Impact of Manure Best Management Practices on Environmental Input of Emerging contaminants

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VIRGINIA TECH

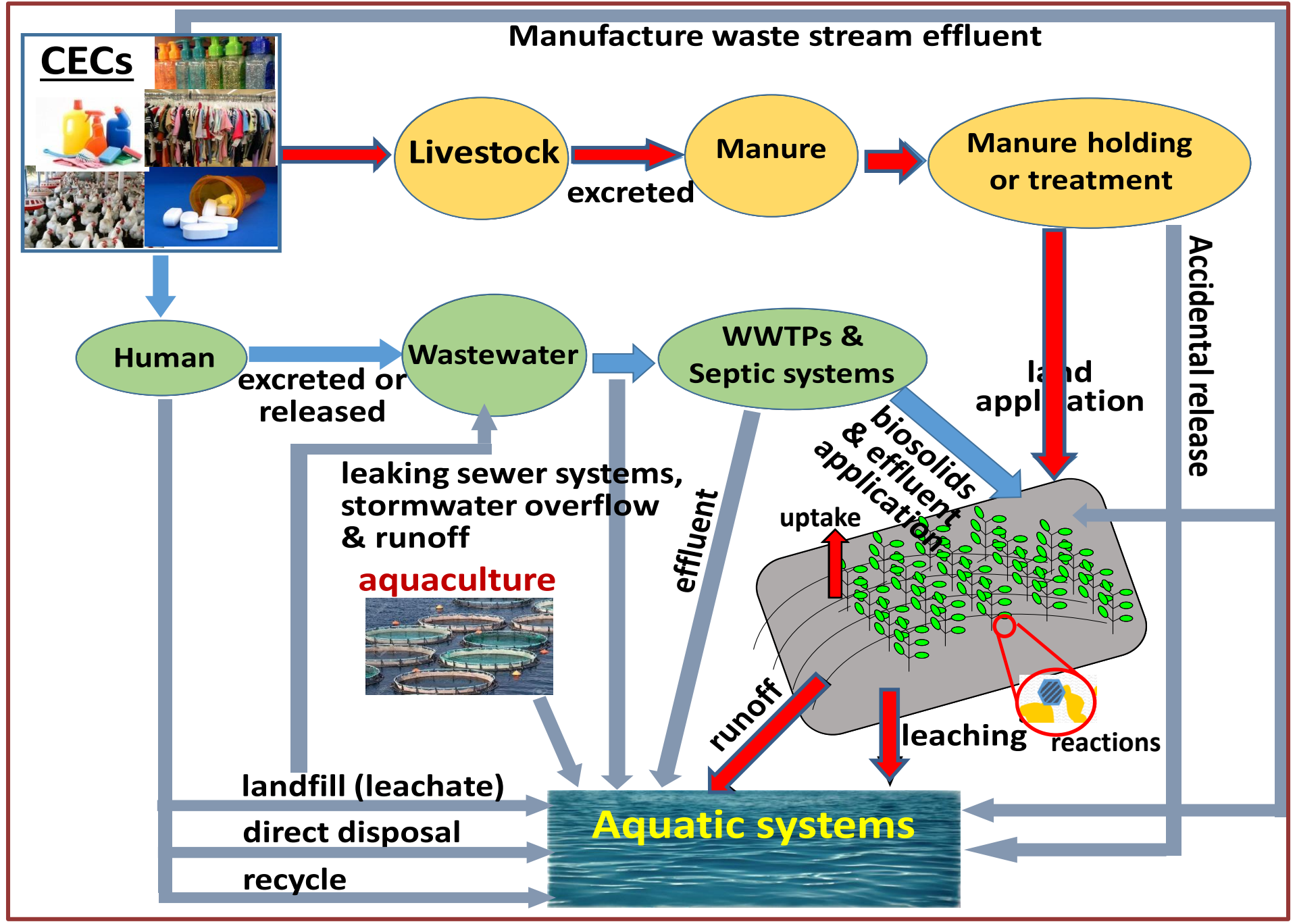


Figure 1. Major sources and pathways of CECs in the environment.

Question #1

What are the emerging contaminants associated with animal production?

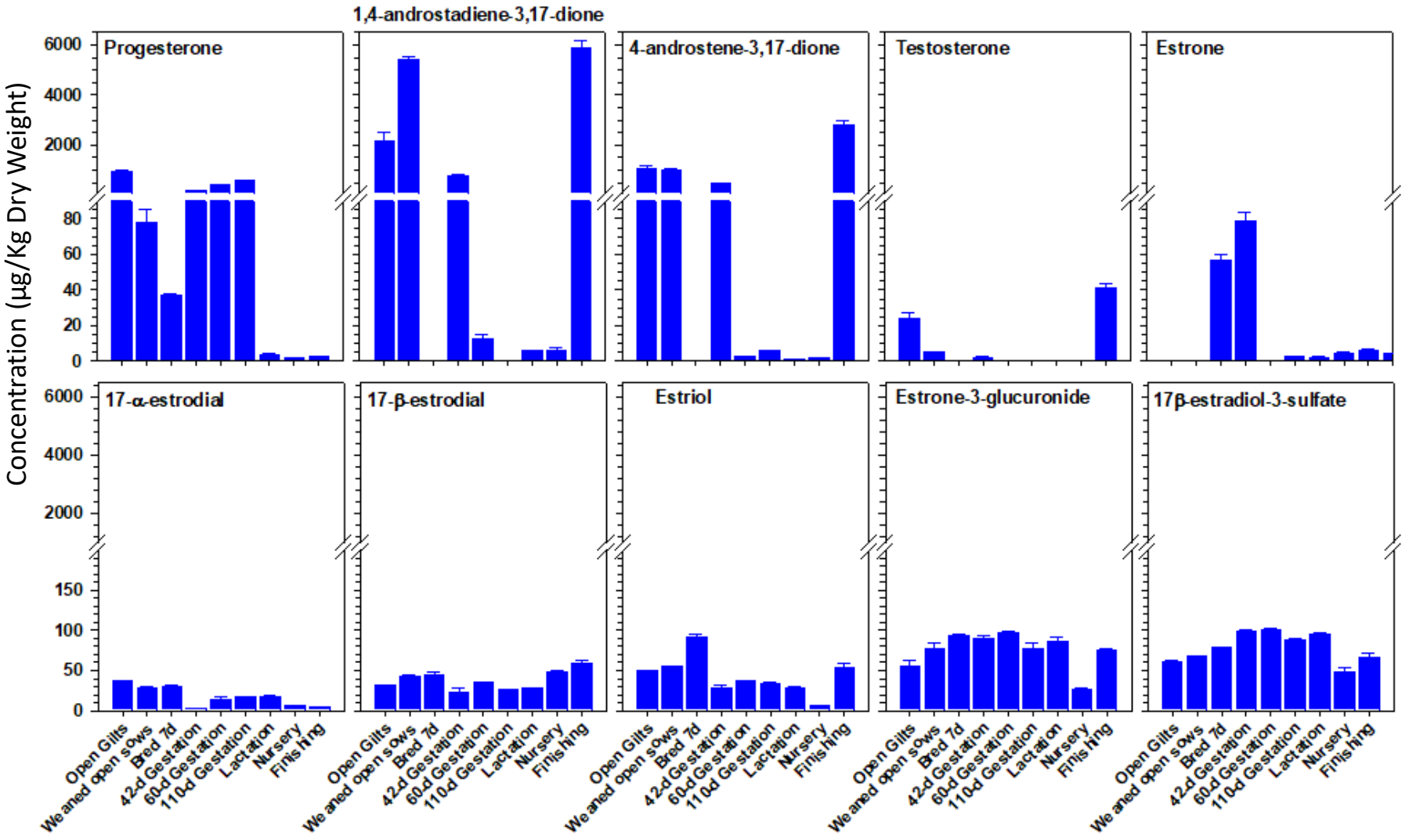
- **Hormones**
- **Antimicrobials**
  - Antimicrobial resistant microorganisms (ARM)
  - Antimicrobial resistant genes (ARGs)

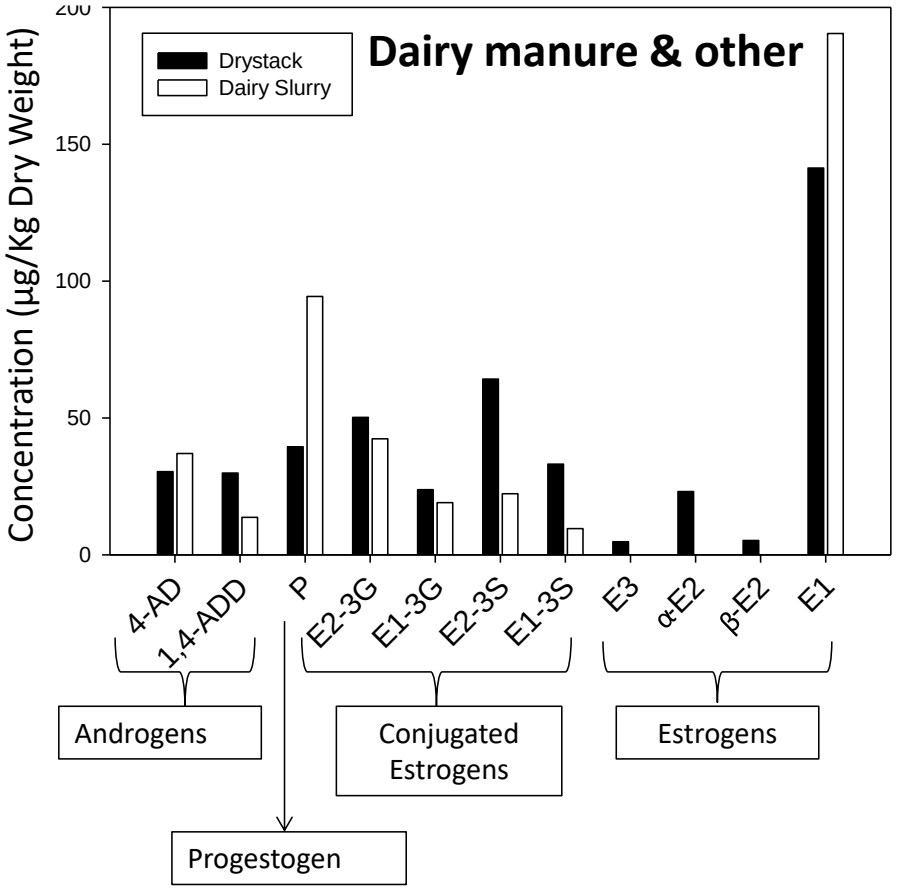
"Antibiotic resistance is one of the most critical human health challenges of the 21st century."

