

# **The Magic of Soil**

**by**

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Bowen Municipality Climate Conversation Series**



REUTERS

SUSTAINABILITY

# Only 60 Years of Farming Left If Soil Degradation Continues

Generating three centimeters of top soil takes 1,000 years, and if current rates of degradation continue all of the world's top soil could be gone within 60 years, a senior UN official said

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By Chris Arsenault (Thomson Reuters Foundation), Dec. 5, 2014



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The causes include chemical-intensive farming, plowing or tilling, current livestock management, deforestation, and global warming. About 1/3 of the world's soil has already been degraded.



# Soil degradation

To keep up with the global food demand, the United Nations estimates,

**6 million hectares** of new farmland will be needed every year.

Instead,

**12 million hectares/year** are lost through soil degradation.

<http://www.un.org/en/events/desertificationday/background.shtml>

Rickson, R.J., Deeks, L.K., Graves, A. et al. Food Security (2015) 7: 351.

We are going backwards at a rate of

**18 million hectares/ year.**

For comparison the area of England is

**13 million hectares.**

1 hectare = 2.47 acres

# **My Investigation**

**Decided that I needed to investigate the subject to make my own assessment and to discover what if anything could be done.**

**This led me on a fascinating two year journey into current agricultural practices, soil biology, desertification, and grazing practices.**

**I learned about some amazing advances that have been made in the last 20 to 30 years and especially in the arena of soil biology and understanding nature's complexity.**

**I benefitted from 4 online courses that I completed from one of the pioneers of this new revolution, Dr. Elaine Ingham.**

**Please consider this presentation as a viewpoint on the subject through an astronomer's lens after two years of study.**

# The Good News

**My findings indicate that we now possess the knowledge to:**

- 1) rapidly reverse the degradation of soils,**
- 2) there is good evidence to suggest that we can sequester much of the excess atmospheric carbon (perhaps all of it) in the soil,**
- 3) and mitigate the root cause of much of the suffering in Africa and the Middle East caused by the collapse of agriculture.**

**They are all connected and the solution may not be that expensive as nature can do a lot of the work.**

**The real challenge is to re-educate ourselves in the limited time frame available.**

# **An Astronomer's Perspective**

This short video features another astronomer, Dr. Laura Danly of California's Griffith Observatory. She is helping the U.S. Department of Agriculture promote its "healthy soils" campaign.

**Permission granted by USDA Natural Resources Conservation Service**

<https://www.youtube.com/watch?v=6tJlkAjDjjo&index=6&list=PL4J8PxoprGZ-uMTxScBBn9nYT6CMX8aD>



# Microbes are the secret behind healthy soil.

Each teaspoon of healthy soil contains as many microbes as the population of humans on earth.





