Sequestering Carbon in Agricultural Soils: What works?

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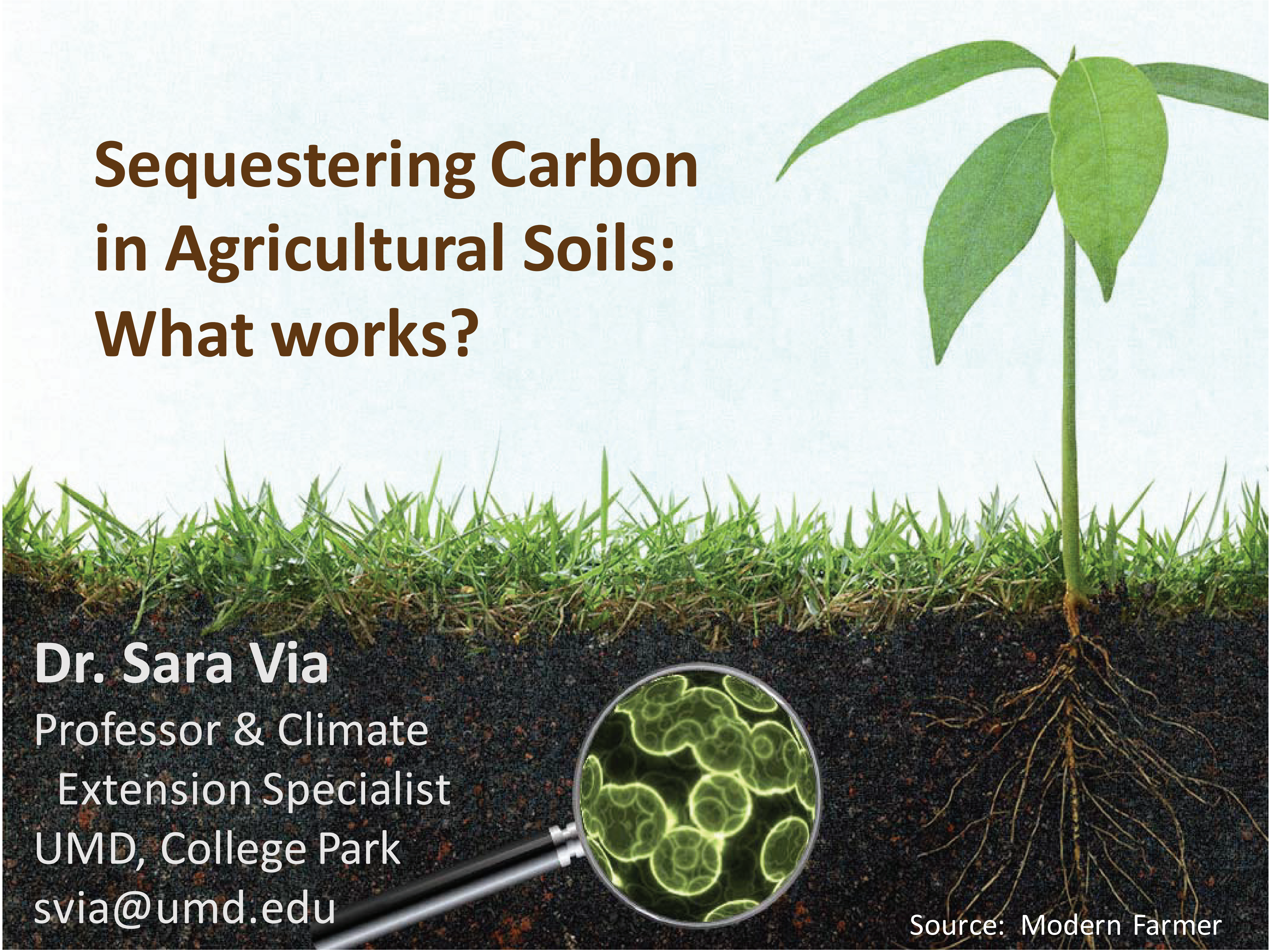


Source: Modern Farmer

Maryland's Healthy Soils Initiative

2016: MDA proposed Initiative to Maryland Commission on Climate Change

2016: Healthy Soils Consortium established by MDA

* Diverse stakeholder advisory group

2017: Maryland Healthy Soils Legislation

* Improve health, yield & profitability of MD soils
* Increase carbon sequestration in agricultural soils in Maryland
* Promote more widespread use of healthy soils practices by Maryland's farmers
* Bipartisan
* No funding

Healthy Soils Initiative: Actions

2017: Healthy Soils Workshops for farmers

2018: Begin work on carbon sequestration program

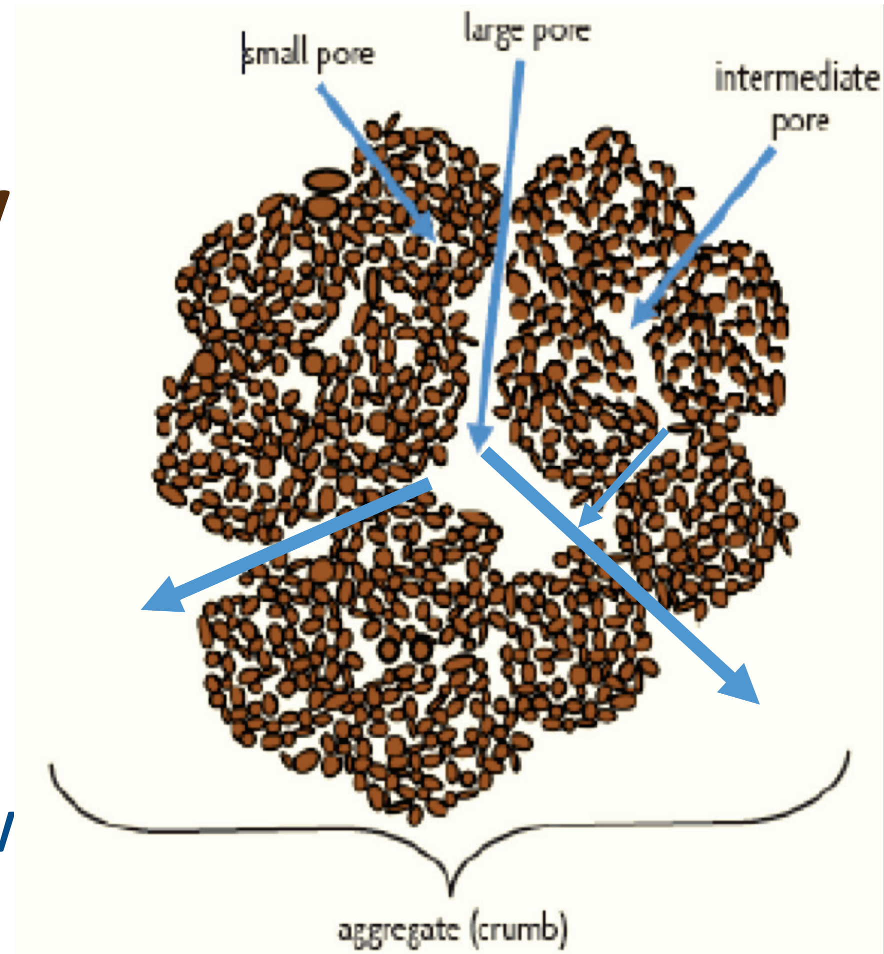
* Comprehensive review of scientific literature
* Synthesis and determination of practices likely to be successful in Maryland

2019 * Preparation of report for MDA

* Input and feedback from stakeholders
* Development of incentive program
* **Include program in next Greenhouse Gas Reduction Act Plan** to help MD reach 40% reduction by 2030

Healthy soil reduces climate risk

Stable aggregate structure of healthy soil increases infiltration, reducing flood risk