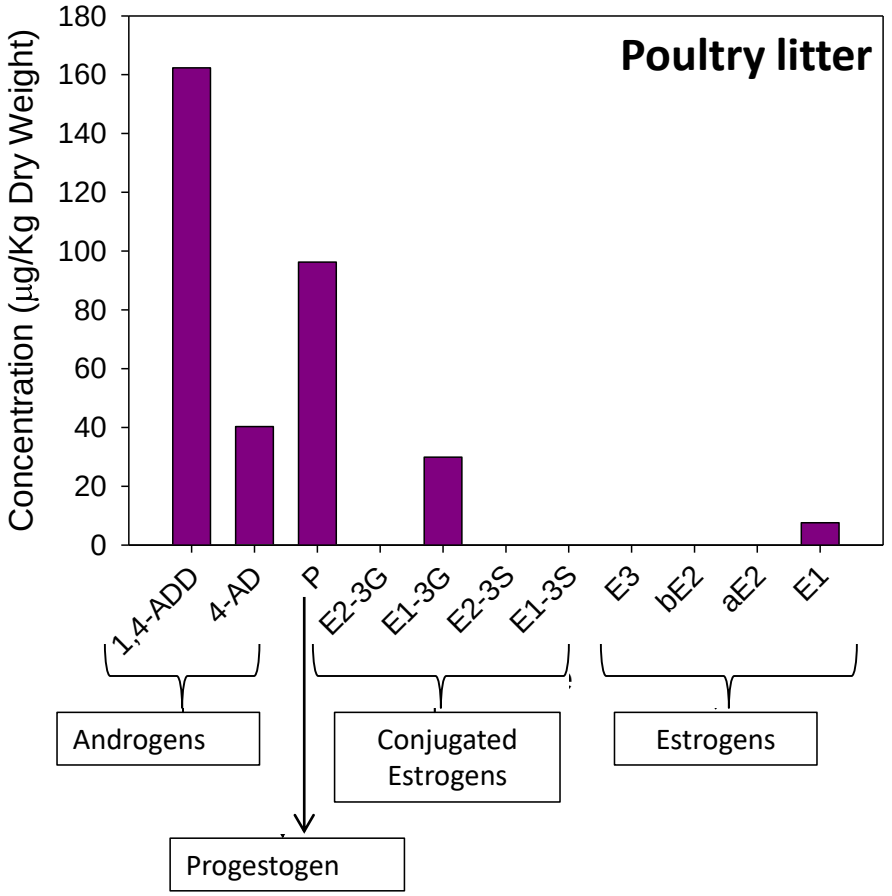
—WHO *Antimicrobial Resistance Global Report on Surveillance 2014*

Occurrence of natural hormones in animal manure

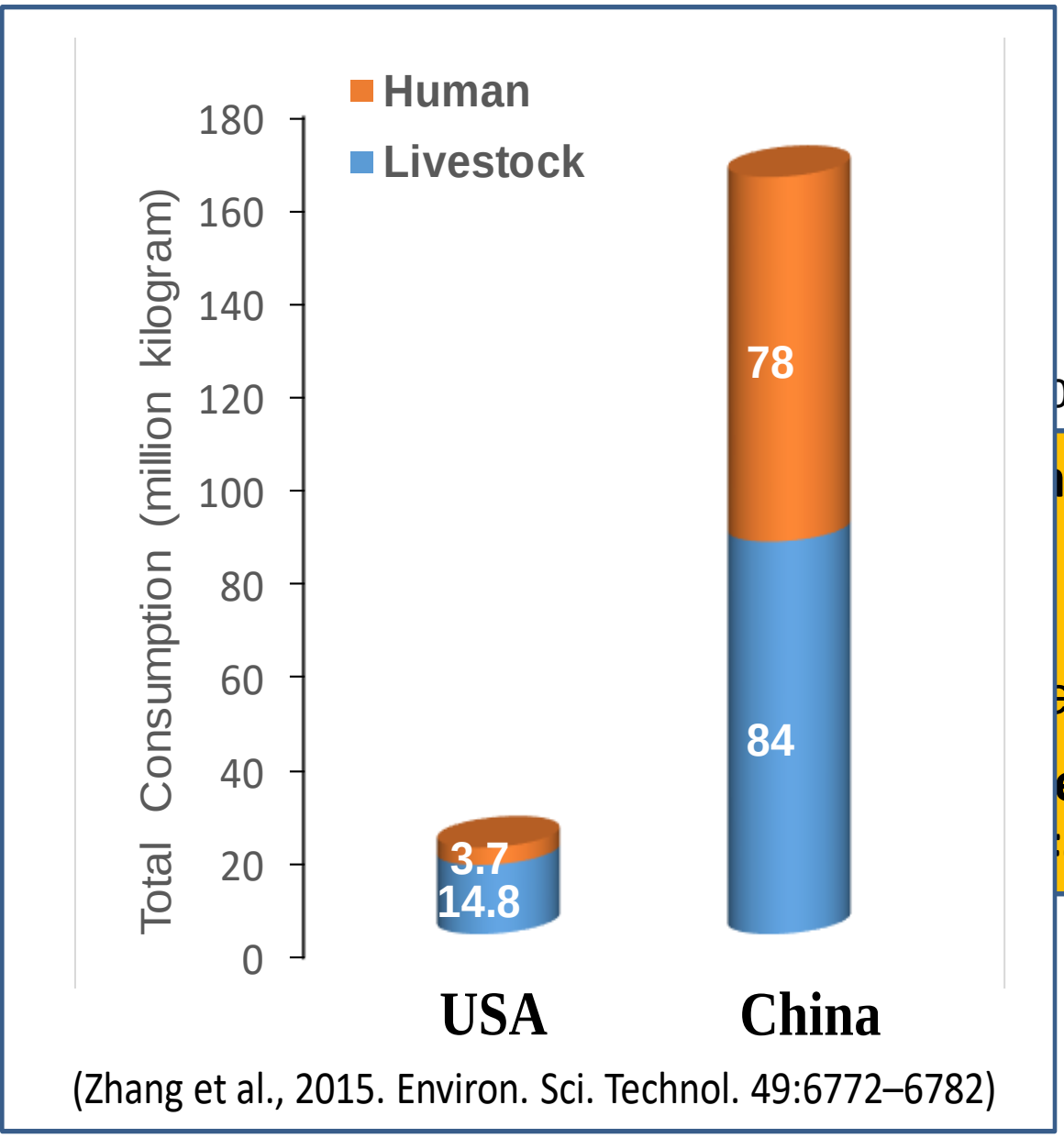
swine manure




Dairy manure & other
Drystack
Dairy Slurry
Concentration (µg/Kg Dry Weight)
200
150
100
50
0
4-AD
1,4-ADD
P
E2-3G
E1-3G
E2-3S
E1-3S
E3
α-E2
β-E2
E1
Androgens
Conjugated Estrogens
Estrogens
Progestogen


Poultry litter
Concentration (µg/Kg Dry Weight)
180
160
140
120
100
80
60
40
20
0
1,4-ADD
4-AD
P
E2-3G
E1-3G
E2-3S
E1-3S
E3
bE2
aE2
E1
Androgens
Conjugated Estrogens
Estrogens
Progestogen

Usage of antimicrobials in animal production



(Zhang et al., 2015. Environ. Sci. Technol. 49:6772–6782)

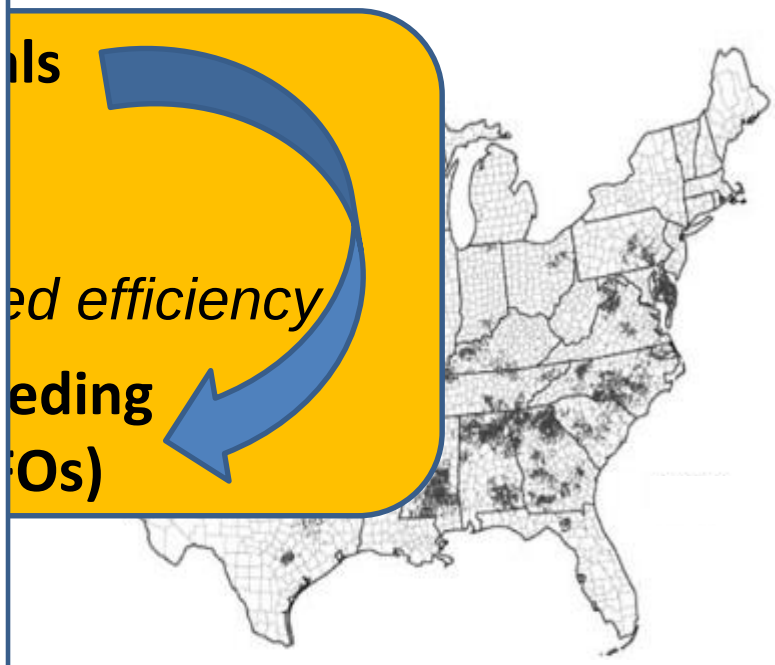
000,000 chickens/year

ls

ed efficiency

eding

Os)



Usage of antimicrobials in animal production

Antibiotics approved for domestic use in food-producing animals in the United States in 2017

	Drug Class	Annual Totals (kg)[2]	% Subtotal	% Grand Total
Medically Important[3]	*Aminoglycosides*	259,184	5%	2%
	Amphenicols	49,321	1%	<1%
	Cephalosporins[1]	29,369	<1%	<1%
	Fluoroquinolones	22,904	<1%	<1%
	Lincosamides[1]	152,497	3%	1%
	Macrolides	468,794	8%	4%
	Penicillins[1]	690,889	12%	6%
	Sulfas	274,112	5%	3%
	Tetracyclines[1]	3,535,701	64%	32%
	NIR[1,4]	76,440	1%	1%
	Subtotal	***5,559,212***	***100%***	***51%***
Not Medically Important[5]	*Ionophores*	4,394,850	82%	40%
	NIR[6]	979,306	18%	9%
	Subtotal	***5,374,156***	***100%***	***49%***
	Grand Total	***10,933,367***		***100%***

Antibiotics approved for domestic use in food-producing animals in the United States in 2015

Drug Class	Annual Totals (kg)[2]	% Subtotal	% Grand Total
Aminoglycosides[1]	344,120	2%	2%
Amphenicols	44,968	<1%	<1%
Cephalosporins[1]	32,341	<1%	<1%
Fluoroquinolones	20,063	<1%	<1%
Ionophores	4,740,615	30%	30%
Lincosamides[1]	182,543	1%	1%
Macrolides	627,770	4%	4%
Penicillins[1]	936,669	6%	6%
Sulfas	380,186	2%	2%
Tetracyclines[1]	6,880,465	44%	44%
NIR[1,4]	1,387,236	9%	9%
Subtotal	***15,576,975***	***100%***	***100%***

(FDA Annual Summary Report on Antimicrobials Sold or Distributed in 2015 for Use in Food-Producing Animals)

Occurrence of antimicrobials in animal manure

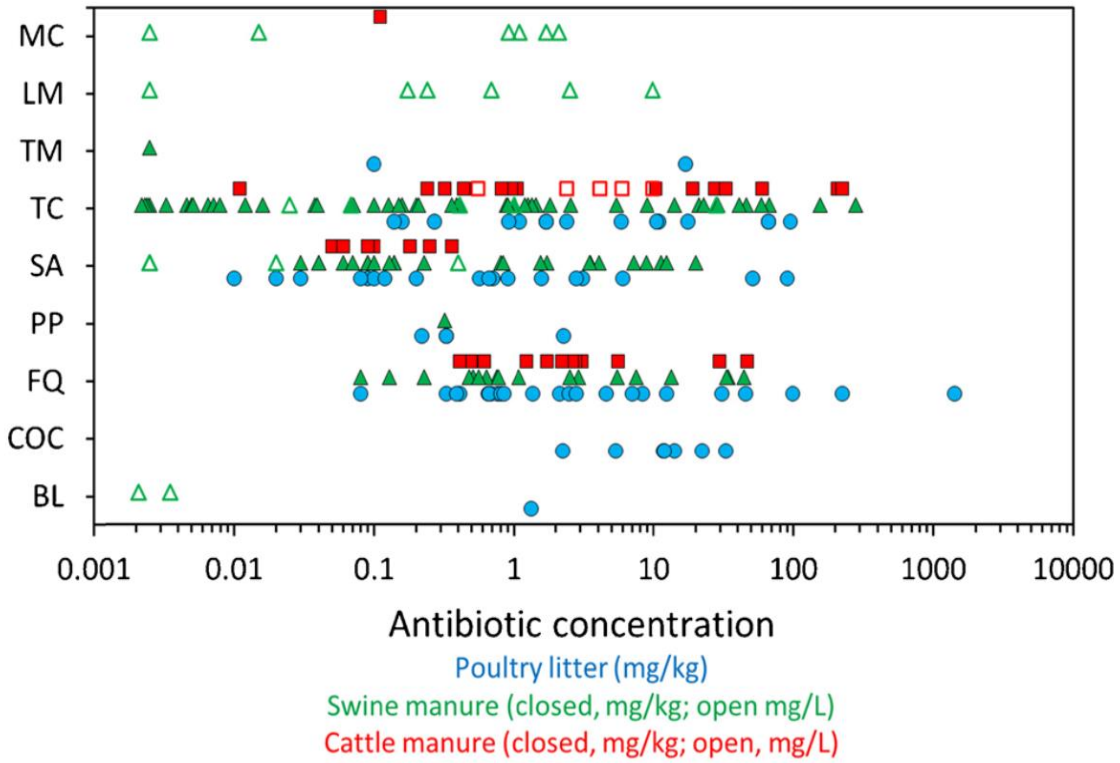


Fig. 1 Antibiotic concentrations detected in poultry, swine, and beef cattle manure. Data was aggregated from available reports [13, 16, 18, 21, 39–59]. Antibiotic class codes on the *y*-axis are as follows: *MC* macrolide, *LM* lincosamide, *TM* trimethoprim, *TC* tetracycline, *SA* sulfonamide, *PP* polypeptide, *FQ* fluoroquinolone, *COC* coccidiostat, *BL* beta-lactam. For clarity, only the minimum and maximum antibiotic concentrations from individual studies were included here. This list is not exhaustive but is meant to convey the relative antibiotic detection and concentration ranges in animal manures