# The Soil Food Web (Some of the key players)

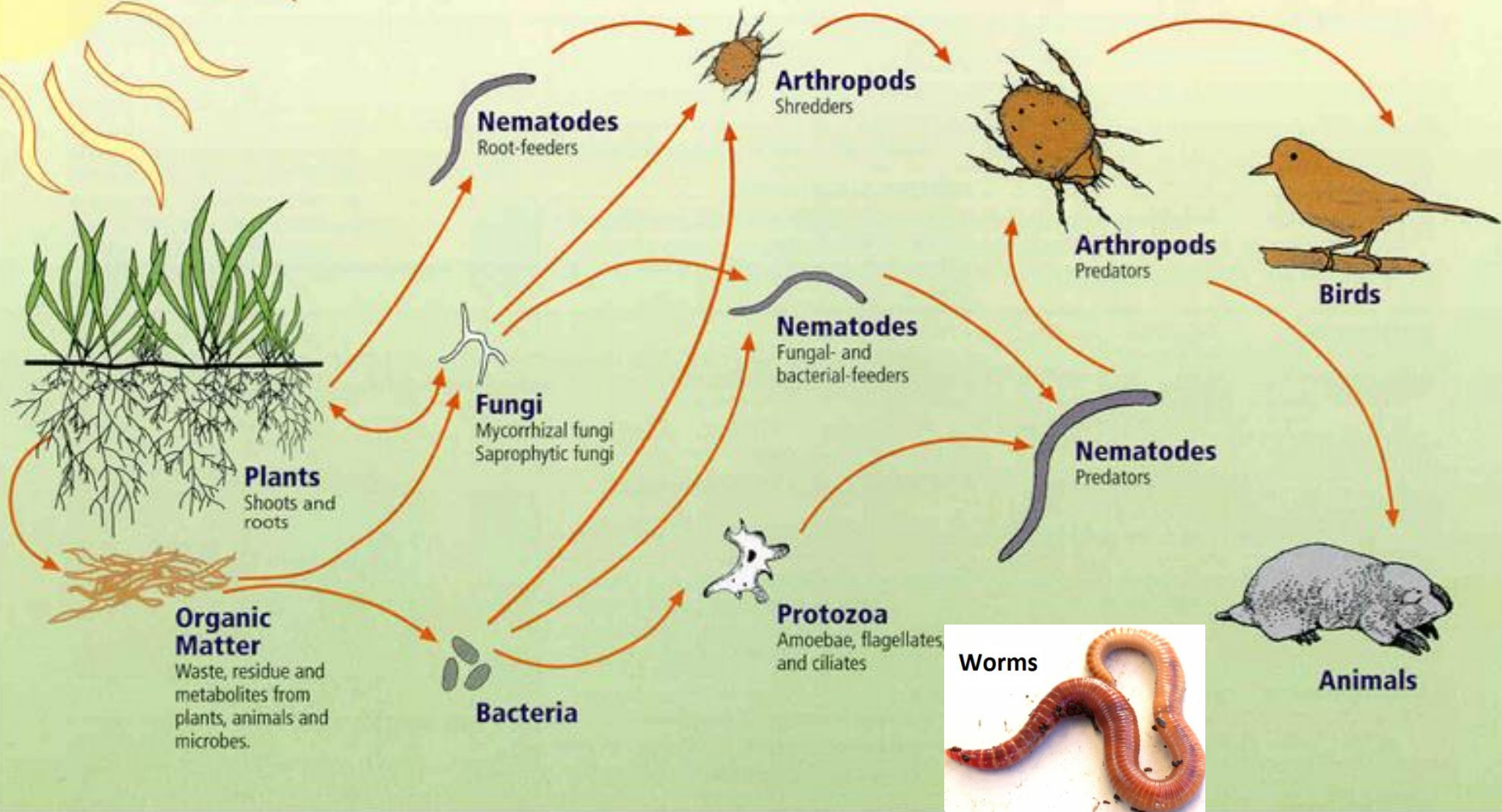
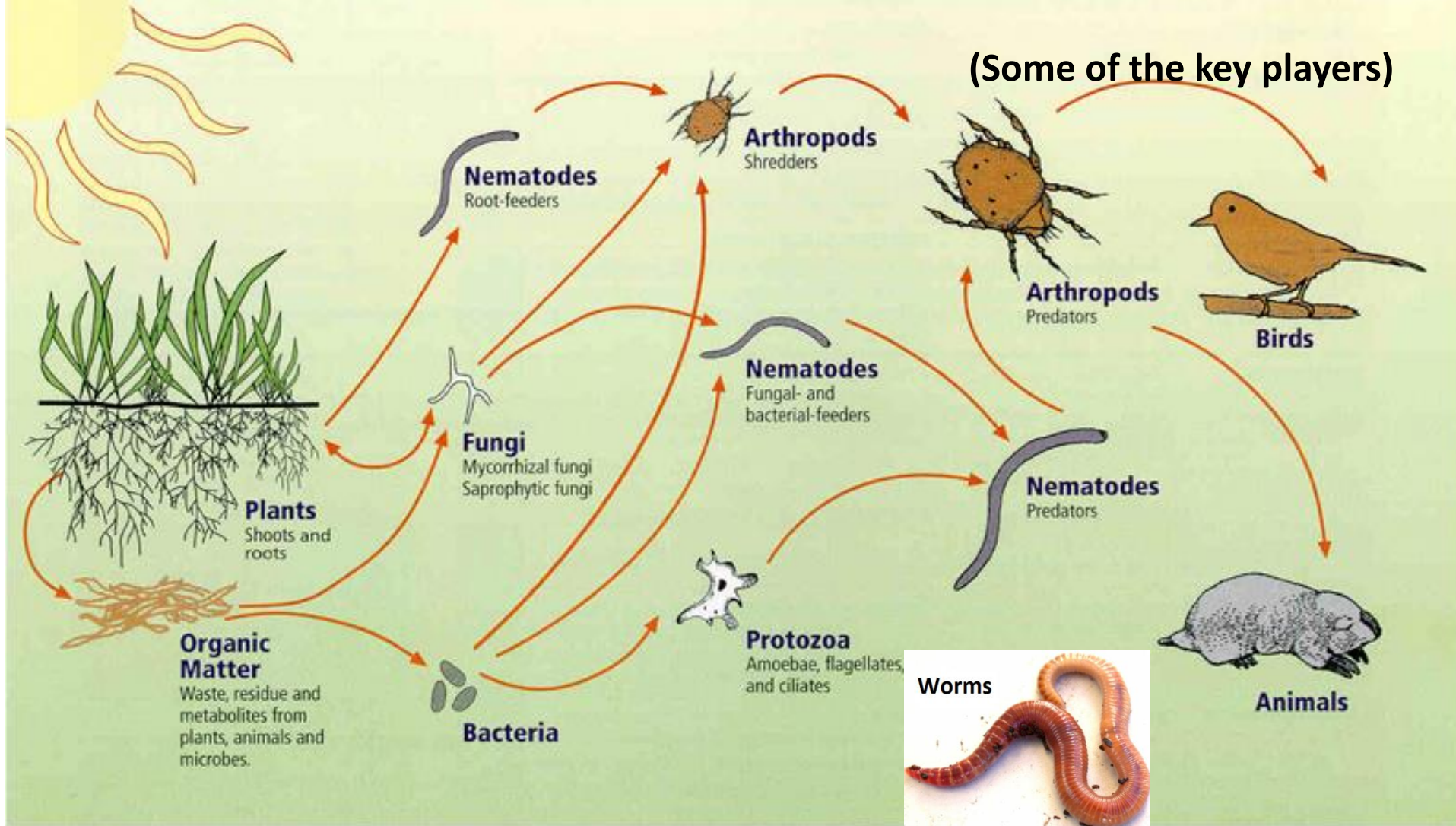


Image courtesy of USDA Natural Resources Conservation Services  
<http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/biology/>



**For a fascinating account of the mining capabilities of fungi see:**

1) 'The World's Largest Mining Operation Is Run by Fungi'

Jennifer Frazer, Scientific American Nov. 5, 2015

2) 'Linking Plants to Rocks: ectomycorrhizal fungi mobilize nutrients from minerals'

Renske Landeweert et al., Trends in Ecology & Evolution 16, no. 5 (2001): 248



# Plants are the conductors of this symphony of nature

## How do they do it?

Up to 40% of the sugars, carbohydrates and proteins that plants produce through photosynthesis are released from their roots to attract the microbes the plant requires.

Called root exudates.



Credit: Argan tree at Agadir by lgt 1400 CC BY SA 4.0

[https://commons.wikimedia.org/wiki/File:Argan\\_tree\\_@\\_Agadir.jpg](https://commons.wikimedia.org/wiki/File:Argan_tree_@_Agadir.jpg)



# Plants are the conductors of this symphony of nature

“What do you make when you mix sugar, a carbohydrate like flour and protein like eggs and milk?

That’s a recipe for cakes and cookies. So the plant is putting out cakes and cookies to attract the microbes.”

Dr. Elaine Ingham



Credit: Argan tree at Agadir by lgt 1400 (CC BY SA 4.0)