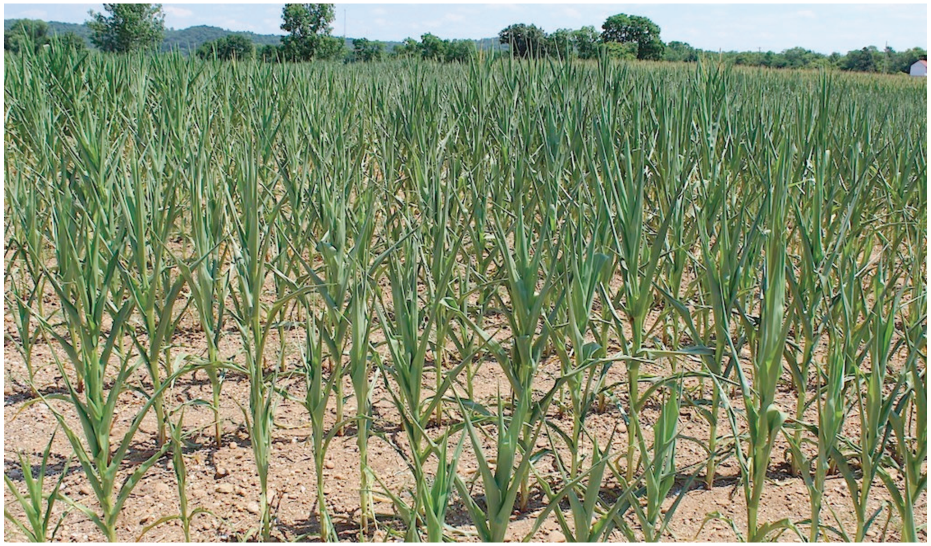
Modified from Cornell Soil Health Manual

Soil aggregates stabilized by

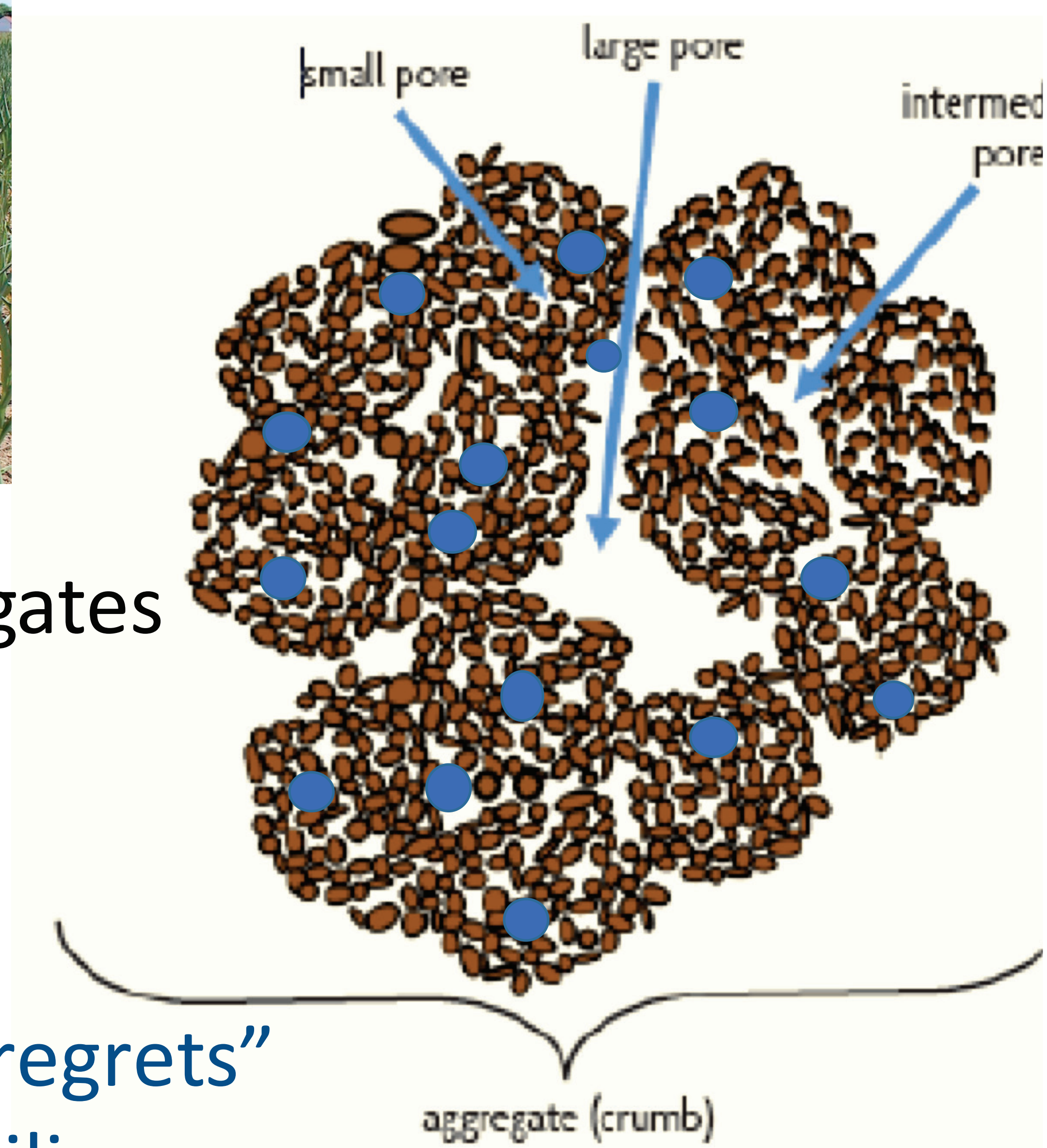
- roots & their exudates
- mycorrhizae & "glue"
- other sticky material from soil organisms

In healthy soil, aggregates are stable in water & pores allow good drainage

Healthy soil reduces climate risk



farmanddairy.com



- water held within aggregates in small pores reduces drought risk

Soil health is the top “no regrets” strategy for climate resilience

Agriculture can be part of climate solution

Reducing emissions is not enough

- Land-based carbon sequestration is the most practical and effective strategy
  - forests
  - farms

- Maryland already a leader in healthy soils practices, incentivized to reduce nutrient flow to Chesapeake Bay

- Now, build on & expand current incentives based on water quality to increase carbon-sequestering practices

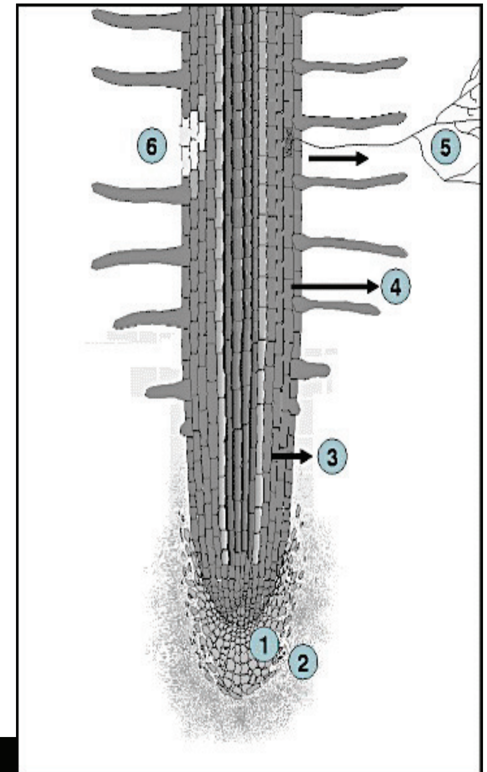
Sequestering Carbon in Healthy Soil

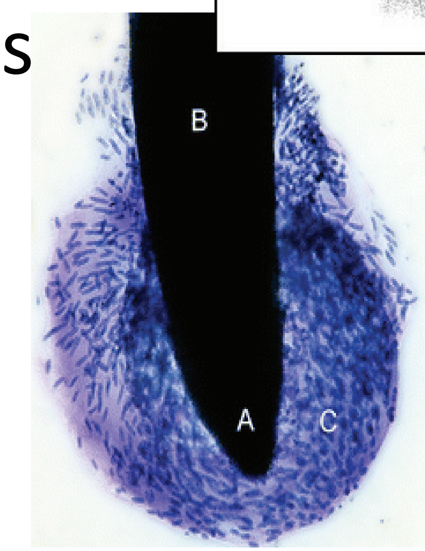
Plants absorb atmospheric C during photosynthesis and make sugar

- In healthy soil, up to 40% of this carbon is passed on to microbes.

