture

- **Much of the United States agricultural soils have lost up to 50% of their original soil organic carbon due to negligent agronomic practices (i.e., land clearing and heavy tillage)**

Conventional vs. Reduced Tillage



Carbon Sequestration In Agricultural Systems
The Role of Agriculture

- **United States cropland can sequester around 75-208 million metric tons of atmospheric carbon per year.**

- ***"Increasing the organic C content of degraded soils by 0.01% per year could lead to C sequestration equal to the annual increase in atmospheric CO_2-C."***

Greenhouse Gases (GHG)
Water vapor, carbon dioxide, methane, nitrous oxide, and ozone

- **GHGs** act like the glass in a greenhouse
  - They absorb infrared light from the sun, trapping this heat and warming the earth
- Because of the GHG effect, the average surface temperature of the Earth is about 15 °C, instead of - 18 °C

Kyoto Protocol

In 1997, Kyoto Protocol was signed and aimed at reducing emissions from the participating countries to at least 5% below 1990 levels, by 2008 to 2012.

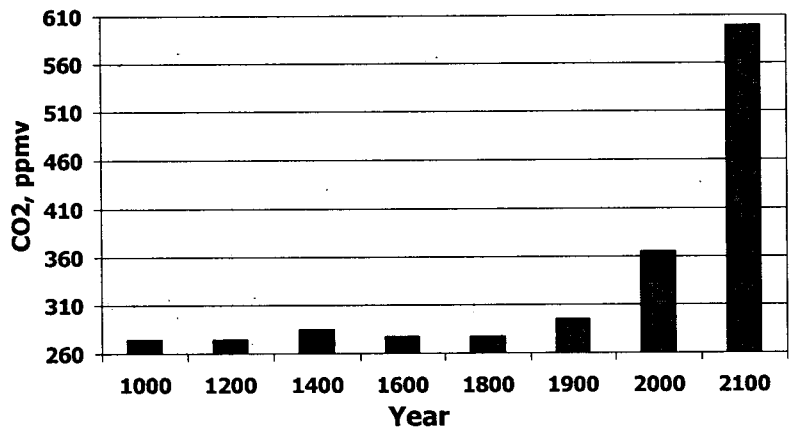
Sources of Greenhouse Gases in Agriculture

- Carbon dioxide; the burning of fossil fuels
- Methane; landfills, wastewater treatment, rumen fermentation, and liquid manure systems
- Nitrous oxide; soils after nitrogen fertilizer or manure

Carbon Sequestration In Agricultural Systems
Why The Current Interest in C Sequestration?

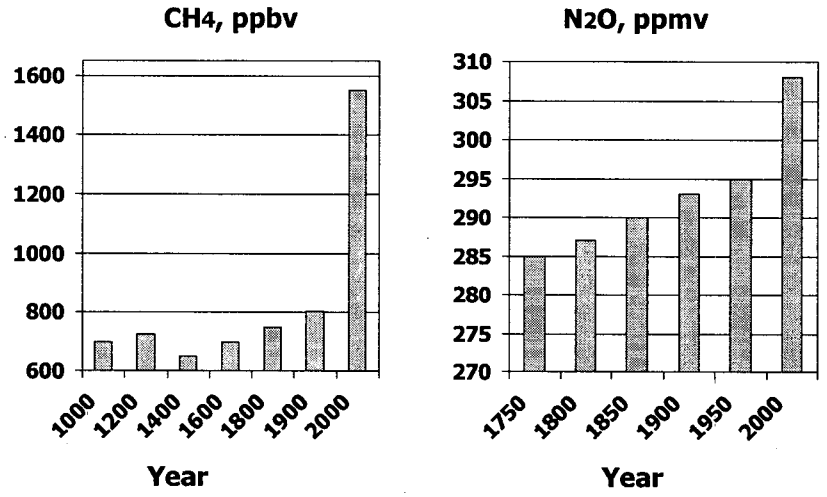
1850: 280 ppmv CO_2 ⟶ 1995: 365 ppmv CO_2

~600 ppmv CO_2 by 2100



Carbon Sequestration In Agricultural Systems

Why The Current Interest in C Sequestration? *(cont.)*



Greenhouse gases in the big picture

- **In 2000, agricultural activities were responsible for 485 MMT CO_2 Equivalent, which is approximately 9% of the total U.S. emissions (EPA, 2003)**

Global Warming Potential (GWP)

- **GWP; the ratio of global warming or radiative forcing from one kilogram of a greenhouse gas to one kilogram of carbon dioxide over the 100-year period.**

- **This GWP index provides a way to calculate the contributions of each of the GHGs to the annual increases in radiative forcing**

Global Warming Potential (GWP) of GHGs

Emissions and global warming potential of three greenhouse gases from the U.S. and U.S. farming activities