# Plants also release exudates through their foliage.

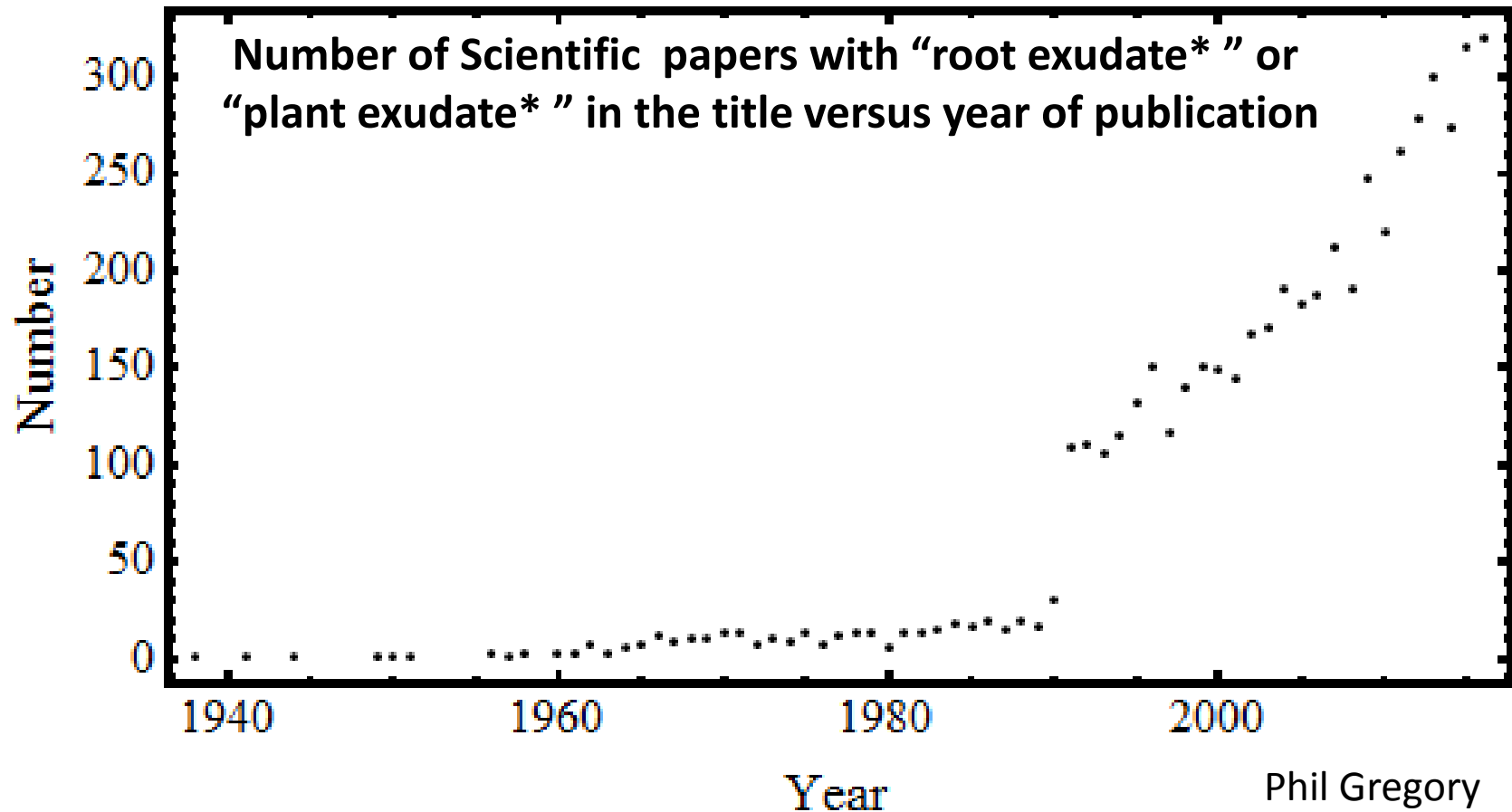
In healthy soil conditions leaf surfaces are covered by microbes held to the plant by the strong biotic glues. That protective layer is one of nature's way of achieving disease suppression.



Credit: Argan tree at Agadir by lgt 1400 CC BY SA 4.0

[https://commons.wikimedia.org/wiki/File:Argan\\_tree\\_@\\_Agadir.jpg](https://commons.wikimedia.org/wiki/File:Argan_tree_@_Agadir.jpg)

# One indicator of the recent revolution in soil biology (sudden jump in publication rate in 1991)



## One of the key papers indicating the important role of soil biology:

“Interactions of Bacteria, Fungi, and their Nematode Grazers: Effects on Nutrient Cycling and Plant Growth,” by Russell E. Ingham, J. A. Trofymow, Elaine R. Ingham, and David C. Coleman, *Ecological Monographs*, Vol. 55, No. 1 (Mar., 1985), pp. 119-140. (672 citations to 2016)



# Bacteria and fungi build soil structure



Image credit UN FAO.

**microaggregate**

Bacteria secrete biotic glues that stick soil minerals and organic matter together in what are called microaggregates.

Fungal strands (right) tie microaggregates together forming aggregates.

Together they build underground cities for the microbes to live in, with passage ways that allow water and air to penetrate to great depths.





# Mycorrhizal Fungal Network

*Fungal hyphae are long thin strands, invisible to the naked eye.*

*Mycelium is a visible network or bundle of hyphae, for example mold on spoiled food.*