- Most stored carbon comes from roots and has been processed by microbes

Healthy soil practices that boost microbes should increase carbon storage

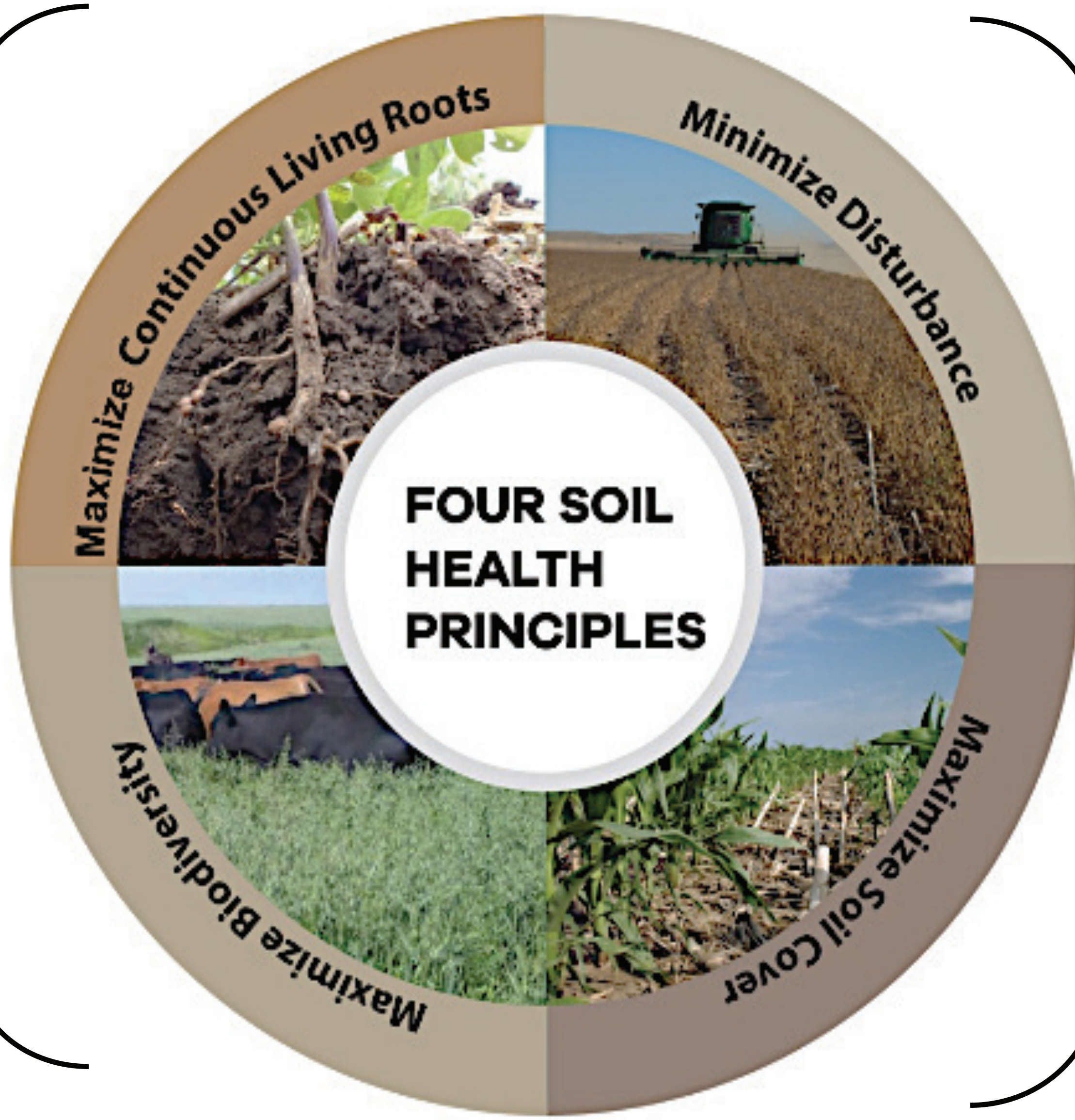




Jones et al. 2009. Plant Soil 321:5

Natural Resources Conservation Service (NRCS) principles: All about the microbes

Feed & Diversify the Soil Biota*



Protect Soil Aggregates & Organic Matter

modified from Dennis Chessman NRCS Kentucky

NRCS Soil Health Principles

Minimize disturbance & Keep the soil covered

* Maintains stable aggregates
* Reduces erosion
* Buffers temperature & moisture
* Maintain soil organic matter

These outcomes protect the microbial community

NRCS Soil Health Principles

Maximize biodiversity &

Maintain living roots

***Increase aboveground diversity**

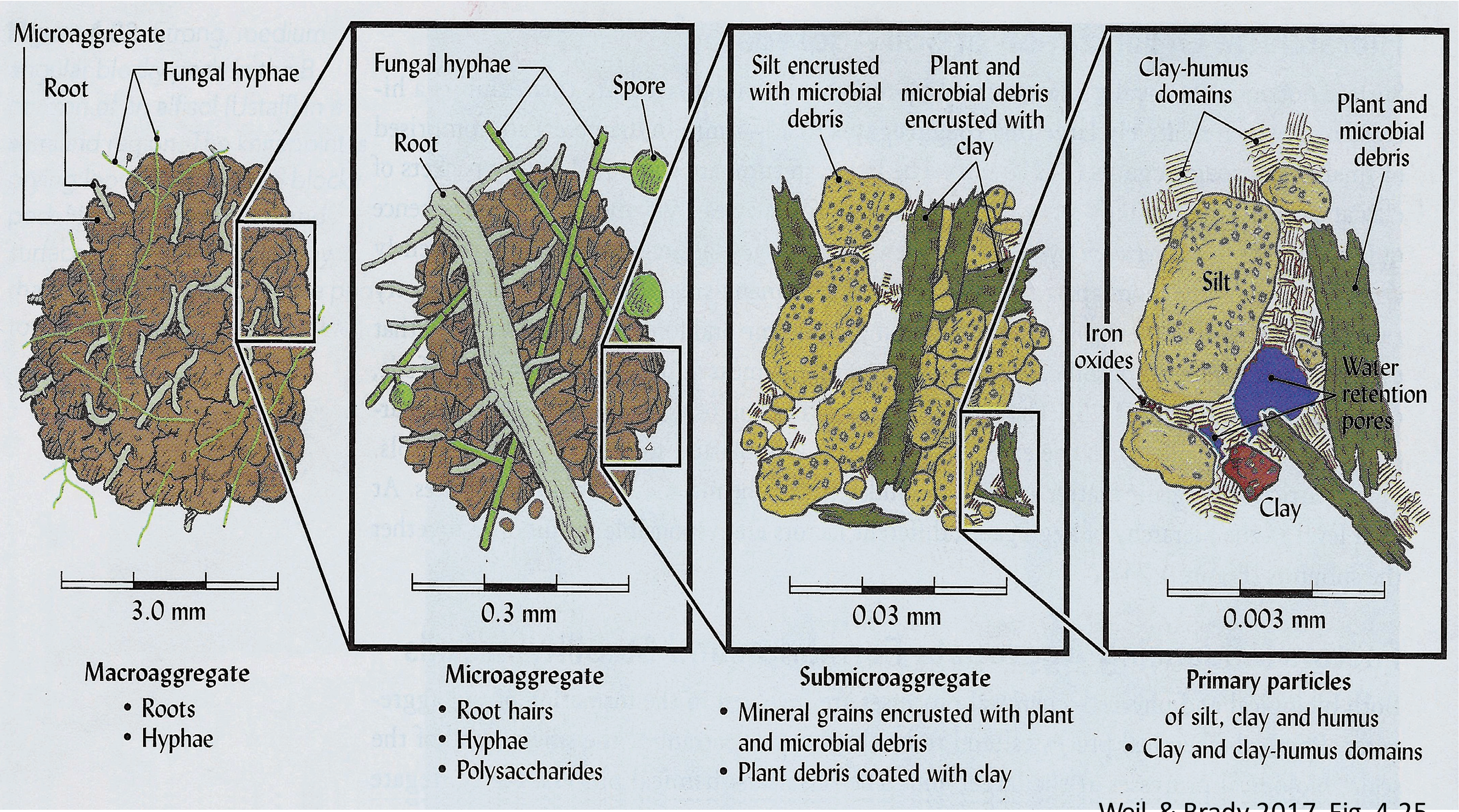
- -Boosts predators & pollinators
- -More biomass in mixtures
- -Increases soil organic matter