(Van Epps & Blaney, 2016, Curr Pollution Rep. 2:135–155)

Occurrence of ARM in animal manure

Tested microorganisms	Compounds resistant to	Resistant microbial isolates (%)	manure	Sample #
Enterococcus spp.[1]	vancomycin	80	broiler	10
	oxytetracyline	90		
Enterococcus spp.[11]	lincomycin	99	broiler	80
	tetracycline	68		
	erythromycin	54		
	penicillin	27		
Enterococcus spp.[12]	erythromycin	2-59	swine	400
Enterococcus faecalis[14]	multi-antimicrobial	42	poultry	50
Enterococcus faecium[14]		84		
Escherichia coli[12]	multi-antimicrobial	15	swine	178
		12	chicken	90
		6	dairy cow	60

Occurrence ARGs in animal manure

The absolute abundance: 10^5 to 10^{11} gene copies g^{-1} (d.w.) in solid waste

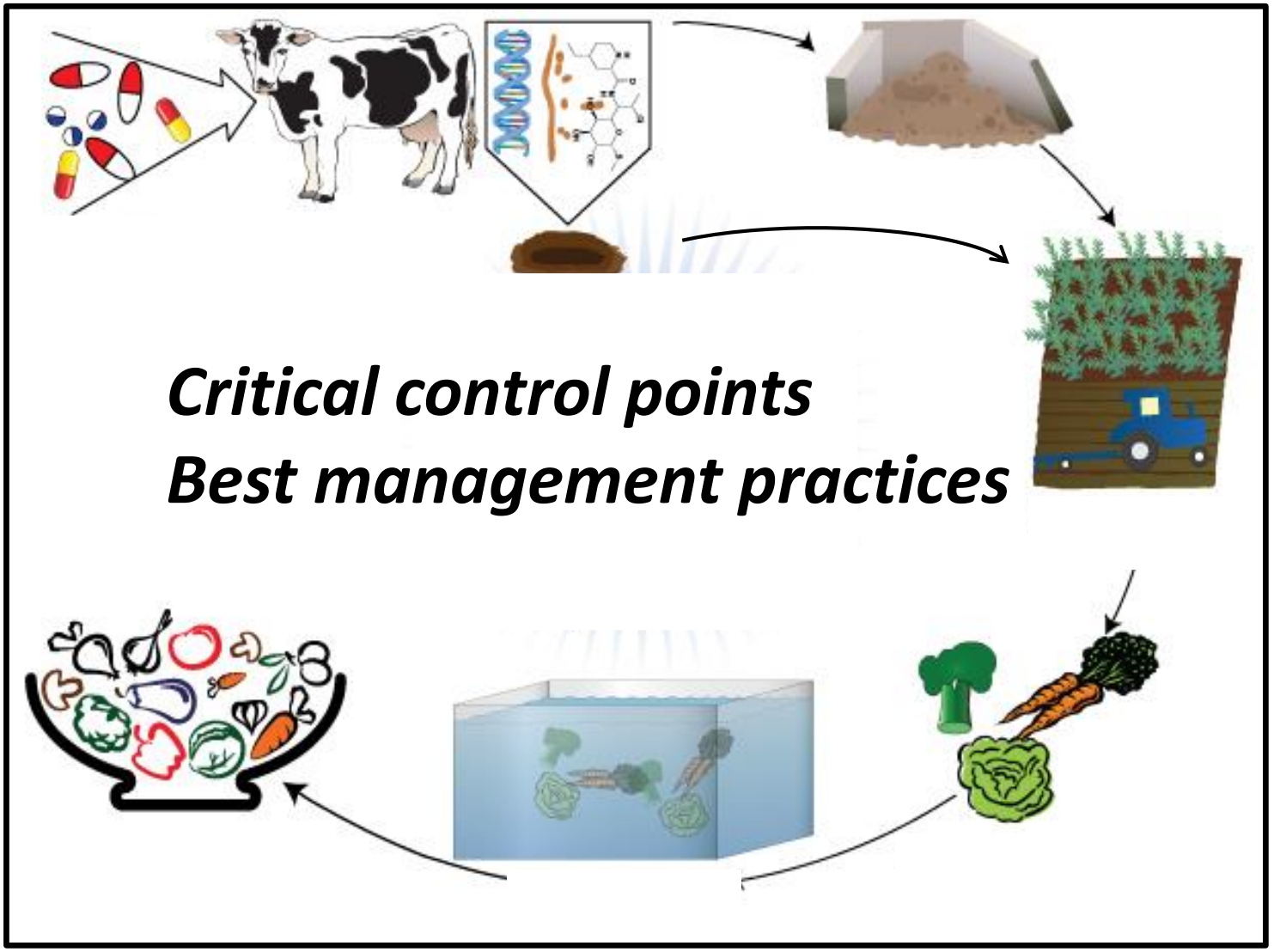
10^2 to 10^{11} copies mL^{-1} in liquid waste

Chen and Xia, 2017. Current pollution report. 3:38-54.

Question #2

What are the co-benefits of existing manure best management practices?

Farm to Fork



Major research projects *(recent 5 years)**:***

Major collaborators at Virginia Tech:

- Dr. Amy Pruden
- Dr. Peter Vicksland

} Civil and Environmental Engineering

- Dr. Leigh Anne Krometis
- Dr. Henssion Cully

} Biological System Engineering

- Dr. Katharine Knowlton (Dairy Science)
- Dr. Monica Ponder (Food Science)
- Dr. Lenwood Heath
- Dr. Liqing Zhang

} Computer Science

- Dr. Rory Maguire
- Dr. Mark Williams
- Dr. Steve Hodges

} School of Plant & Environmental Sciences

Major collaborators outside Virginia Tech:

Dr. Heather Gall (Penn State)
Dr. Peter Kleinman (USDA-ARS)

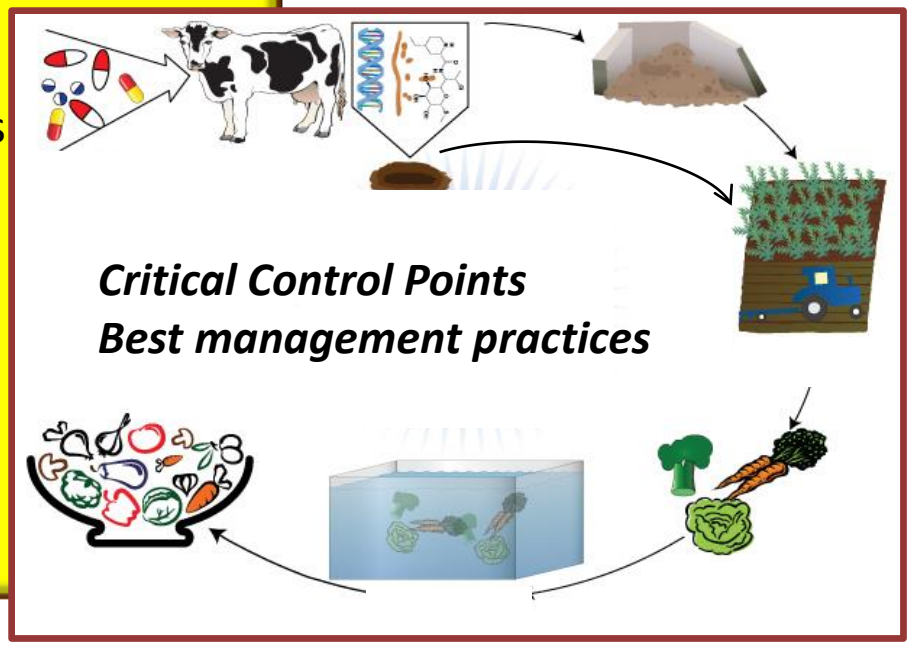
nts for Mitigating the Spread
M/3 years

Spread of ***Antibiotic***
$2.25M/3 years

USDA NIFA, $0.5M/3 years

ient Management Reduce the
s and Enhance Overall

ended with ***Animal Manure***
f Multi-scale Soil Processes –



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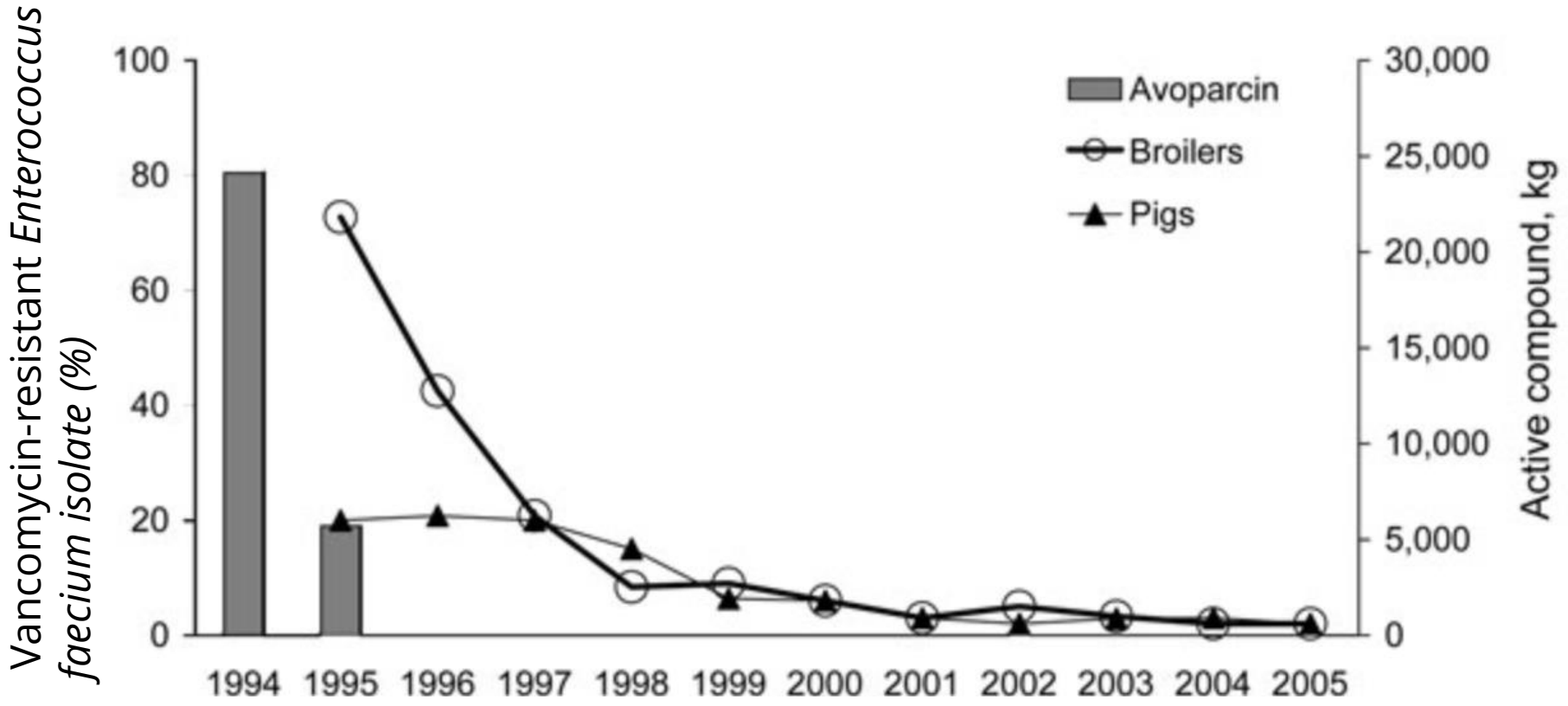
https://www.fda.gov/animalveterinary/guidancecomplianceenforcement/guidanceforindustry/ucm216939.htm

Antibiotics

therapeutic
control & prevention
} **veterinarian oversight**

~~*growth promotion/feed efficiency*~~

Concentrated feeding operations (CFOs)



Ban on avoparcin lowered the occurrence of **Vancomycin**-resistant microbial isolates from fecal samples from broiler chickens and pigs, Denmark

Hammerum et al., 2007. Emerg Infect Dis. 13:1632-1639.