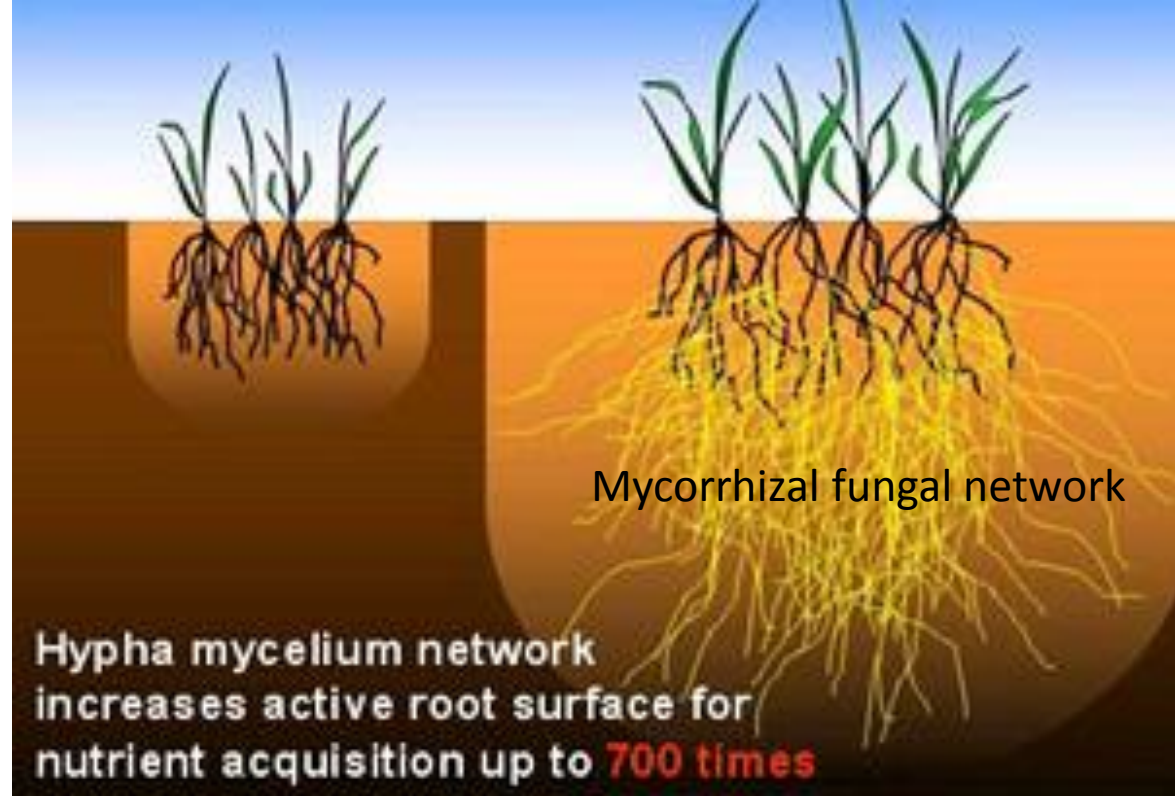


Illustration by Michael Rothman

**Strange but True: the largest organism on Earth is a fungus, nearly 10 square km in size and estimated to be 2400 years old. (Oregon Blue Mountains)**



# Current Agricultural Practices

- Plowing or tillage
- Growing of monocultures in the belief that diversity means competition.
- Application of chemical fertilizers, herbicides and pesticides



[https://commons.wikimedia.org/wiki/File:Potato\\_blight\\_spraying\\_system.jpg](https://commons.wikimedia.org/wiki/File:Potato_blight_spraying_system.jpg)  
Credit: Chafer Machinery (CC BY 2.0)



- Livestock in confinement (from poultry battery cages to feed lots)



Public Domain  
<http://www.epa.gov/region7/water/cafo/images/hogssm2.jpg>



Credit: Slim Virgin U.S. EPA, Public Domain  
[https://commons.wikimedia.org/wiki/File:Confined\\_animal-feeding-operation.jpg](https://commons.wikimedia.org/wiki/File:Confined_animal-feeding-operation.jpg)



# Examples of plowing (also called tillage)



Credit: Aalang (CC BY-SA 3.0)

[https://commons.wikimedia.org/wiki/File:Plowing\\_ecomat.jpg](https://commons.wikimedia.org/wiki/File:Plowing_ecomat.jpg)

**Plowing slices and dices the soil structure built by bacteria and fungi with their biotic glues - turning living soil into dirt.**

**Those underground cities were home to a diverse ecosystem capable of providing all the nutrients required by plants without the need for chemical fertilizers.**

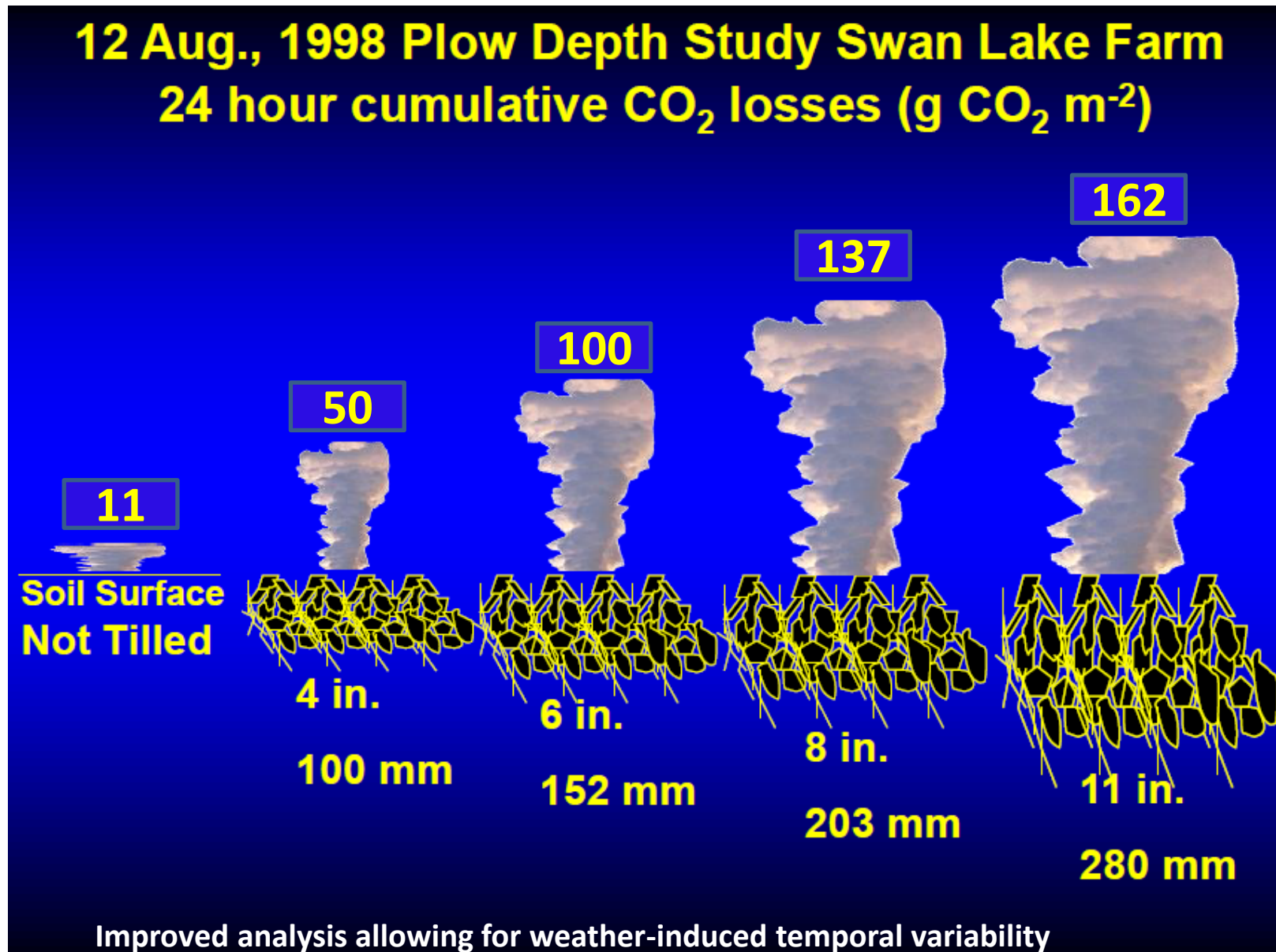


Credit: Trish Steel, (CC BY-SA 3.0)