***Increase belowground diversity & provide living roots**

- -Increases diversity & stability of microbial community
- -Increases nutrient cycling
- -Enhances plant growth

How is carbon stored in the soil?

- Humus held tightly within microaggregates
- Microbial debris adsorbed onto clay & minerals



Weil & Brady 2017, Fig. 4.25

Goals of Carbon Sequestration Project

1. Identify research-based practices for sequestering C on Maryland's farms.

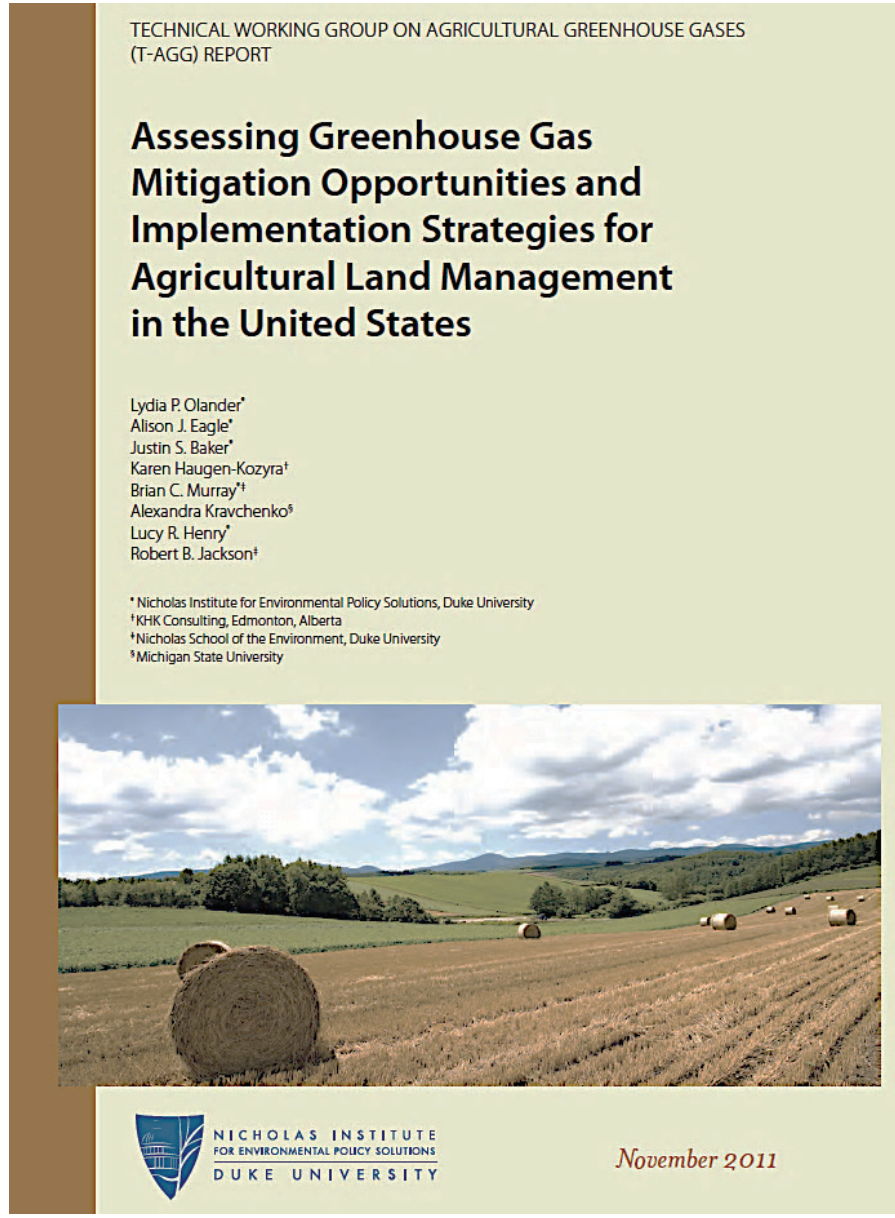
2. Estimate potential GHG reduction from each.

3. Determine costs/benefits for each.

4. Explore ways to build on current incentive programs to increase use of key practices

Identifying research-based practices for sequestering C in soils

- **Reviewed recent scientific reports** on carbon sequestration, primary literature
- **Evaluated support** for various practices


TECHNICAL WORKING GROUP ON AGRICULTURAL GREENHOUSE GASES (T-AGG) REPORT

Assessing Greenhouse Gas Mitigation Opportunities and Implementation Strategies for Agricultural Land Management in the United States

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NICHOLAS INSTITUTE FOR ENVIRONMENTAL POLICY SOLUTIONS DUKE UNIVERSITY

November 2011

Identifying research-based practices for sequestering C in soils

- **Aligned with NRCS conservation practices**
  - Many already used in MD for water quality
  - Farmers familiar with them
  - Incentives already established
  - CA Healthy Soils program uses NRCS practices
  - COMET-Planner estimates GHG reduction for each practice (moist & humid environment)

GHG reductions from carbon-sequestering practices already used in Maryland for water quality

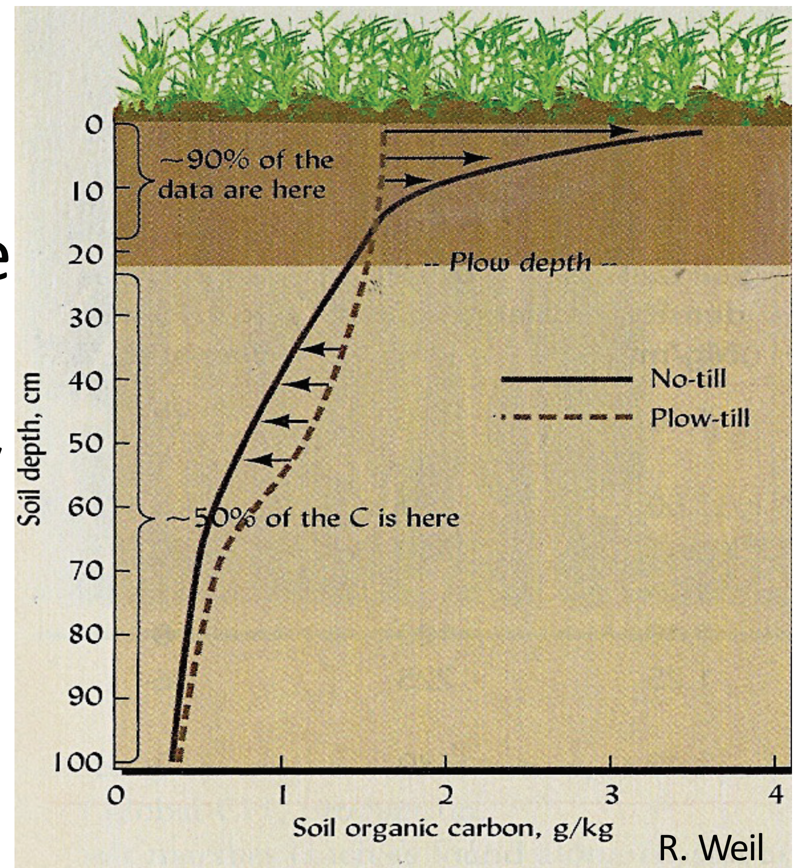
Greenhouse Gas Reductions From Agricultural Practices, Current					
comet-planner.nrel.colostate.edu/COMET-Planner_Report_Final.pd	GHG red (MT CO_2e/ac/yr)				
NRCS Conservation Practices	(CO_2)	(N_2O)			
Cropland Management	Mean	Mean	Sum	acres 2017	GHG red in 2017
Conventional Tillage to **No Till (CPS 329, s)**	0.42	-0.11	0.31	1,079,000	334,490
Conventional Tillage to **Reduced Tillage (CPS 345, s)**	0.13	0.07	0.2		-
Nutrient Management - N Fertilizer Management (CPS 590, s,r	0	0.11	0.11		-
Conservation Crop Rotation (CPS 328, s)	0.21	0.01	0.22	304625	67,018
Cover Crops (CPS 340, s),	0.32	0.05	0.37	559000	206,830