PNAS | May 5, 2015 | vol. 112 | no. 18 | 5649–5654

Global trends in antimicrobial use in food animals

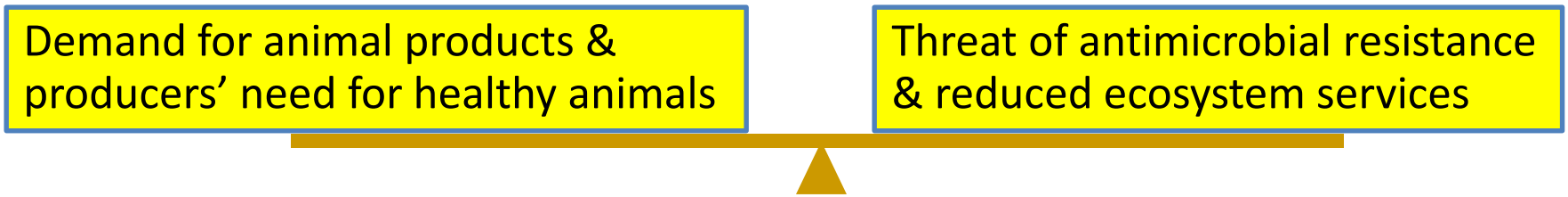
Thomas P. Van Boeckel[a,1], Charles Brower[b], Marius Gilbert[c,d], Bryan T. Grenfell[a,e,f], Simon A. Levin[a,g,h,1], Timothy P. Robinson[i], Aude Teillant[a,e], and Ramanan Laxminarayan[b,e,j,1]

Significance

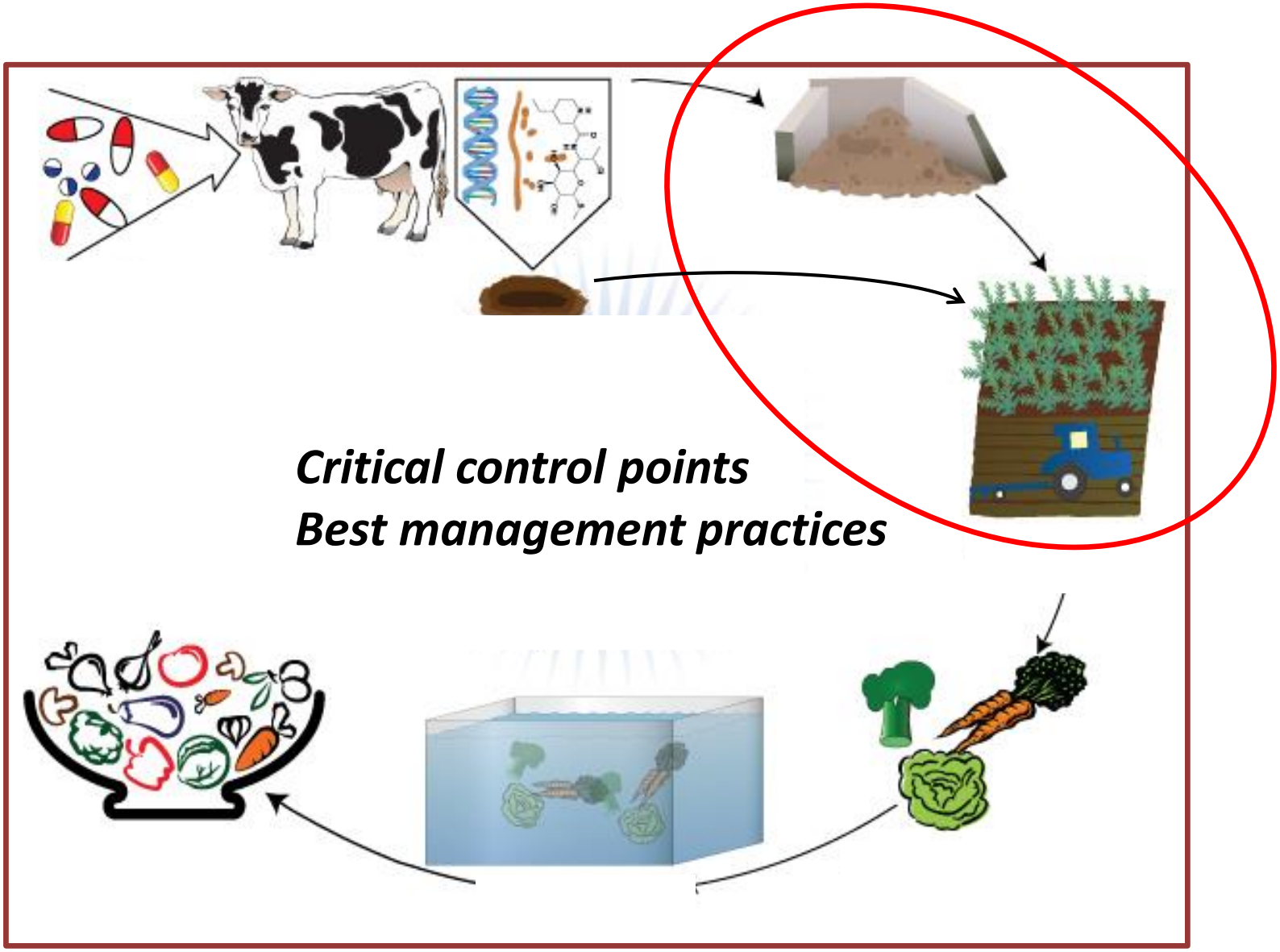
Antimicrobials are used in livestock production to maintain health and productivity. These practices contribute to the spread of drug-resistant pathogens in both livestock and humans, posing a significant public health threat. We present the first global map (228 countries) of antibiotic consumption in livestock and conservatively estimate the total consumption in 2010 at 63,151 tons. We project that antimicrobial consumption will rise by 67% by 2030, and nearly double in Brazil, Russia, India, China, and South Africa. This rise is likely to be driven by the growth in consumer demand for livestock products in middle-income countries and a shift to large-scale farms where antimicrobials are used routinely. Our findings call for initiatives to preserve antibiotic effectiveness while simultaneously ensuring food security in low- and lower-middle-income countries.

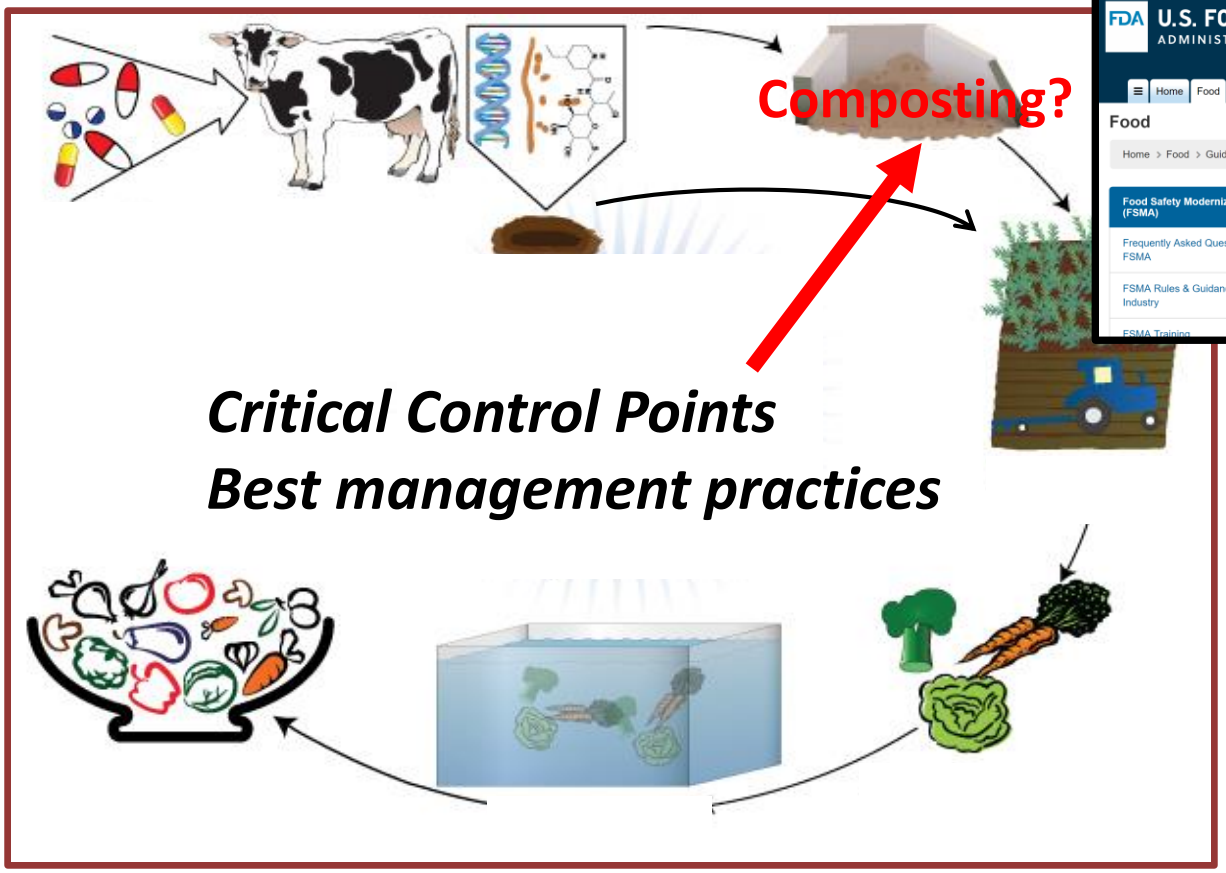
Demand for animal products & producers' need for healthy animals

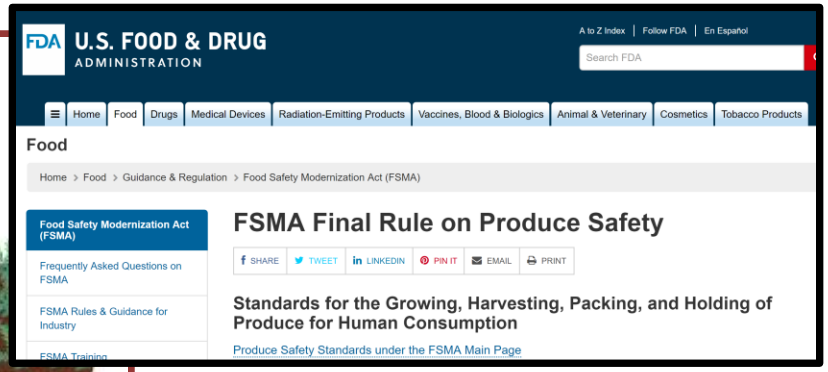
Threat of antimicrobial resistance & reduced ecosystem services



Farm to Fork - research findings at VT







USDA Organic Regulations for Manures and Manure-Based Compost 7 CFR § 205.203(c)

The NOP has very specific guidelines about manure-composting procedures.

- Raw manure must not contaminate soil, water, or crops with pathogens, excess nutrients, etc. Manure should not be applied on frozen ground.
- Raw animal manure must be composted unless it is:
  - Applied to land used for a crop not intended for human consumption;
  - Incorporated into the soil not less than 120 days prior to the harvest of a product whose edible portion has direct contact with the soil surface or soil particles; or
  - Incorporated into the soil not less than 90 days prior to the harvest of a product whose edible portion does not have direct contact with the soil surface or soil particles.