[https://commons.wikimedia.org/wiki/File:Feeding\\_Frenzy,\\_Faulston\\_Farm\\_-\\_geograph.org.uk\\_-\\_702677.jpg](https://commons.wikimedia.org/wiki/File:Feeding_Frenzy,_Faulston_Farm_-_geograph.org.uk_-_702677.jpg)

# Effect of tilling on CO<sub>2</sub> emission

Dr. Don Reicosky , USDA  
Agricultural Research Services





# Tillage and planting: impact on carbon and soil quality

Dr. Don Reicosky USDA-ARS

M = Mobile  
R. = Research  
G = Gas  
E = Exchange  
M = Machine

## MR. GEM





# **Soil health lessons in a minute:** by Ray Archuleta, USDA

Permission granted by USDA Natural Resources Conservation Service

**a) Water infiltration test: shows how healthy soil can capture (infiltrate) much more of the rainfall and store it in the soil. This alleviates drought and prevents soil erosion.** credit :U.S. Department of Agriculture

[https://www.youtube.com/watch?v=Rpl09XP\\_f-w](https://www.youtube.com/watch?v=Rpl09XP_f-w)

**b) Soil stability test: comparison of healthy soil with lots of microbes creating biotic glues and fungal strands that hold the soil together, to soil that has been turned to dirt by repeated plowing.**

[https://www.youtube.com/watch?v=9\\_ItEhCrLoQ](https://www.youtube.com/watch?v=9_ItEhCrLoQ)

**Without the biotic glues and living plant roots, soil is easily washed away by rain or blown away during periods of drought, creating massive dust storms.**

Each soil sample used in the demonstration was air dried

# Dust storm approaching Stratford, Texas 1935.



Credit: NOAA George E. Marsh Album (Public Domain)

<https://commons.wikimedia.org/w/index.php?title=Special%3ASearch&profile=default&search=2015+dust+storm+Colorado&fulltext=Search&uselang=en>

# Dust storm Phoenix 5 July 2011



Credit: Roxy Lopez (CC BY – SA 3.0)

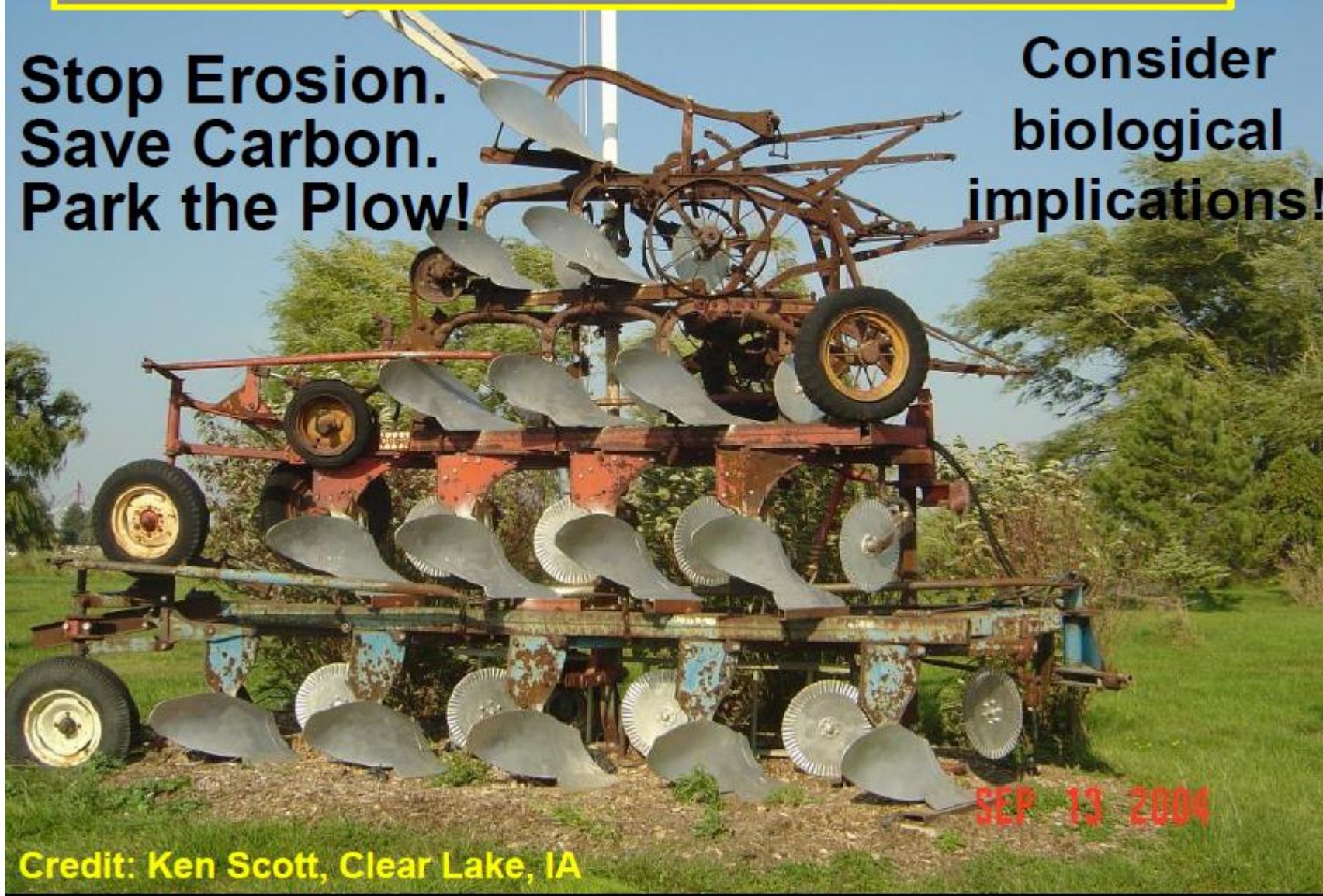
<https://commons.wikimedia.org/wiki/File:Duststorm.jpg>



# Time to pack away those plows!

**Stop Erosion.  
Save Carbon.  
Park the Plow!**

**Consider  
biological  
implications!**



**Credit: Ken Scott, Clear Lake, IA**

**SEP 13 2004**





**Current agricultural model involves a lot of killing of  
weeds, fungi, insects, & biodiversity**

**1,700 beneficial or indifferent insect species for every 1 pest species  
Address cause of pest problem rather than the symptoms  
(Entomologist, Dr. Jonathan Lundgren)**

**We try to keep monoculture production  
and the factory-farming of livestock viable  
through chemistry, drugs, machinery,  
genetic engineering and  
ultimately cash subsidy.  
(Allan Savory, Holistic Management)**

**Current agricultural model uses 10 calories of fossil fuel energy  
to produce one calorie of food**

# Alternative Agricultural Model

## Nature's way (biomimicry)

### -Nature doesn't plow or till the soil

A certain amount of disturbance by animals is natural as plants and animals co-evolved together.