These agronomic practices have significant research support

This slide contains preliminary results/data, please consult Dr. Sara Via before referencing: svia@umd.edu

No-Till or Not??

- **No-till a key element of soil health**
- **Co-benefits:** better water infiltration and storage, less erosion, less compaction, less fuel use
- **BUT** some studies in which C was measured to 1 m claim to show more C at surface but less at depth in no-till due to inversion of organic matter into soil by tillage



*** Scrutiny of primary literature:**

- many cited papers are low quality
- recent papers show slightly more C in the top 1m in no-till*

* CA & COMET Planner include no-till as a sequestration practice

*e.g., Anders & Eriksen-Hamer 2008. doi:10.2136/sssaj2007.0342

Reduce synthetic N fertilizer by 15%

- **Fertilizer application boosts yields**
- **Farmers regard fertilizer as an insurance policy**
- **Most University fertilizer recommendations** have not been modified in many years; do not consider soil health
- **Applying excess N increases pollutants**

* **Nitrate (NO_3)-** pollutes groundwater

- in 2018 most starter fertilizer lost after major spring rains

* **Nitrous oxide (N_2O) -** 300x CO_2

- increases exponentially when N applied in excess

Reduce synthetic N fertilizer by 15%

To reduce runoff

- try nitrification inhibitors,
- increase use of split applications
  to maximize uptake by plants
- use 4R fertilizer principles

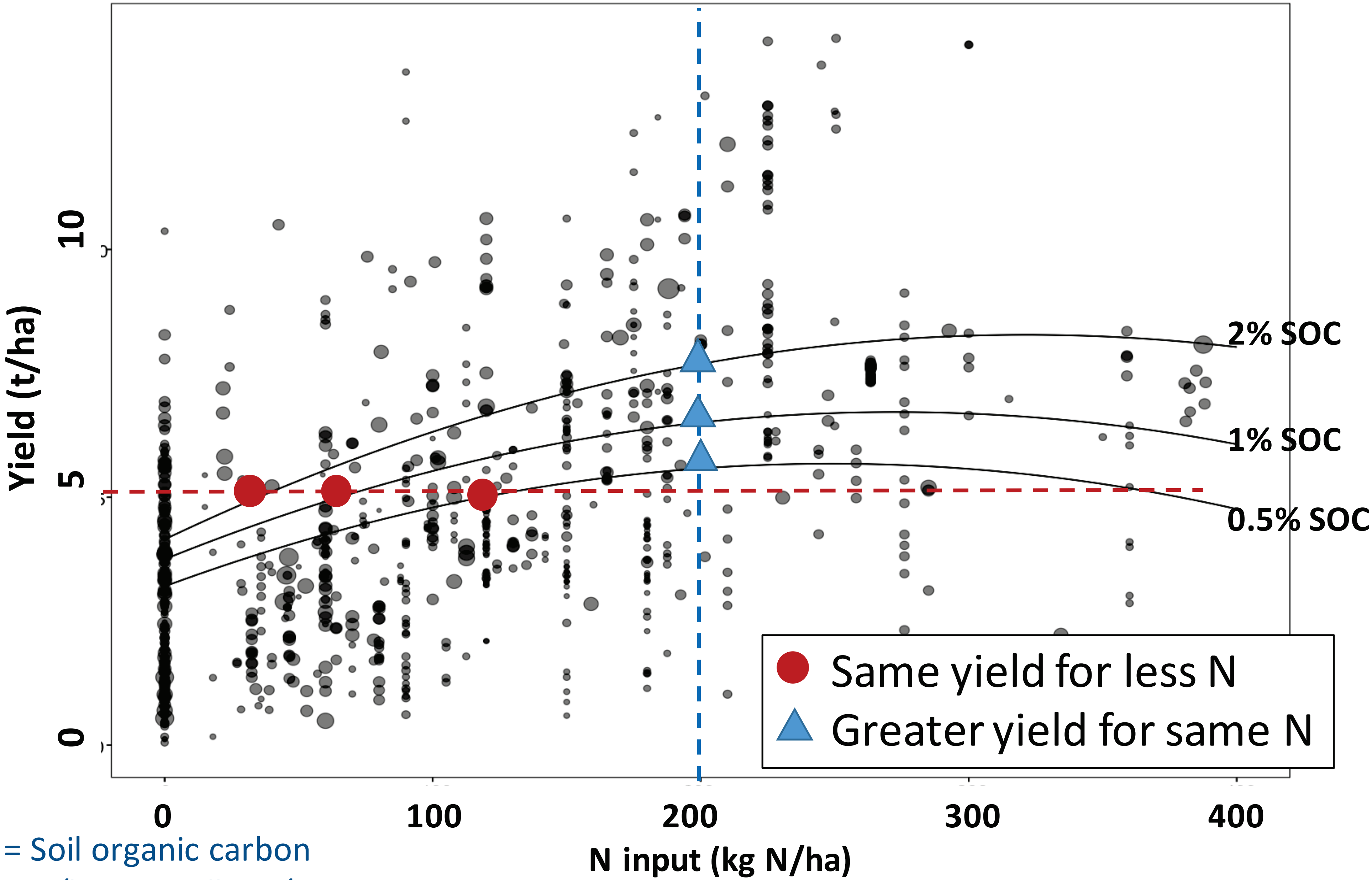
Replace with manure, compost?

- slow release, adds SOM

BUT

- must apply manure & compost at low rate to avoid excess P
- now hard to obtain manure on Eastern Shore
- adequate supply of compost not currently available
- possibly revisit if food waste or leaf composting scaled up

Benefits of Increasing Soil Health



SOC = Soil organic carbon
200kg N/ha = 178 lbs N/acre

Modified from Oldfield et al. 2019. Soils. https://doi.org/10.5194/soil-5-15-2019