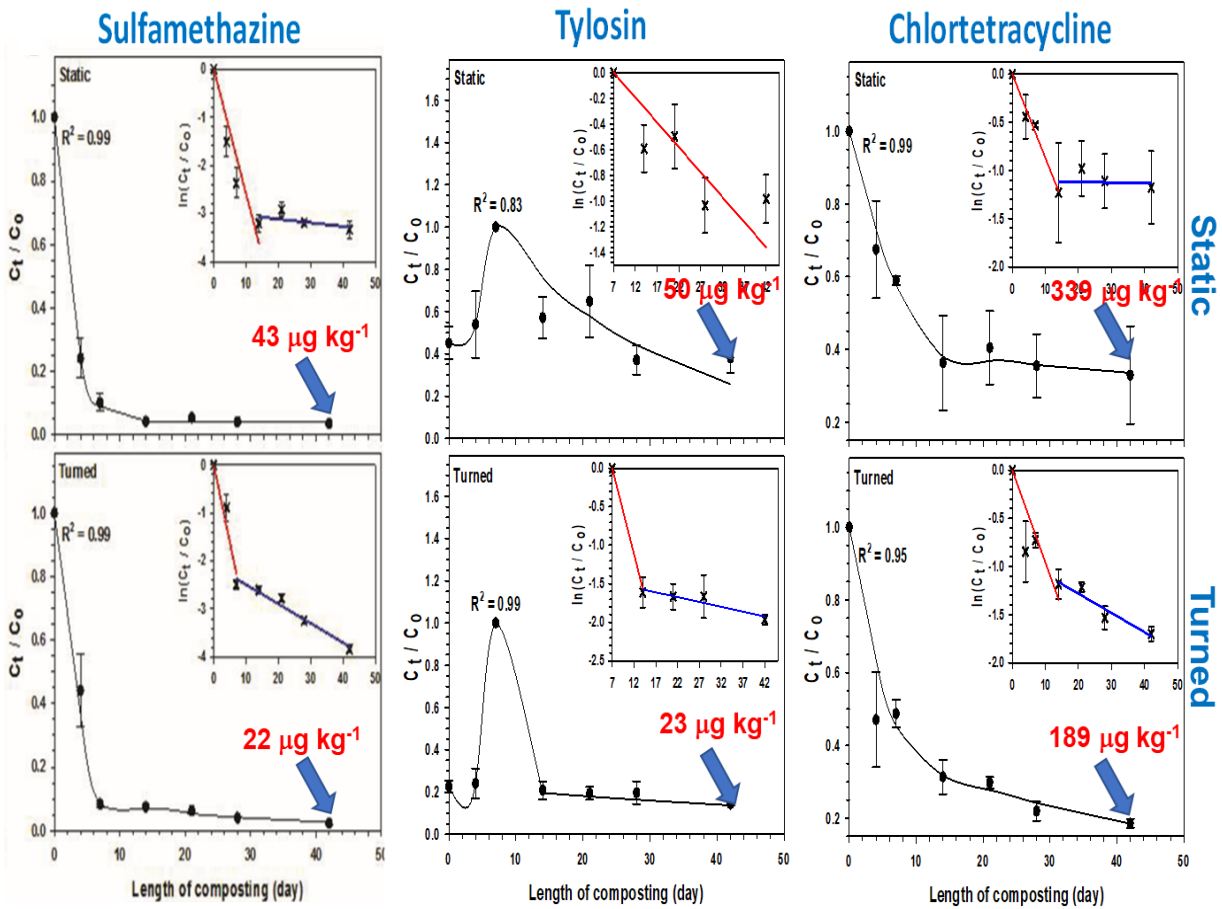
Latest US FDA Rules (FSMA) for animal manure composting:

- **Static composting** that maintains aerobic conditions at a minimum of 131°F (55°C) for **3 days** and is **followed by adequate curing**, which includes proper insulation; or
- **Turned composting** that maintains aerobic conditions at a minimum of 131°F (55 °C) for **15 days**, with a minimum of 5 turnings, and is **followed by adequate curing**, which includes proper insulation.

FDA microbial standards for composted animal manure	
L. monocytogenes	Not detected using a method that can detect one CFU per five gram analytical portion
Salmonella species	Less than three (3) MPN per four (4) grams of total solids (dry weight basis)
E. coli O157:H7	Less than 0.3 MPN per one gram analytical portion

http://www.fda.gov/downloads/Food/GuidanceRegulation/FSMA/UCM359281.pdf

- **FDMA-recommended manure composting protocols significantly reduce levels of antibiotics in composted manure - 62-99% removal by 42-d**



US FDA manure compost methods

Static

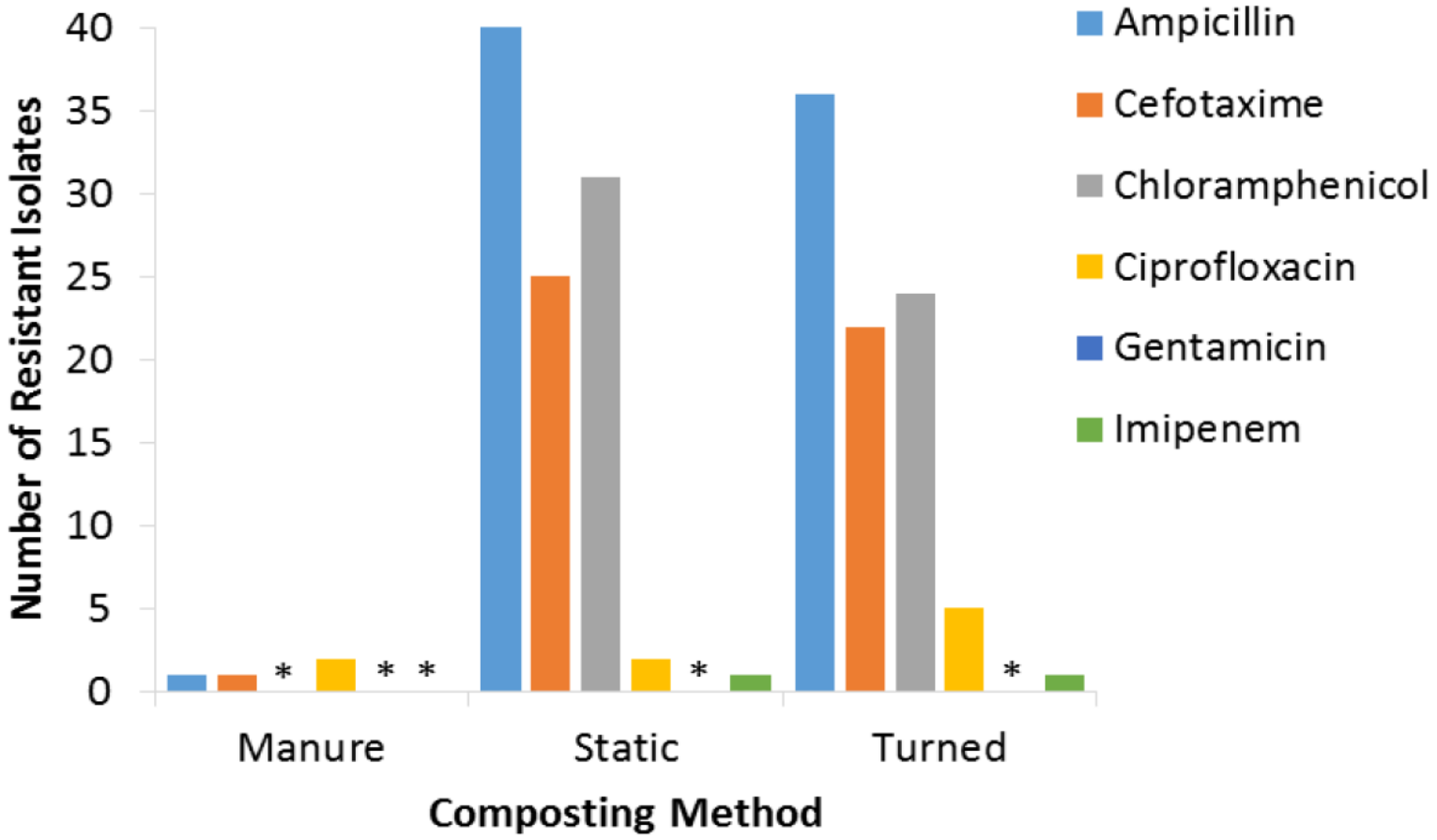
Turned

42-d small scale composting of manure from beef cattle given feed with antibiotics

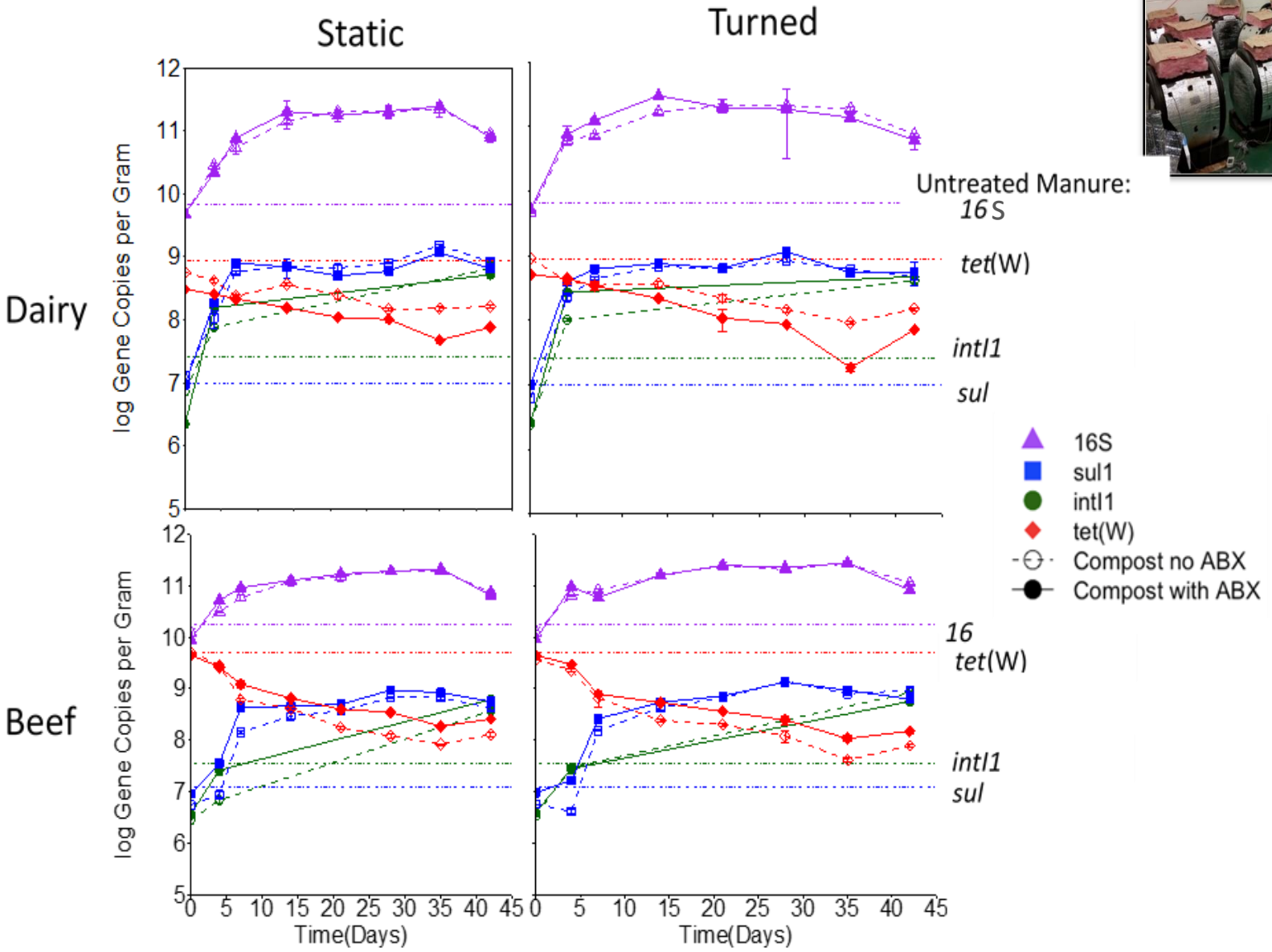
- **However, trace levels remain in the composted manure**
- **Less input of antibiotics to the environment if composted manure is applied to land comparing to raw manure**