### -Nature favors biodiversity

A typical natural prairie grassland has over 100 different plants living together in a mutually beneficial (symbiotic) relationship.

### -Natural soil is full of living microbes:

They provide all the nutrients plants need and protect against disease. Adding fertilizers upsets this ecology.

### -Nature has plants covering the ground year round

### -Nature's way is sustainable and more profitable for the farmer

Move to **regenerative agriculture** where we rebuild the soil biology and sequester more carbon at the same time as we grow food.



# How to rebuild the soil biology?

- By inoculating the dirt with a thin layer of compost or by spraying with a compost extract and compost tea.

It is important to ensure the compost is teeming with a good selection of soil microbes using a soil microscope.



- Ensure a good cover of plants providing root exudates to feed the microbes.

# **Soil Solutions to Climate Problems**

**Video created by the Center for Food Safety  
19 Nov 2015, Narrated by Michael Pollan**

**Permission granted by the Center for Food Safety**

<https://www.youtube.com/watch?v=NxqBzrx9yIE>

**The final segment of this presentation concerns desertification  
and livestock grazing practices.**



# Desertification



**Although desertification can include the encroachment of sand dunes, it doesn't refer to the advance of deserts. It is the persistent degradation of dryland ecosystems by human activities — including unsustainable farming, mining, overgrazing and clear-cutting of land — and by climate change.**

# Desertification: the extent of the problem



Drylands, areas prone to desertification, occupy approximately 40% of Earth's land area and are home to more than 2 billion people.



# **Desertification**

**Conventional wisdom has it that one of the main causes of desertification is overgrazing by cattle, sheep and goats.**

**According to one of my agricultural heroes, the African biologist Allan Savory, we were once just as certain that the earth was flat. As he has shown, it is not about numbers, it is all about timing.**

**It's our failure to manage plant recovery time that leads to overgrazing and land desertification.**



**Continuous grazing is a common practice in which livestock have unrestricted access throughout the grazing season.**



Cattle grazing on farm, Gruyere, Victoria by Nick Pitsas, CSIRO (CC BY 3.0)  
[https://upload.wikimedia.org/wikipedia/commons/b/b7/CSIRO\\_SciencImage\\_6866\\_Cattle\\_grazing\\_on\\_farm.jpg](https://upload.wikimedia.org/wikipedia/commons/b/b7/CSIRO_SciencImage_6866_Cattle_grazing_on_farm.jpg)



# **Desertification**

**It is common practice to put cattle into a fenced pasture for an extended period of time. A typical native grassland contains more than 100 plant species and like humans, herbivores have their preferences, and from these they choose the freshest growth.**

**They first eat their preferred grasses and only move to other type after it is all gone. They will return to eat their favourite as soon as it starts to regrow before the root has been recharged by photosynthesis.**

**In drought prone areas this repeated cropping kills the grass leaving bare ground with no plants to feed the soil microbes. This leads to desertification and a loss of soil carbon. The dark bare soil gets very hot, causing soil moisture to evaporate leading to soil erosion, droughts, famine and poverty.**

**How does nature prevent overgrazing?**



Aerial view of a herd of wildebeest







**Wildebeests only safe  
inside the herd.**

Credit: Kevin Pluck (CC BY 2.0)  
[https://commons.wikimedia.org/wiki/  
File:Lion\\_waiting\\_in\\_Namibia.jpg](https://commons.wikimedia.org/wiki/File:Lion_waiting_in_Namibia.jpg)



Credit: by Guido Appenzeller (CC BY 2.0)  
[https://commons.wikimedia.org/wiki/File:Spotted\\_hyena\\_gnawing\\_gnu.jpg](https://commons.wikimedia.org/wiki/File:Spotted_hyena_gnawing_gnu.jpg)



**They pee and dung everywhere and have to keep moving to avoid eating their own waste.**





# How can humans imitate nature?

One method: use electric fence to emulate the predators



**The farmer spends about 20 minutes each day setting up the electric fence for the next paddock.**



Neil Dennis, Saskatchewan rancher



## **Wait a minute - aren't we supposed to eat less meat?**

**Methane produced by ruminants is a potent green house gas (GHG)**

## **But we have been ignoring a whole other side to this story.**

**When herbivores are adaptively grazed to emulate nature there is a net reduction in GHG. The GHG emission of methane is more than compensated for by the amount of atmospheric carbon sequestered in the soil.**

### **Some of the recent science.**

<https://www.youtube.com/watch?v=crG4L4J-OEg>

W.R. Teague et al., *Journal of Soil and Water Conservation*, 71, #2, p. 156, 2016