	CO_2	CH_4	N_2O
Emissions from all U.S sources (MMT of gas)	5287	31	0.471
Emissions from U.S. agriculture (MMT of gas)	157	9	0.174
U.S. agriculture/all U.S. emissions	3	29	37
Global warming potential (100 yrs relative to CO_2)	**1**	**21**	**310**

Roles of pastures and hay lands for mitigating greenhouse gases

Carbon Sequestration In Agricultural Systems
The Role of Agriculture

- **United States grazing land can sequester up to 30 to 90 million tons (Tg) of atmospheric carbon per year by using best management practices such as controlled grazing, improved varieties, and proper fertilizer and manure application.**

Carbon Sources in Forage Fields

- Growth and die-back of forage plants
- Forage wastage during grazing
- Plant root mass
- Manure deposition

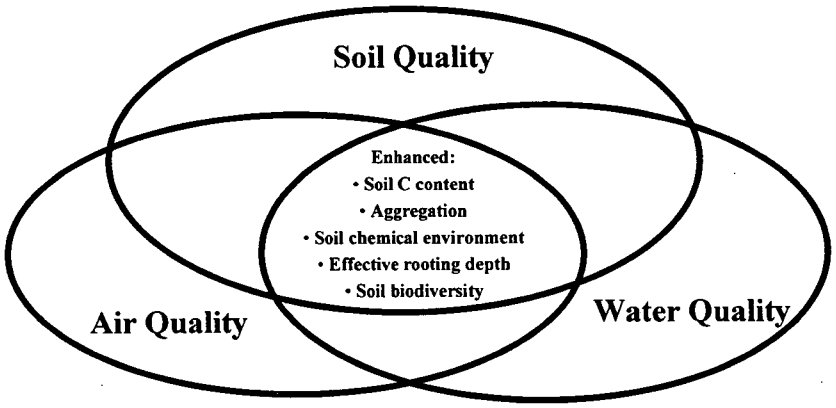
Roles of Forage/Grassland in Greenhouse Gases Mitigation

- Photosynthesis (recycling CO_2)
- Ground cover (less erosion and runoff)
- Bio-energy crop (i.e., switchgrass)
- Less manure/animal waste problems

Roles of Forage/Grassland in Greenhouse Gases Mitigation

- Better water quality
  - Riparian buffers established along a stream
  - Grass waterways on a steep slope area
- Less nitrogen fertilizer by planting legumes

Enhancement of Grassland Ecosystem



Grazing vs. Haying

- The rate of increase in SOC is higher under grazing than when hay is removed.
- Grazing returns 60 to 95 % of indigested nutrients to the pasture as excreta.
- Stubble production with grazing can be up to 5 % greater than with mechanical harvest.

No-Till as a Key Role in Carbon Sequestration

- Provide a good amount of organic matter in the soil
- Makes more stable soil aggregates
- Increase earthworm and biological populations
- Reduce fossil fuel energy costs

Relative GWPs (CO_2 equivalents, g m^{-2} y^{-1}) for different management systems. Negative values indicate a global warming mitigation potential.

Ecosystem Management	CO_2				N_2O	CH_4	Net GWP
	Soil C	N fert.	Lime	Fuel			
Annual Crops (Corn-Soybean-Wheat)							
Conventional Tillage	0	27	23	16	52	-4	114
No till	-110	27	34	12	56	-5	14
Low input with legume cover	-40	9	19	20	60	-5	63
Organic with legume cover	-29	0	0	19	56	-5	41
Perennials							
Alfalfa	-161	0	80	59	59	-6	-20
Poplar	-117	5	0	10	10	-5	-105
Early Succession	-220	0	0	0	15	-6	-211
Late S. Forest	0	0	0	0	21	-25	-4

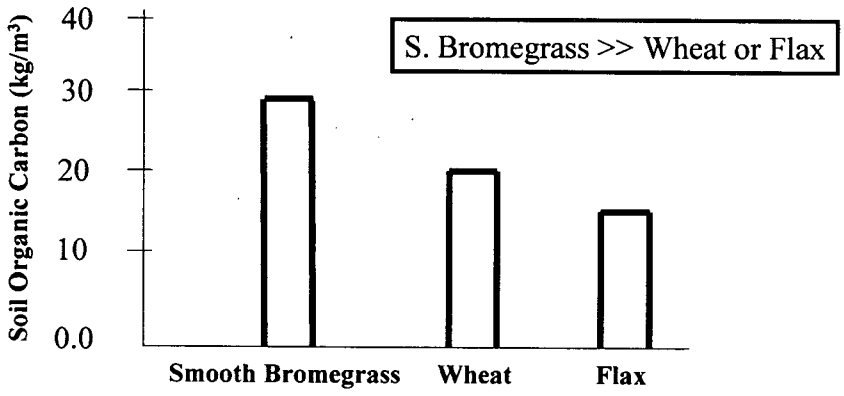
Role of soil organic matter

- More stable soil aggregates
- Better water holding capacity
- Better nutrient-supplying capacity
- Better protection against erosion
- Less soil compaction
- Better soil quality