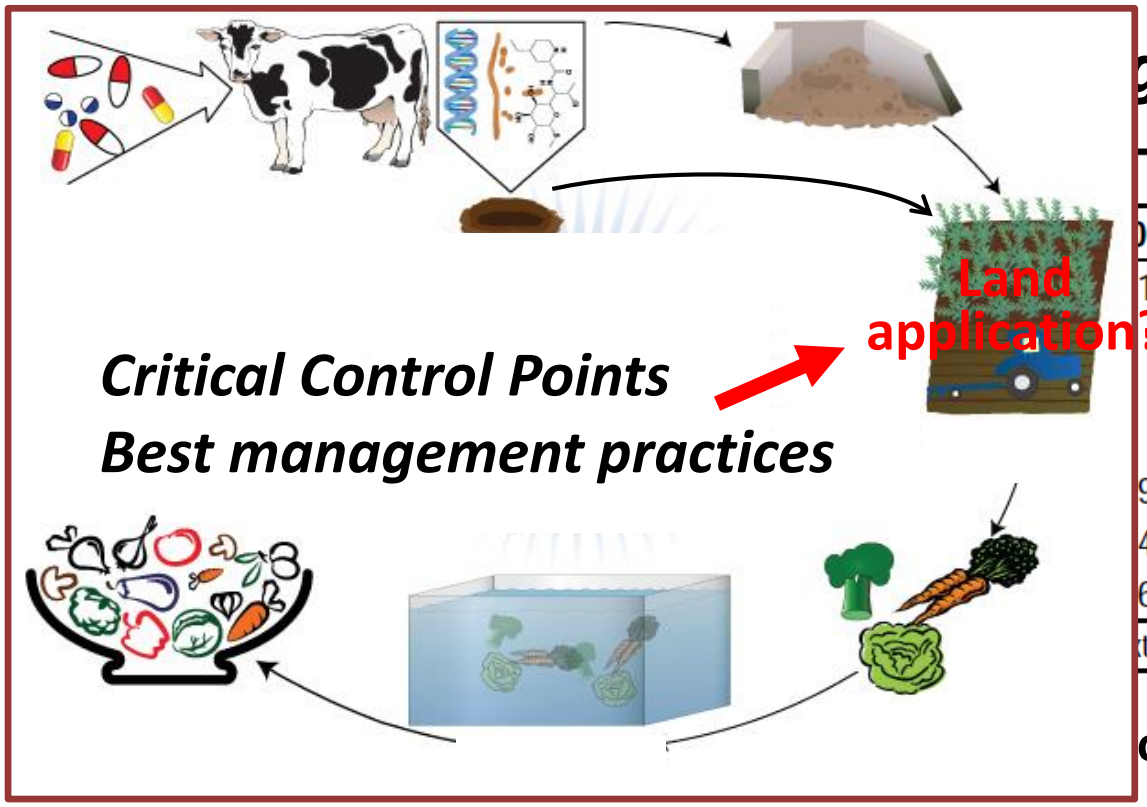
Ray et al., 2017. Journal of Environmental Quality; 46: 45-54

- **Composting increased phenotypic resistance for certain antibiotics in MacConkey isolates**



- **Mixed outcome for ARGs**
- **Composting increased *sul1* and *intI1* to above background & decreased Tet(W) to below background**





ge

005	2010	2015	2020
178	185	193	201
28	29	30	30
21	22	23	24
5	5	5	5
998	7,977	7,939	7,872
495	2,495	2,495	2,495
642	6,970	7,314	7,661

trapolation analysis.

olids generated/year:

U.S. ~ 1 billion tons dry matter

Chesapeake Bay States
~ 44 million tons dry matter

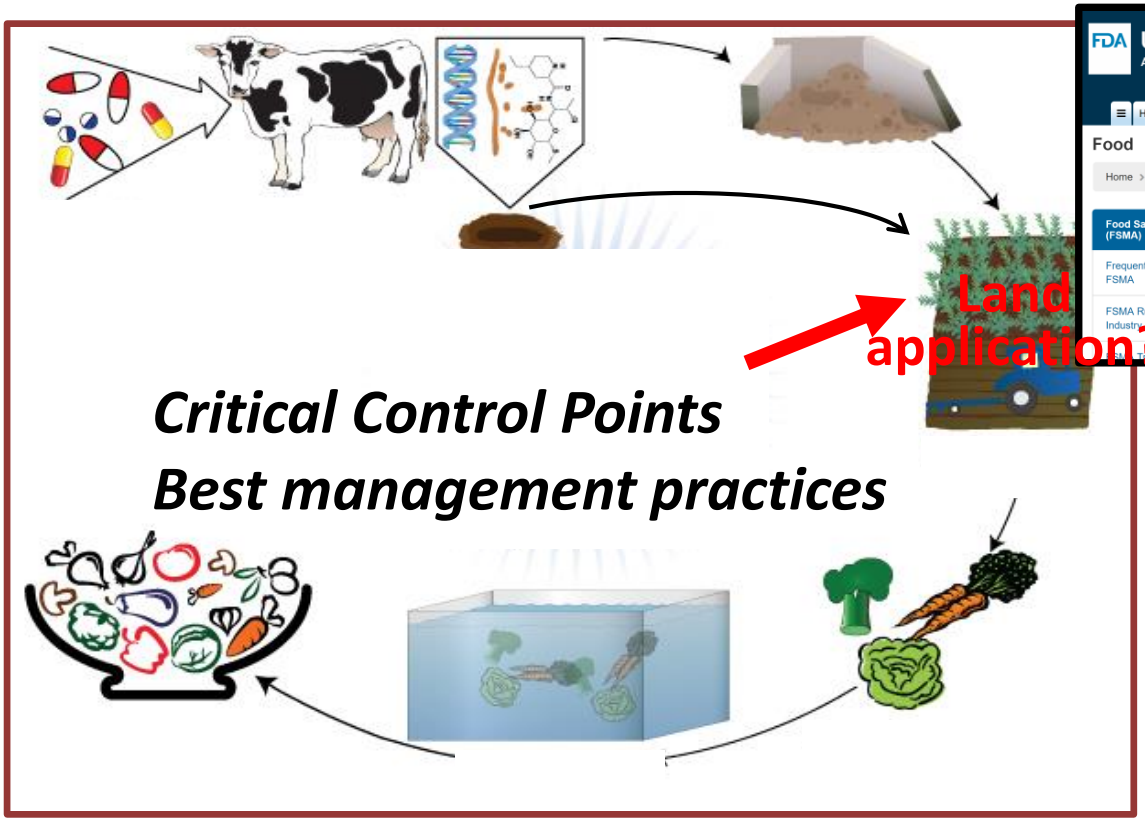
U.S. ~ 14 million tons dry matter

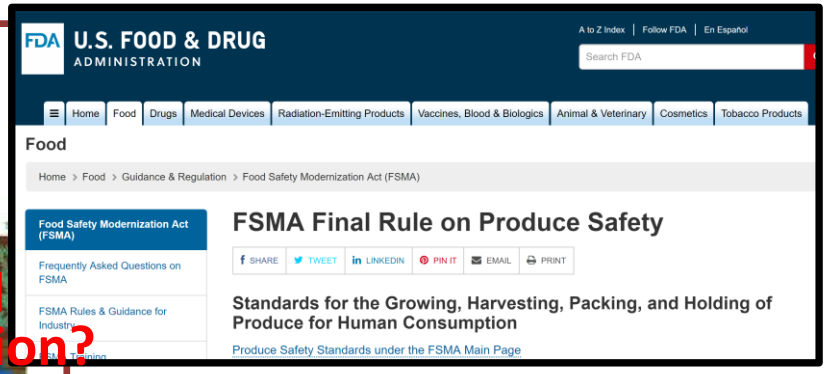
Chesapeake Bay States
~ 1.3 million tons dry matter

- **Land application of animal manure**

Manure is applied to 48% of farmland in the Chesapeake Bay States

Benefits:
- primary nutrients
- secondary nutrients
- enhance soil structure
- Soil organic matter
- C sequestration





Question: manure land application methods?

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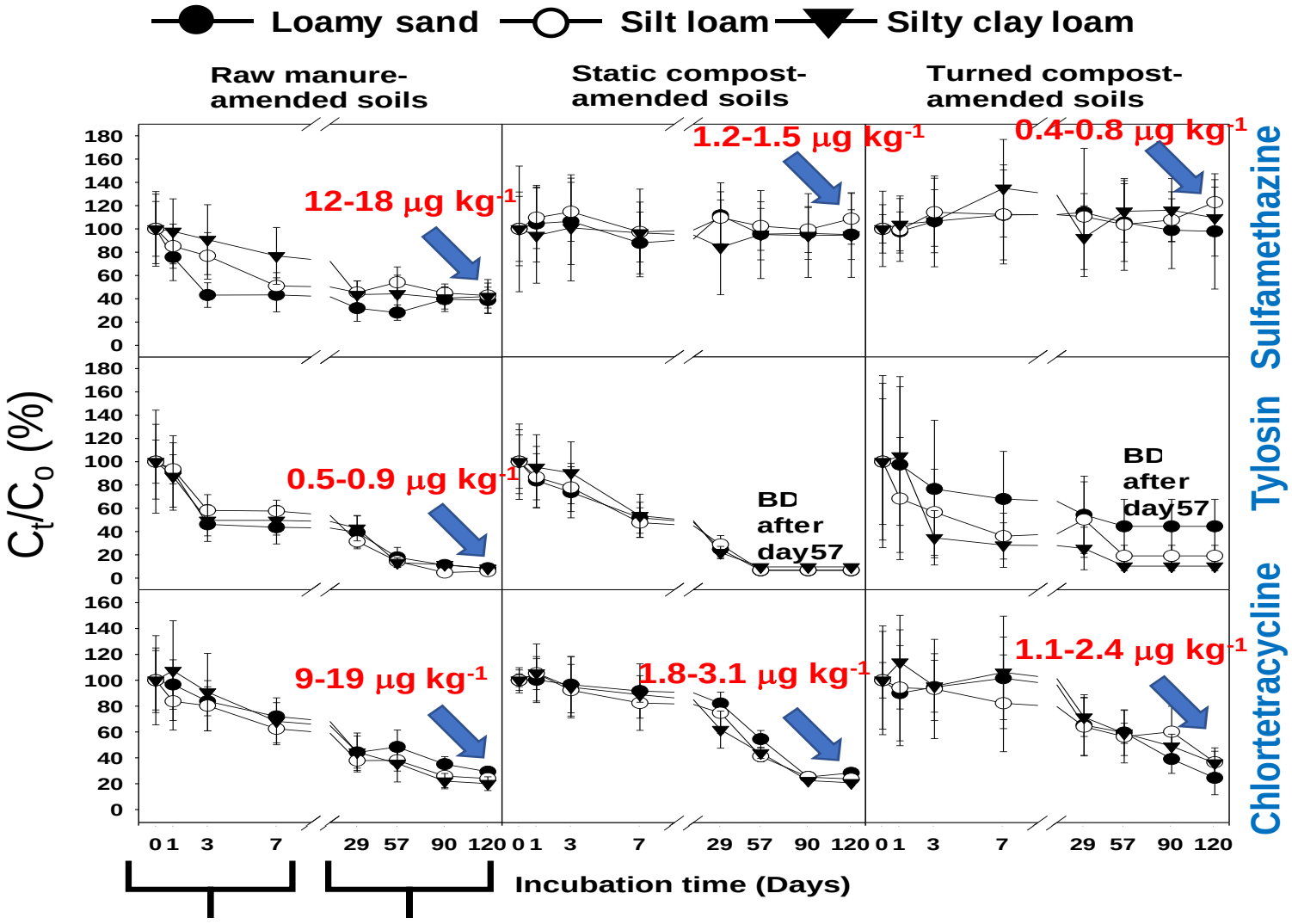
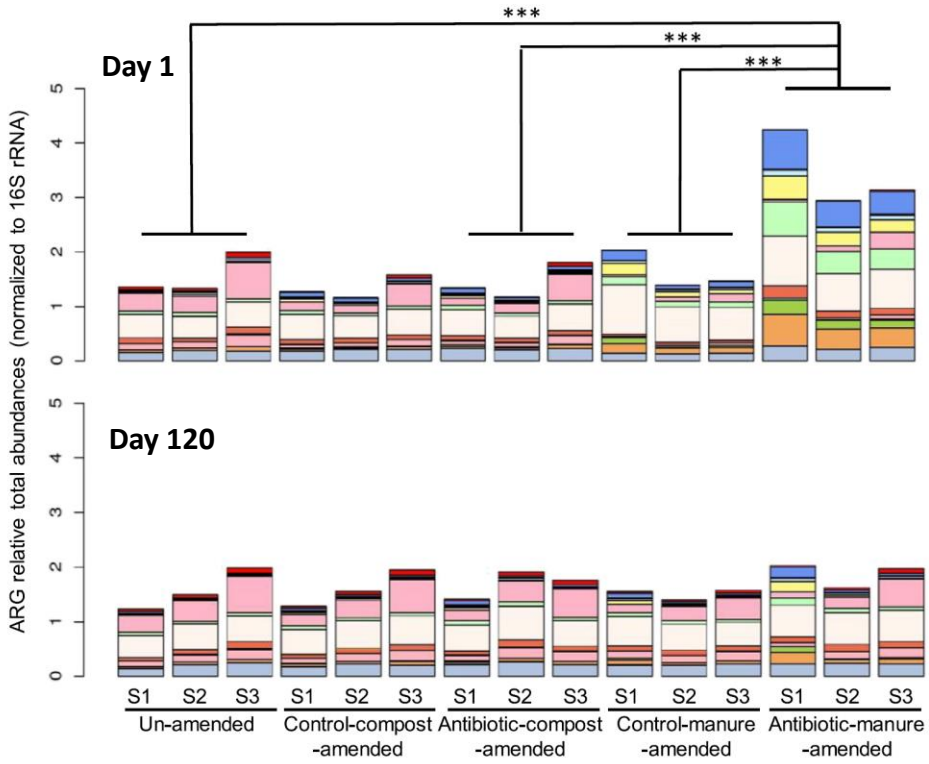
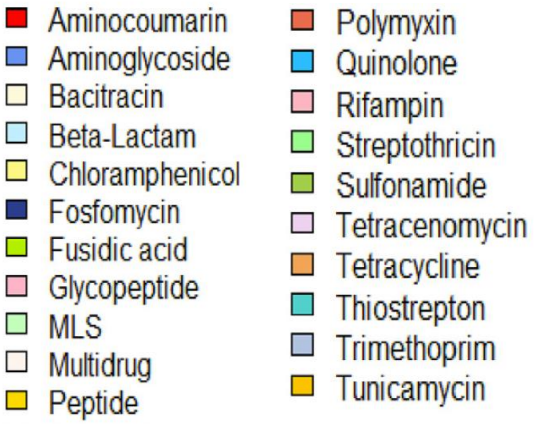
  - Incorporated into the soil not less than 90 days prior to the harvest of a product whose edible portion does not have direct contact with the soil surface or soil particles.