Tong Wang et al., *Sustainability* **2015**, 7(10), 13500-13521

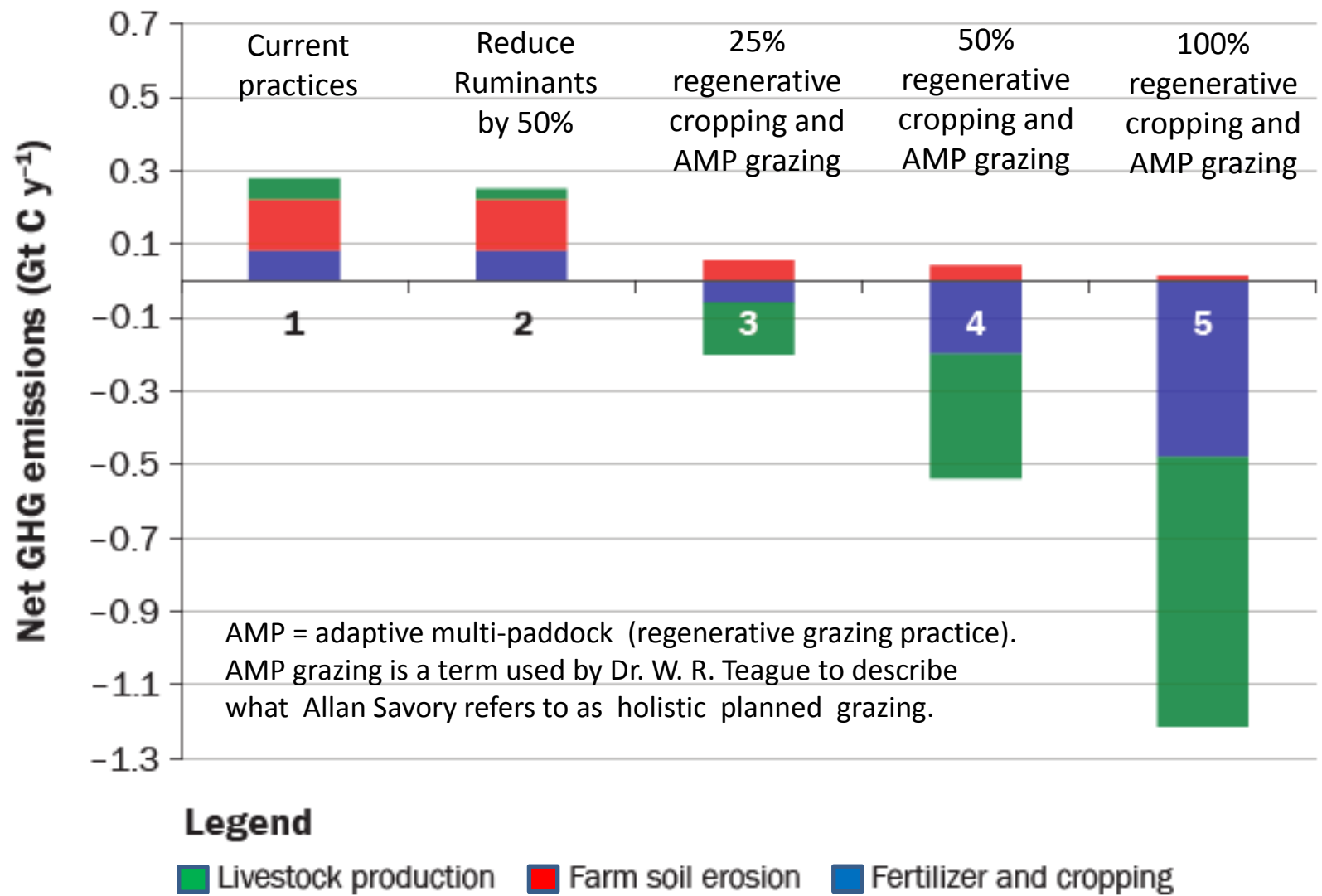
## **Our new knowledge shows how cattle, sheep and goats can be a big part of the solution.**

See the TED talk by Allan Savory at

[https://www.ted.com/talks/allan\\_savory\\_how\\_to\\_green\\_the\\_world\\_s\\_deserts\\_and\\_reverse\\_climate\\_change?language=en](https://www.ted.com/talks/allan_savory_how_to_green_the_world_s_deserts_and_reverse_climate_change?language=en)

# Best working hypothesis for North American agricultural greenhouse gas (GHG) emissions for a transition to regenerative cropping and regenerative grazing practices

Based on: W.R. Teague + 11 authors, Journal of Soil and Water Conservation, 71, #2, p. 156, 2016  
See also Quivira Conference presentation <https://www.youtube.com/watch?v=crG4L4J-OEg>





# Potential for Improved Data

- **As an astronomer I would like to have 5 planet earths to test out the different scenarios indicated in the previous slide. Since this is not possible we need to treat these estimate for the green house gas emissions for regenerative agriculture as the best working hypothesis.**
- **Fortunately, over the next 4 years we may acquire a lot more data as the French Government has embarked on an ambitious regenerative agriculture program aimed at sequestering large amounts of atmospheric carbon with improved soil monitoring. This '4 per 1000' initiative was announced at the 2015 Paris Climate Meeting COP 21.**

**(For more ongoing research in regenerative agriculture see the supplementary notes.)**

# French Government's '4 per 1,000' Initiative proposed at the Paris Climate meeting COP 21

France is committed to ensuring that at least 50% of its agricultural holdings will have adopted this approach by 2020.

## 4 PER 1000

### CARBON SEQUESTRATION IN SOILS FOR FOOD SECURITY AND THE CLIMATE

Ministère de l'Agriculture, de l'Agroalimentaire et de la Forêt

The quantity  
of carbon contained  
in the **atmosphere**  
increases by  
**4.3 billion tons**  
every year

**+4.3** bn tons  
carbon  
/ year

↑↑  
CO<sub>2</sub> emissions



Forests ⊖⊖

Oceans ⊖⊖

Human activities ⊕⊕⊕⊕

Deforestation ⊕

⊖ absorption ⊕ emission

The world's **soils**  
contain  
**1 500 billion tons**  
of carbon in the form  
of organic material

absorption of CO<sub>2</sub>  
by plants



storage of organic  
carbon in soils

**1500** bn tons  
carbon

**If we increase by 4‰ (0.4%) a year**  
the quantity of carbon contained  
in soils, **we can halt the annual**  
**increase in CO<sub>2</sub> in the atmosphere,**  
which is a major contributor  
to the greenhouse effect  
and climate change

increased  
absorption  
of CO<sub>2</sub>  
by plants :



farmlands,  
meadows,  
forests...



**+4‰ carbon storage**  
**in the world's soils**

= more fertile soils  
= soils better able to cope with  
the effects of climate change



# **Countries participating in the French “4 pour 1000” initiative (as of Nov. 2016)**

<b>Australia</b>	<b>Mexico</b>
<b>Austria</b>	<b>Morocco</b>
<b>Bulgaria</b>	<b>Netherlands</b>
<b>Costa-Rica</b>	<b>New Zealand</b>
<b>Croatia</b>	<b>Philippines</b>
<b>Denmark</b>	<b>Poland</b>
<b>Estonia</b>	<b>Portugal</b>
<b>Ethiopia</b>	<b>Slovenia</b>
<b>Finland</b>	<b>Spain</b>
<b>France</b>	<b>Sweden</b>
<b>Germany</b>	<b>Tunisia</b>
<b>Hungary</b>	<b>Ukraine</b>
<b>Iran</b>	<b>United Kingdom</b>
<b>Ireland</b>	<b>Uruguay</b>
<b>Japan</b>	<b>Andalusia</b>
<b>Latvia</b>	<b>Wallonie Region</b>
<b>Lithuania</b>	