Additional practices with significant or medium research support

comet-planner.nrel.colostate.edu/COMET-Planner Report Final.pd

Cropland to Herbaceous or Woody Cover	GHG red. Mt CO_2e/acre/yr CO_2	N_2O	Sum	#acres 2017	GHG red. 2017 (Mt CO_2e)
Retiring marginal soils ==> permanent grass cover (CPS 327,s)	0.98	0.28	1.26	27555	34,719
Insert forage planting into rotation (CPS 512,s)	0.21	0.01	0.22	13416	2,952
Convert cropland strips to permanent herbaceous vegetation					* -
Riparian herbaceous cover (CPS 390)	0.27	0.28	0.55	13113	7,212
Contour buffer strips (CPS 332)	0.27	0.28	0.55	8.5	* 5
Field border (CPS 386)	0.27	0.28	0.55	703	* 387
Filter Strip (CPS 393)	0.27	0.28	0.55	30837	16,960
Grassed Waterway (CPS 412)	0.27	0.28	0.55	6237	3,430
Convert cropland to Farm Woodlot (CPS 612)	1.98	0.28	2.26	1928	4,357
Windbreak/shelterbelt establishment (CPS380)	1.81	0.28	2.09	120	* 251
Riparian Forest Buffer Establishment (CPS (391)	2.19	0.28	2.47	19439	48,014
Hedgerow Planting (CPS 422)	1.42	0.28	1.70	15.4	* 26
Alley Cropping (CPS 311)	1.71	0.03	1.74	total 2017:	726,651
Multistory Cropping = Permaculture (CPS 379)	1.71	0.03	1.74		
Increase efficiency of farm equipment (CPS 372)	0.01	-	0.01		
Mulching (CPS 585)	0.32	-	0.32		

best practice < 50,000 MtCO_2e

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Potentially useful but more data needed

Grazing	GHG red. Mt CO_2e/acre/yr		
Silvopasture on grazed grassland/pasture (data gaps)	1.34	0.00	**1.34**
Rotational grazing (from T-AGG,data gaps)	range CO_2: -5.27 - 1.90		
Other strategies from T-AGG with low research support			
improve irrigation management, e.g. drip	possible, but data gaps		
Improve manure managem for lo N_2O	possible, but data gaps		
agroforestry on grazing land	possible, but data gaps		
Replace N Fertilizer with Soil Amendments (CPS 590)but life cycle	**1.75**	**0.00**	**1.75**
convert dryland to irrigated	life cycle problems?		
biochar	life cycle problems?		

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Silvopasture

- add 5% trees to pastureland
- provides energy-free shade for grazing animals
- keeps animals out of streams
- trees sequester additional carbon
- trees may provide another income source
- pines or hardwoods, including N-fixers
- may be attractive to Maryland horse industry

Other practices that mix woody & herbaceous

Largely unfamiliar to Maryland farmers

windbreaks/hedgerows- trees

shrubby hedgerows with conservation cover

alley cropping

Rotational grazing: High variation in success

A well-managed rotational grazing program requires "adaptive management", ie continuously:

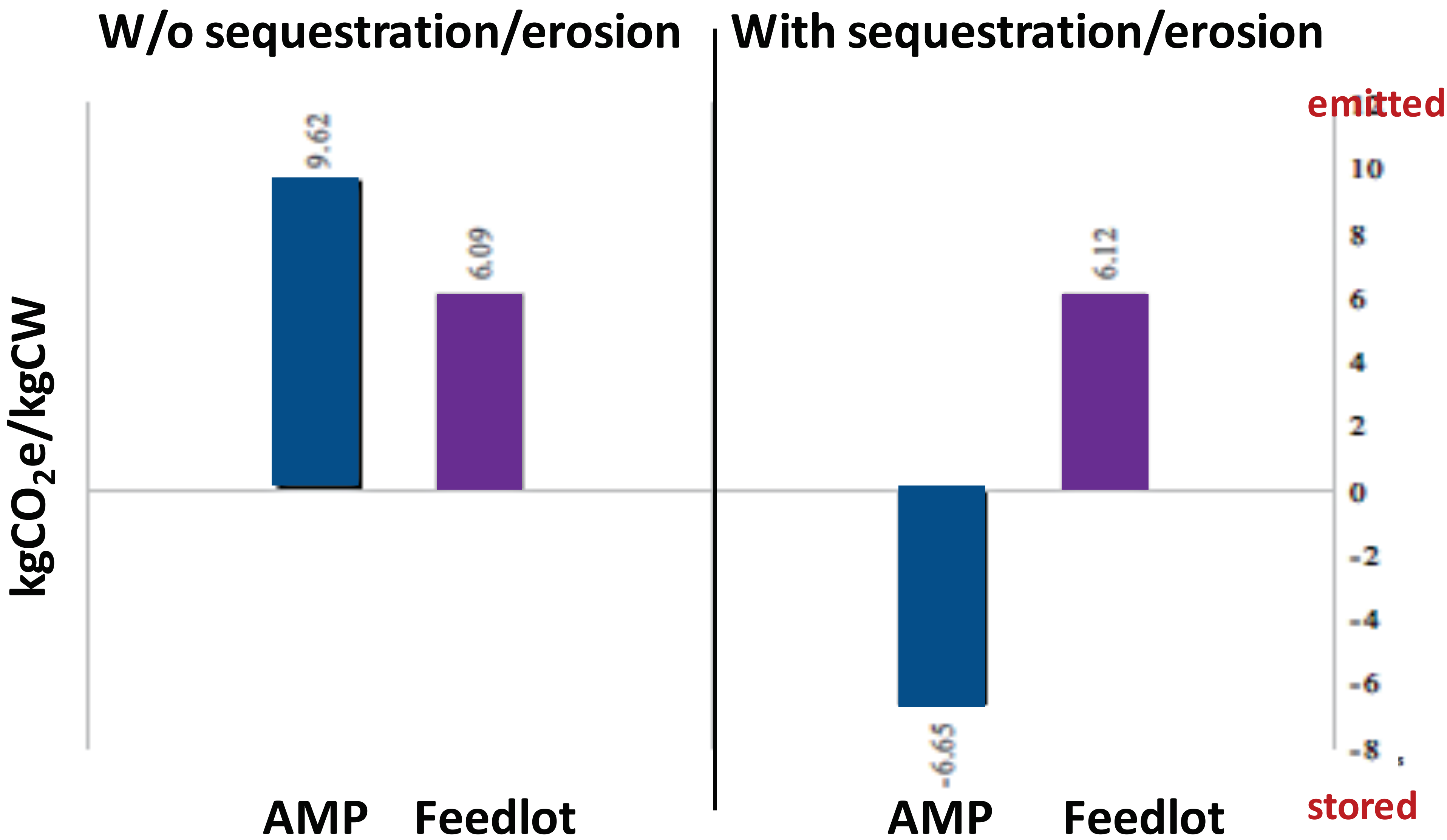
- evaluate the nutritional and forage needs of animals,
- assess forage quality & quantity for stocking rate,
- regulate the acreage of access
- enough consumption to stimulate roots but not so much that overgrazing occurs

Most successful w/ motivated & experienced farmer

Multiple definitions: mob grazing, adaptive paddock management, holistic grazing

Potentially integrate into rotations with cover crops, addition of deep-rooted perennials

Rotational grazing *can* work



but, grazing takes 2x amount of land as feedlot

Modified from Stanley et al. (2018)