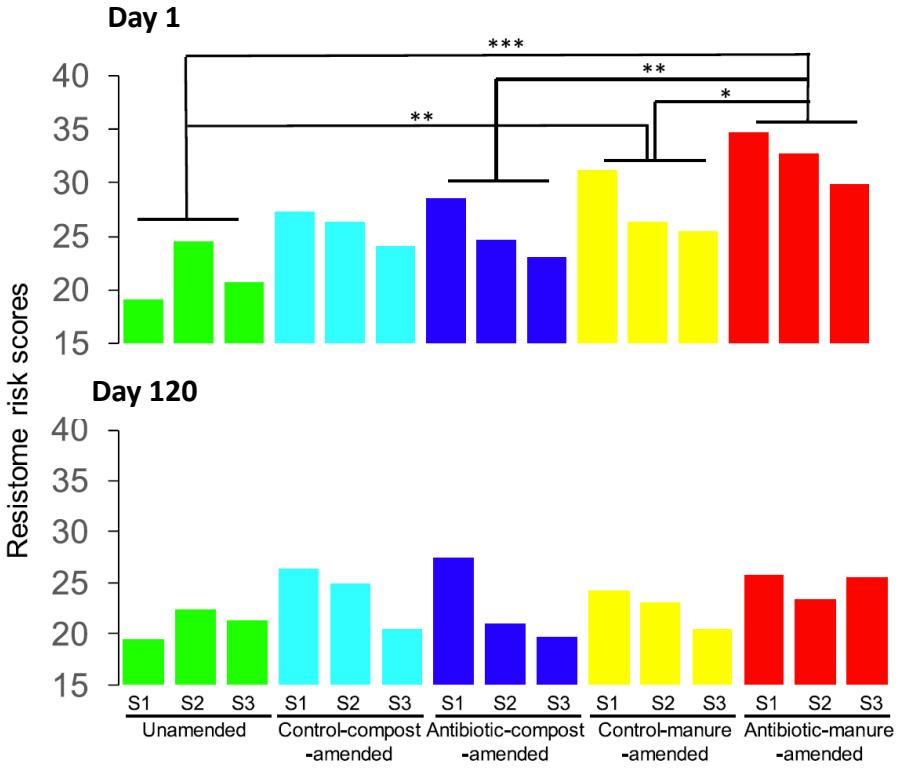
➢ **Animal manure or composted manure-associated antibiotics persist in soils at low concentrations**



(Chen et al., 2017. Chemosphere;196: 270-279)







- **ARG total abundance and antimicrobial resistome risk returned to background levels 120-d after manure or compost addition to soils**
- **120-d wait period before crop harvest is adequate**

Chen et al., 2019. Environment International 128:233–243

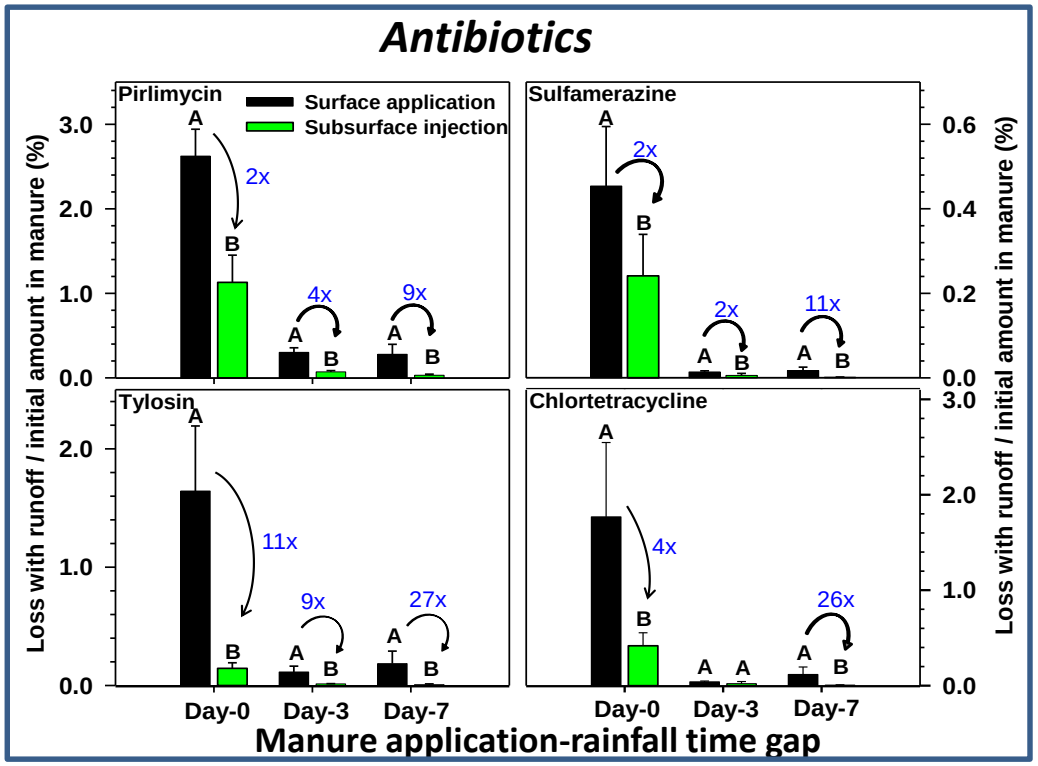
Manure land application methods – field study

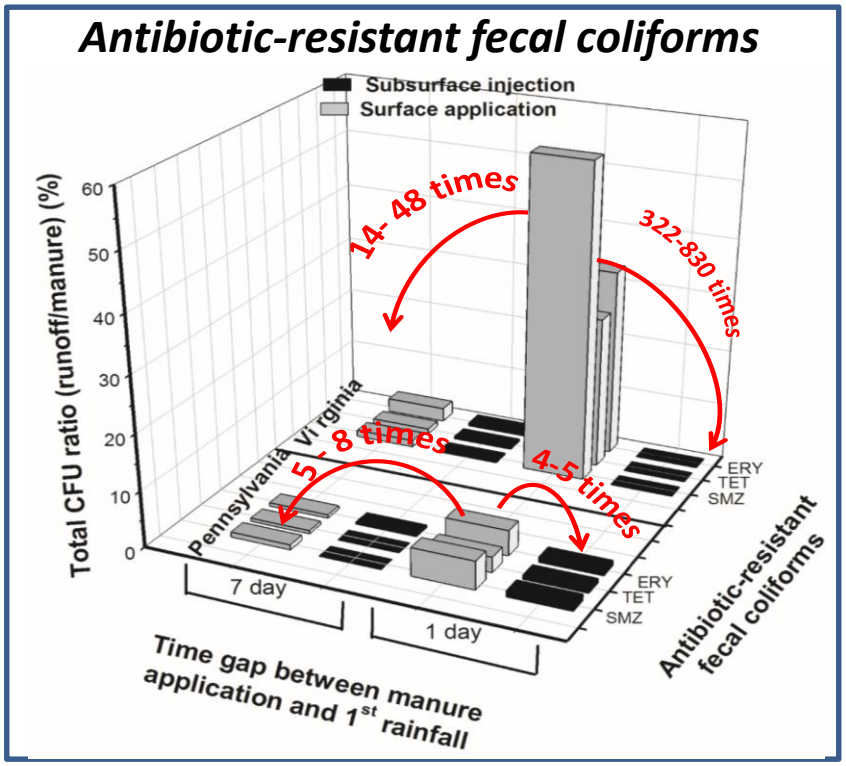
Broadcast
(surface application)

Soil incorporation
(subsurface injection)

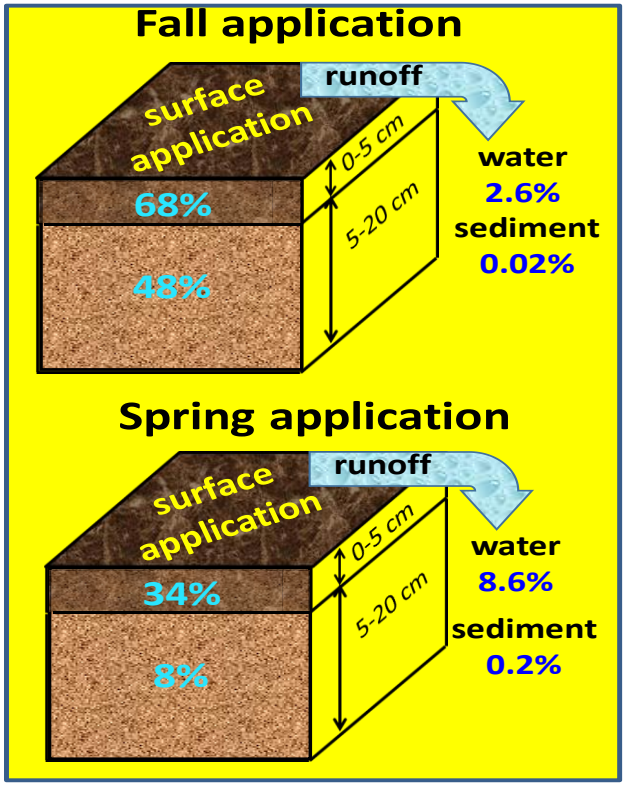
Le et al., J. Environ. Qual. 2018. 47:1310-1317
Kulesza et al., *J. Environ. Qual.* 2016. 45:511–518