Strategies for increasing soil carbon in cultivated soils

- Reduce tillage intensity (i.e., no-till or minimum till)
- Intensify cropping systems
- Use higher yielding perennial forage species/varieties
- Use organic manure
- Eliminate summer fallow
- Avoid burning of residues

Total organic carbon storage under long-term cultures of bromegrass, spring wheat, and flax in a 1 m profile depth



Annual rates of soil carbon change in Iowa (0 - 20 cm)

County	Year 1 – 10 after management change Intensive tillage	No-Tillage	CRP
	kg ha^{-1} yr^{-1}		
A	149	625	843
B	132	648	940
C	130	631	967

County	Year 11 – 20 after management change Intensive tillage	No-Tillage	CRP
	kg ha^{-1} yr^{-1}		
A	72	351	438
B	63	361	459
C	55	346	454

Switchgrass for Biomass Fuel

- **Native to North America**
- **Perennial Warm-Season Grass**
- **Wide Range of Soil pH (5.5 – 7.0)**
- **Higher Water Use Efficiency**

Switchgrass for Biomass Fuel

- **Responsive to Warming Climate**
- **Higher Bioenergy Content (BTU)**
- **Higher Net Energy Gain than Corn Ethanol (energy output/input ratio= 4.4 vs. corn ethanol; 1.2)**

Switchgrass: a multi-use biomass crop

- **Paper**
- **Ethanol**
- **Biofuel pellets and briquettes**
- **"Straw Bale" Housing**
- **Automobile door panel**

Strategies for increasing soil carbon in grassland

- Grazing management
- Use of organic manure
- Improved use of fertilizers
- Planting of improved species/varieties

Comparison of total soil carbon and nitrogen of the top 0 – 5 cm depth for meadow, cool-season grass, warm-season grass, and corn-soybean rotation in Ohio

Crop	Years	Total carbon	Total nitrogen
		kg ha^{-1}	
Meadow	4	12,037	1,139
Cool-season grass	10	21,877	2,359
Warm-season grass	8	13,663	976
Corn-soybean	7	11,874	895

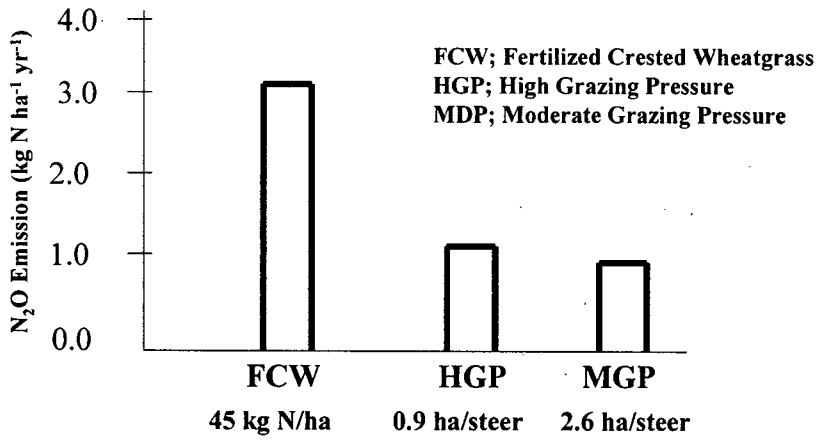
Nitrogen Sources in Forage Fields

- Chemical fertilizer
- Animal manure
- Nitrogen fixation

Reducing Nitrous Oxide

- Pre-sidedress nitrate test (PSNT) for corn
- Split application of fertilizer or manure
- Use of cover crops
- Planting legumes into the pasture
- No manure application to fallow fields in fall and winter

N_2O Emissions from Different Pasture Systems



Reducing Nitrous Oxide

- No manure application onto wet soil
- Avoid excessive manure applications
- Improve soil aeration
- Lime acid soils (optimum soil pH of 6 – 7)
- Apply manure or fertilizer based on soil N, manure N, and crop nutrient requirements

Summary

- Carbon sequestration will enhance the soil, water, and air qualities.
- CO_2, CH_4, and N_2O are the major GHGs and reducing N_2O is very critical in agriculture.
- Nitrogen fertilizer and manure management will play a key role in reducing N_2O emission.
- Developing a bio-energy crop will contribute to the reduction of greenhouse gases.

Conclusion

- Carbon sequestration;
  - Long-term win-win process in agriculture
  - Effective tool to increase sustainability (i.e., agronomic productivity, profitability, and environmental quality)
  - Carbon credit; another possible source of income in the USA
- Carbon sequestration and greenhouse gases emissions should be considered as a full-cost accounting at the whole-farm or regional landscape scale.