**Hopefully more countries  
will join this important  
initiative**

## **My conclusion after two years of investigating this issue:**

**1) If regenerative agriculture, including both regenerative cropping and regenerative grazing, is practiced on 100% of the world's agricultural land then the current best estimate of the net global green house gas emissions is -0.5 G t C/yr.**

**We would be removing CO<sub>2</sub> from the atmosphere.**

**2) If we were only to achieve this on 1/3 of the agricultural land we could reduce green house gas emissions by approximately 35%.**

**3) If we use livestock to reverse desertification then we don't need to destroy rain forests to grow more grain for feedlot operations!**



# **Regenerative agriculture is a win-win - - - win situation.**

- 1) Less money for chemicals and plowing, reduced use of fossil fuels, saves farmers money, reduced soil erosion and water pollution.**
- 2) Increased soil organic matter, greater biodiversity, improved soil structure, more water infiltration and storage.**
- 3) Increased long term production and greater resistance to droughts.**
- 4) Reduced famines and agricultural collapses.**
- 5) Reduced workload for farmer as the soil biology does most of the work.**
- 6) More nutritious food.**

# Video showing the connections between Soil Carbon, Climate Change, and Food Security

## **“The Soil Story”**

was produced by Kiss the Ground and is narrated by the Carbon Underground President Larry Kopald.

Open source and free to use for educational purposes.

<https://thecarbonunderground.org/the-carbon-underground-president-larry-kopald-narrates-the-soil-story/>





# **Supplementary material for lecture by Dr. Phil Gregory, Physics and Astronomy Dept., University of British Columbia**

**How are seeds planted in no till farming**

<https://www.youtube.com/watch?v=V5uK-1dcIRY>

**The Hidden Half of Nature: The Microbial roots of Life and Death  
by David R. Montgomery and Anne Bilké, Norton Publishers, 2016**

**Gabe Brown's story: a farmer ahead of his time**

<https://www.youtube.com/watch?v=GxlyKfWf9kU>

**Singing Frogs Farm** <https://www.youtube.com/watch?v=zAn5YxL1PbM>

**Carbon cowboys**

[https://www.youtube.com/results?search\\_query=Carbon+cowboys](https://www.youtube.com/results?search_query=Carbon+cowboys)

**Soil Food Web (Dr. Elaine Ingham)**

[https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/health/biology/?cid=nrcs142p2\\_053868](https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/health/biology/?cid=nrcs142p2_053868)

**We need regenerative farming, not geoengineering**

<https://www.theguardian.com/sustainable-business/2015/mar/09/we-need-regenerative-farming-not-geoengineering>

**Oxford Real Farming Conference keynote talk by Dr. Elaine Ingham**

<https://www.youtube.com/watch?v=x2H60ritjag>

**Slides for this talk are online here**

<https://drive.google.com/file/d/0B6tV3TorfmstbXIIUU5yMXB2MWM/view>

# Supplementary material continued

**French initiative 4 per 1000 to sequester C in the soil for food security and climate**

<http://4p1000.org/understand>

<https://concilium.digital/wp-content/uploads/2016/11/Leaflet-4per1000-GB.pdf>

**Scientific talk on 4p1000 program**

<https://www.youtube.com/watch?v=sBeCHZNf2L4>

**Dr. Elaine Ingham's Life in the Soil Classes** <http://www.lifeinthesoilclasses.com/>

**Introduction to gardening with nature** *by Dr. C. A. Rollins and Dr. Elaine Ingham*

<http://www.soilfoodweb.com/Article.html>

**Industrial Farming Threatens Food Security in the US, Dr. Mercola, 10 Jan 2017**

[http://articles.mercola.com/sites/articles/archive/2017/01/10/industrialization-versus-regenerative-agriculture.aspx?utm\\_source=dnl&utm\\_medium=email&utm\\_content=art1&utm\\_campaign=20170110Z1&et\\_cid=DM132724&et\\_rid=1836044384](http://articles.mercola.com/sites/articles/archive/2017/01/10/industrialization-versus-regenerative-agriculture.aspx?utm_source=dnl&utm_medium=email&utm_content=art1&utm_campaign=20170110Z1&et_cid=DM132724&et_rid=1836044384)

**What If the World's Soils Run Out?**

<http://world.time.com/2012/12/14/what-if-the-worlds-soil-runs-out/>

**Water in Plain Sight: Hope for a Thirsty World, by Judith D. Schwartz**

St. Martin's Press, New York, 2016

**Draft Policy for Long Term Food Security and Climate Action,**

**by Phil Gregory, UBC, Submitted to the Canadian Federal Government, 2016**

<http://www.phas.ubc.ca/~gregory/papers/CanadaFoodSecurityClimateActionPolicyProposalPhilipGregory27Dec2016.pdf>



## Supplementary material continued

The following is a fictional story that I created for my granddaughter Maia when she was 10 after I learned about regenerative agriculture. Please share it with any young person in your life.

**Hannah's African Dreamtime Video** <https://youtu.be/fQ4hm1N1mVw>

**Allan Savory's TED talk:** inspired the Hannah's African Dreamtime Video

[http://www.ted.com/talks/allan\\_savory\\_how\\_to\\_green\\_the\\_world\\_s\\_deserts\\_and\\_reverse\\_climate\\_change](http://www.ted.com/talks/allan_savory_how_to_green_the_world_s_deserts_and_reverse_climate_change)

**The Savory Institute** <http://savory.global/>

**Holistic Management: A Common Sense Revolution To Restore Our Environment**

by Allan Savory with Jody Butterfield published by Island Press , 3<sup>rd</sup> Edition, 2016.

**Eating Our Way To A Healthy Planet with Allan Savory,** Allan Savory 5 Jun 2013

<https://www.youtube.com/watch?v=sNDCMUgNQtg>

**What Gets Me Up in the Morning,** Joel Salatin TEDxUVA, 28 Feb. 2017

**Pasture Cropping - Profitable Regenerative Agriculture,** talk by Colin Seis, 18 Aug. 2013

Australian farmer in NSW. Fascinating account of the farm's evolution from 1886 to date.

<https://www.youtube.com/watch?v=AAei0NBVBIM>

**The Adaptive Multi-Paddock Grazing Research Project**

<http://www.soilcarboncowboys.com/research>