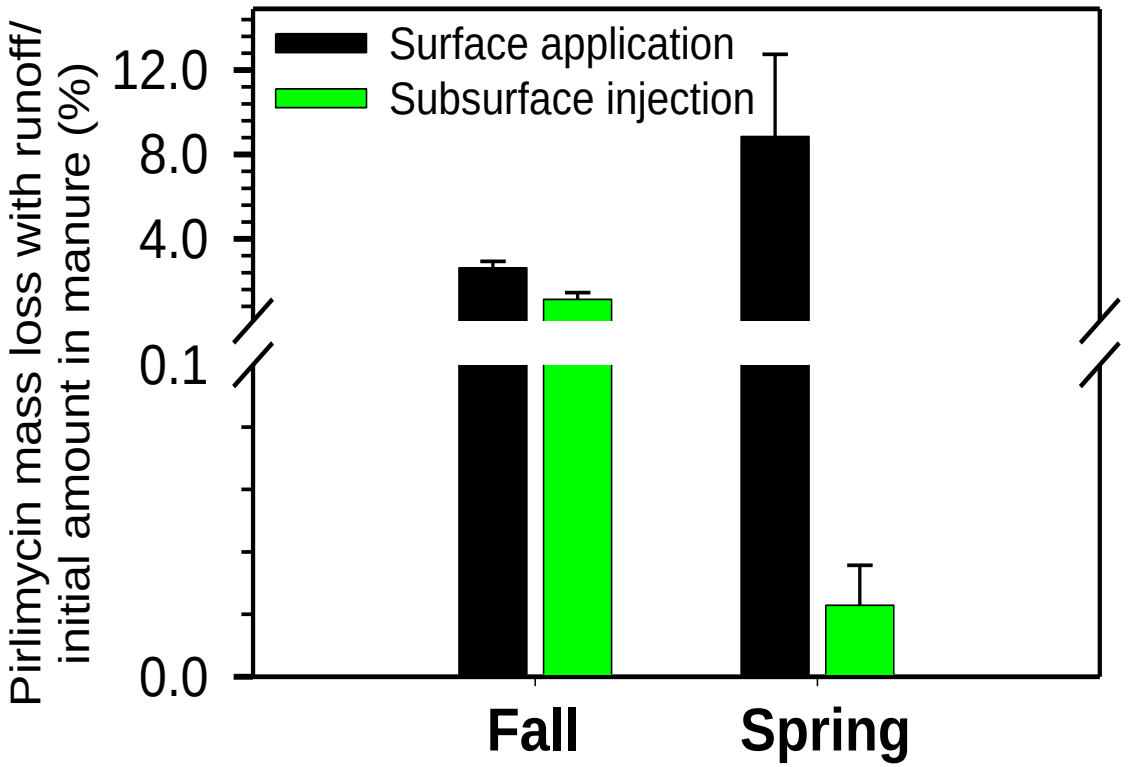
- **Manure subsurface injection reduces surface runoff of antibiotics (2-27 times) and ARB (4-830 times)**



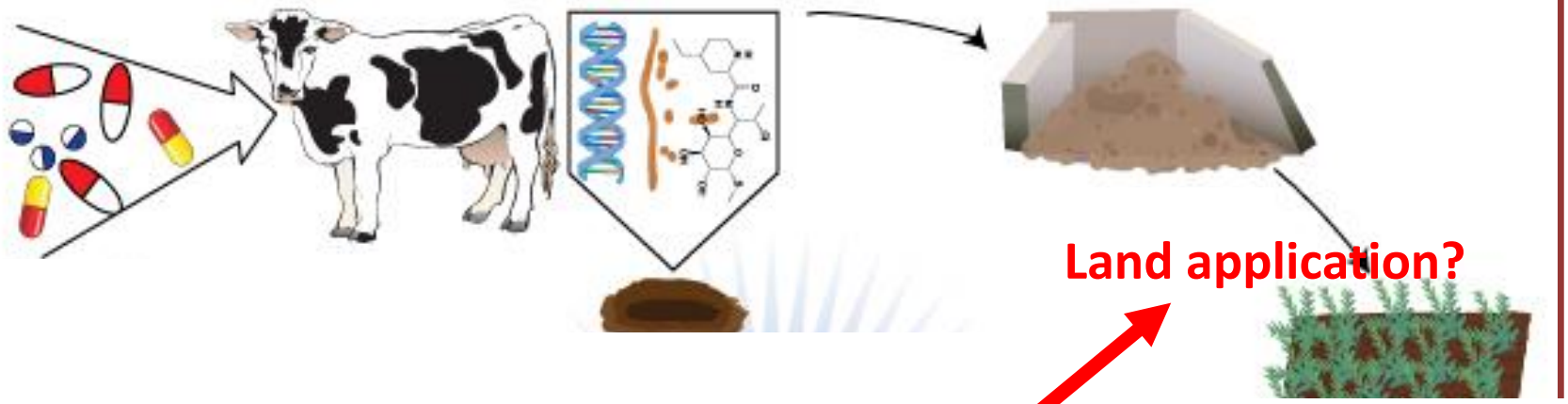


- **Manure surface application – less surface runoff if applied in fall**
- **Benefit of manure subsurface injection is more for spring application**



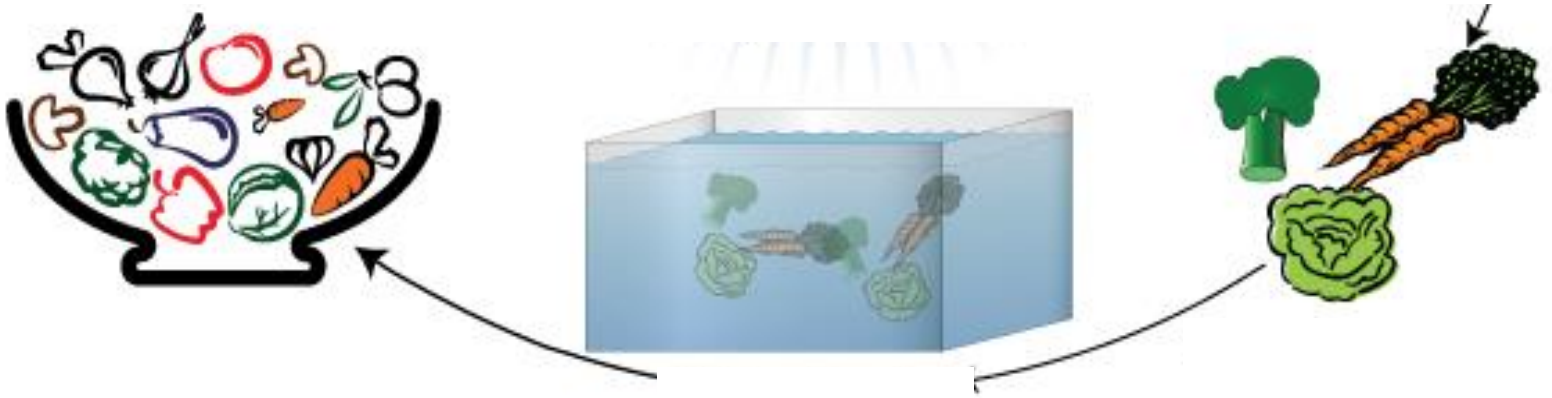


Farm to Fork - research findings

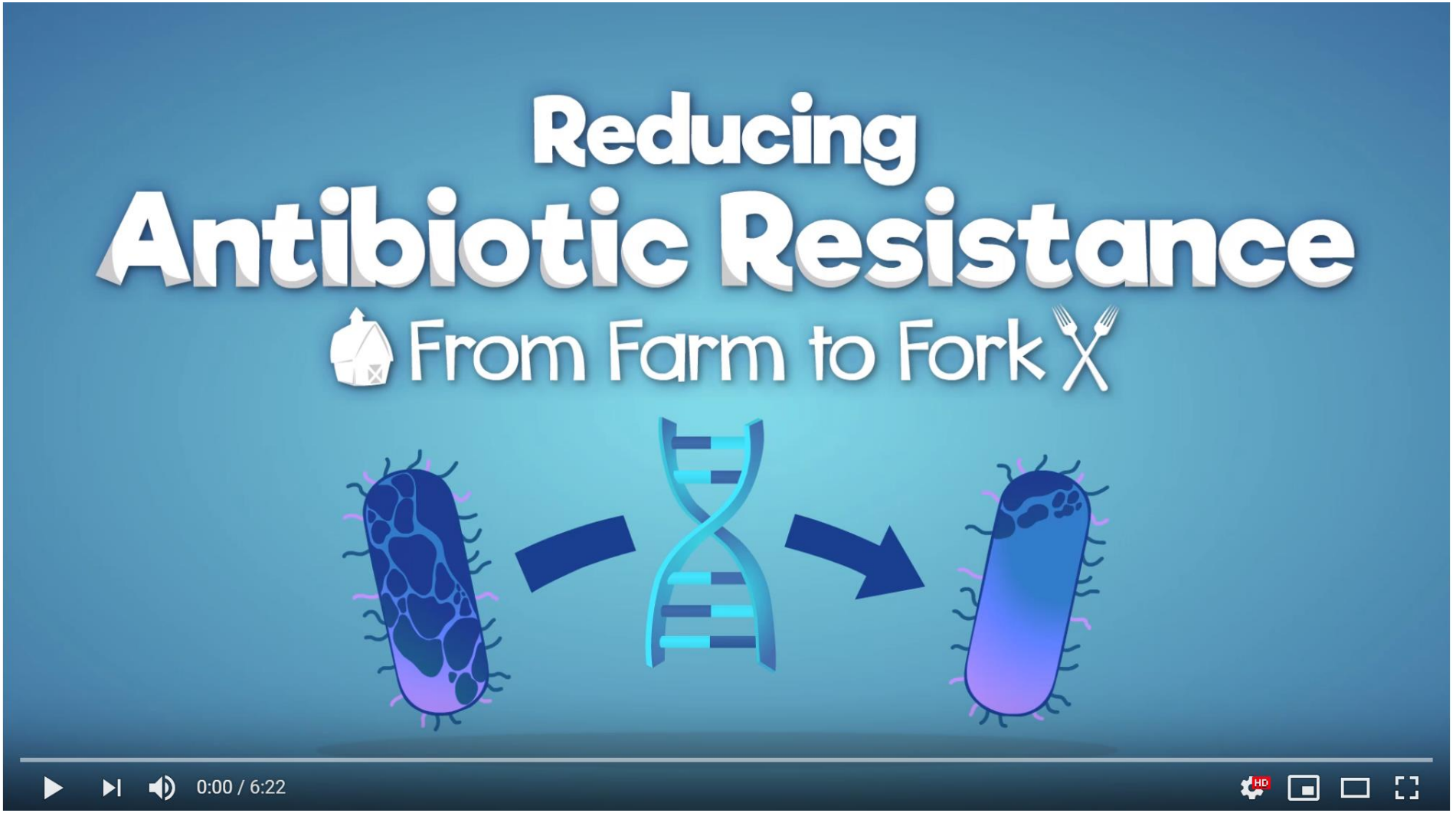


BMP? – apply compost

- ***– 120 d harvest waiting period if raw manure is applied***
- ***– manure surface application at > 3 days before a rain event***
- ***– surface application in fall instead of spring***
- ***– subsurface injection is the best option***
- ***– buffer strips***



It all boils down to:



https://youtu.be/ob4NmLmhFTE

Acknowledgements

- Graduate students & postdoc researchers
- Collaborators

- USDA-NIFA award #2013-67019-21355
- USDA-NIFA award #2014-05280
- USDA-NIFA award # 2017-67019-26401
- USDA-NIFA award #2017-68003-26498

- College of Agriculture and Life Sciences, Virginia Tech

Thank you!

Questions?