GHG reduction from water quality practices 2007-2017

comet-planner.nrel.colostate.edu/COMET-Planner_Report_Final.pdf	GHG reduction (MT CO_2e/ac/y															
NRCS Conservation Practices	(CO_2)	(N_2O)		# acres in each practice												
Cropland Management	Mean	Mean	Sum	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	slope	GHG red, Mt Co2e/ acre/yr
Conventional Tillage to **No Till (CPS 329, s)**	0.42	-0.11	0.31	765,500	794,000	822,500	851,000	879,500	908,000	965,000	979,250	993,500	1,007,750	1,022,000	14,250	3,096,280
Conventional Tillage to **Reduced Tillage (CPS 345, s)**	0.13	0.07	0.2						302,000	290,000	no till slope based on only 2012-2013-- no other data					
Reduced Tillage to No Till	0.29	-0.4	0.25								use only 25% of estimated no-till slope					0
Nutrient Management - N Fertilizer Management (CP	0	0.11	0.11													0
Conservation Crop Rotation (CPS 328, s)	0.21	0.01	0.22	74,888	88,287	101,660	128,889	160,747	194,203	225,553	254,009	275,313	292,467	305,540	17175	462,342
Cover Crops (CPS 340, s), 2017 data	0.32	0.05	0.37	241,914	186,120	232,564	202,723	396,179	421,531	415,072	420,380	473,016	500,342	560,493	25,304	1,498,624
Cropland to Herbaceous or Woody Cover																
Retiring marginal soils ==> permanent grass cover (Cl	0.98	0.28	1.26	19,311	20,162	21,370	21,880	22,790	23,924	24,765	25,515	26,148	26,535	27,210	755	327,109
Insert forage planting into rotation (CPS 512,s)	0.21	0.01	0.22	6,302	6,951	8,071	8,992	9,725	10,617	11,280	11,628	12,180	12,727	13,503	615	24,635
Conservation Cover (CPS 327)	0.98	0.28	1.26	1,327	1,022	1,612	864	1,139	1,032	2,098	357	1,294	265	501		14,504
Riparian herbaceous cover (CPS 390)	0.98	0.28	1.26	9,355	9,427	9,546	9,848	10,983	11,724	12,250	12,532	12,719	12,922	13,146	429	156,811
Contour buffer strips (CPS 332)	0.98	0.28	1.26	7	7	9	9	9	9	9	9	9	9	9		114
Field border (CPS 386)	0.98	0.28	1.26	398	460	527	548	564	572	631	642	654	658	704	22	8,009
Filter Strip (CPS 393)	0.98	0.28	1.26	28,325	29,304	29,982	30,333	30,619	30,935	31,055	31,171	31,216	31,234	31,245	44	422,627
Grassed Waterway (CPS 412)	0.98	0.28	1.26	5,437	5,539	5,651	5,716	5,783	5,874	5,974	6,026	6,106	6,177	6,225	75	81,280
Convert cropland to Farm Woodlot (CPS 612)	1.98	0.28	2.26	1,076	1,090	1,420	1,495	1,512	1,537	1,624	1,709	1,725	1,840	1,933	64	38,334
Windbreak/shelterbelt establishment (CPS380)	1.81	0.28	2.09	47	66	83	91	103	110	113	115	116	116	120	2	2,254
Riparian Forest Buffer Establishment (CPS (391)	2.19	0.28	2.47	17,161	17,399	17,654	17,852	17,976	18,295	18,591	18,796	18,953	19,262	19,447	235	497,421
Hedgerow Planting (CPS 422)	1.42	0.28	1.70	6	6	6	7	7	10	14	15	15	15	15	1	197
														GHG with notill		6,630,541

This slide contains preliminary results/data, please consult Dr. Sara Via before referencing: svia@umd.edu

How much can agriculture contribute to Maryland's GHG reduction goals?

Calculated using actual # acres in NRCS practices 2007-2017 & estimated GHG reduction for each.

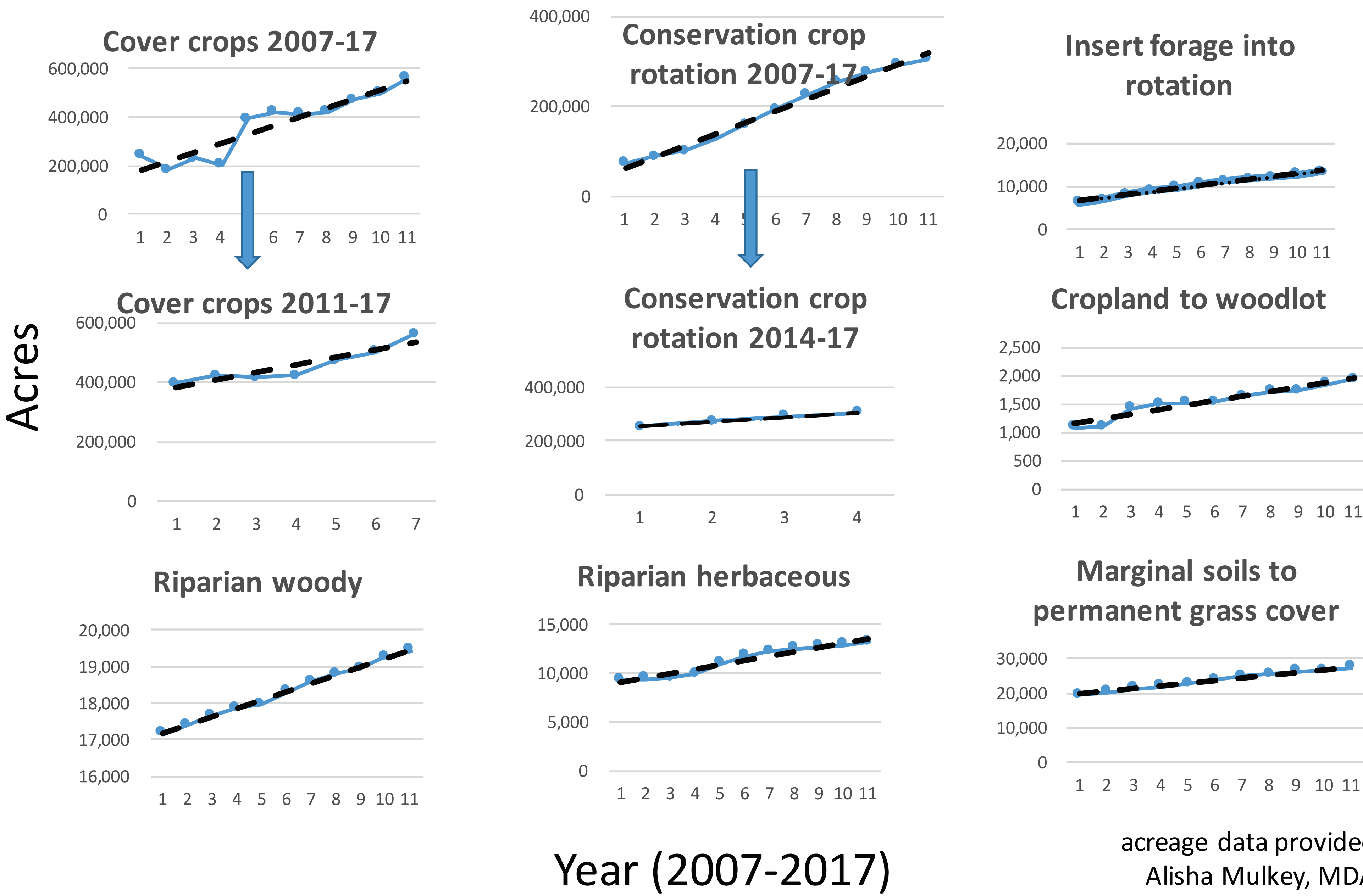
With only practices used for water quality,

GHG reduction from agriculture in Maryland
2007-17: 6.9 MMt CO_2e

This is like removing 1,500,000 cars from the road for one year

This slide contains preliminary results/data, please consult Dr. Sara Via before referencing: svia@umd.edu

Used 2007-2017 slopes to estimate acreages in 2020-2030 for projection



acreage data provided by
Alisha Mulkey, MDA

Maryland's GHG reduction goal: 40% reduction by 2030

GHG reduction 2020-2030 from agriculture
(Estimated, no new practices)
8.9 MMt

Conservative b/c new practices will be added & existing practices will increase with incentives for carbon benefit

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How much scope is there for enrolling more acres in these practices?

- With new funding reflecting the carbon benefit?

- If some key equipment were made available?

- With increased outreach?

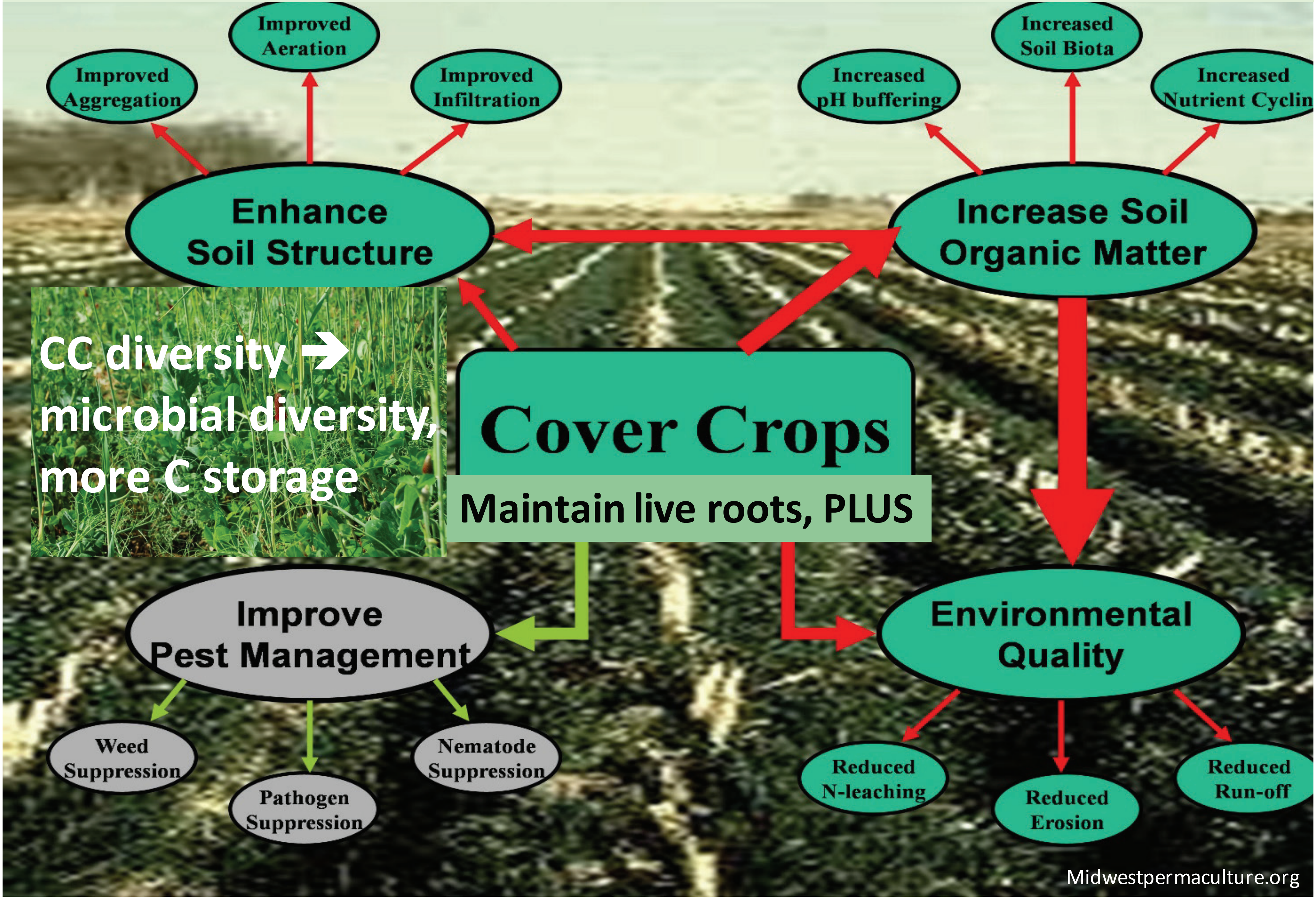
Questions for Ag Extension Personnel

- What will it take to get farmers to increase their use of these practices?

- Will farmers accept some of the practices not commonly used now, such as:
    - Alley cropping
    - Hedgerows
    - Silvopasture etc.

- Can we increase no-till and cover crops in vegetables?

Practices have multiple co-benefits for farmers & societ



But nothing's perfect

Table 6. Potential co-benefits and tradeoffs of agricultural GHG mitigation practices

GHG Mitigation Practice	Biodiversity	Water conservation	Water quality	Air quality	Soil quality	Food security
Switch to no-till or other conservation tillage	Improved habitat for ground-nesting birds and other animals Increased herbicide use	Reduced irrigation need	Reduced sedimentation Increased herbicide use and potential for runoff	Reduced emissions from tractor use, reduced respirable and total dust	Reduced erosion, increased SOM	Increased reliance on GM seeds and homogenization
Eliminate summer fallow	Improved habitat for ground-nesting birds and other animals	Increased water use	Reduced nitrate leaching, but increased fertilizer N needs		Increased SOM	
Add winter cover crop	Increased biodiversity	Improved soil water holding capacity Increased water use	Reduced nitrate leaching	Increased emissions from tractor use	Increased SOM	Increased yield through improved fertility and reduced insect and pathogen damage
Diversify annual crop rotations, increase intensity	Increased biodiversity (native and crop species), possibly detrimental to wildlife (e.g., bird diversity)	Reduced or increased water use	Disease-suppressive soils reduce pesticide and herbicide use or increased inputs and erosion	Increased emissions from tractor use	Improved soil quality	Increased yields, improved disease resistance
Include or substitute perennial crops in rotations, SRWCs	Increased biodiversity	Decreased water use and increased soil water holding capacity or possible increase in water use	Potentially decreased sedimentation and herbicide/ pesticide use	Reduced emissions from tractor use	Improved soil quality, reduced erosion, increased SOM	Decreased overall production of main grain crops

from Olander et al. 2011. T-AGG report *Assessing Greenhouse Gas Mitigation Opportunities and Implementation Strategies for Agricultural Land Management in the United States*

Economic Benefits to Farmers

- Increased soil health allows reduced use of synthetic N, herbicides, pesticides, fuel, irrigation

- It can take time to reap soil health benefits, but profits can grow even if short-term yield decline

- Healthy soil reduces climate risk, stabilizes yields
  better infiltration ➔ flood reduction
  more water held ➔ drought resilience

- Future addition of carbon trading= more $

Economic Benefits to Farmers: No-till

No-till saves money and time (NRCS study)

- Assume a 50 acre field and using figures from the NRCS study

One less pass over field saves 4.16 gall fuel/acre

50 x 4.16 = 208 gall @ $2.05/gallon,

Savings = $426/pass for 50 acre field

Maryland 2013: 965,000 acres no-till row crops

So saved 4.07 million gallons fuel/pass

~ $8.35 million if just one less pass

This slide contains preliminary results/data, please consult Dr. Sara Via before referencing: svia@umd.edu

No-till also reduces emissions by saving fuel

22.4 lbs CO_2 saved/gallon of diesel

Using numbers from the previous slide,

2013: No-till saved 40,788 Mt CO_2 in Maryland

Equal to removing 8,870 cars for one year

This slide contains preliminary results/data, please consult Dr. Sara Via before referencing: svia@umd.edu

Environmental/health benefits to society of carbon-sequestering practices

- Improved water quality, Bay protection
- Reduced erosion, dust, sediment
- Less nitrate in water reduces water treatment costs
- Better ecosystem services worth up to $3500/acre*)
- Reduction of future climate change, BUT
    - practices must be maintained each year
    - saturation will eventually occur

*Farmland LP Impact Report 2018

Increased research & outreach needed

- **Integrate the practices into current strategies**
- **Identify ways to increase value of each practice** (i.e., make cover crops work harder -- mixtures, interseeding, planting green, use in weed control)
- **Outreach to increase farmer acceptance and use**
  - corn/soybeans, hedgerows etc?
  - boost no-till and cover crops in vegetable and organic farming
- **Technical assistance** to guide farmers and verify carbon increase over time

Monitoring carbon sequestration:

Verify that management practices increase SOC

- **Establish a set of permanent sites for regular sampling by trained techs**
  * range of soils, geography and cropping systems
  * standard sampling protocol to 50 - 60 cm
  * standard analyses
  * these repeated samples increase chance of detecting change over time
- **Farmers submit yearly soil tests** with records of field management using recommended protocol (many samples but highly variable)

Conclusions

Agriculture can play pivotal role in GHG reduction in Maryland

Incentivizing carbon-sequestering practices:
a win for the environment,
a win for farmers

email me anytime: svia@umd.edu