The Composting Process

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NC Composting Council

STATE CHAPTER OF THE U.S. COMPOSTING COUNCIL

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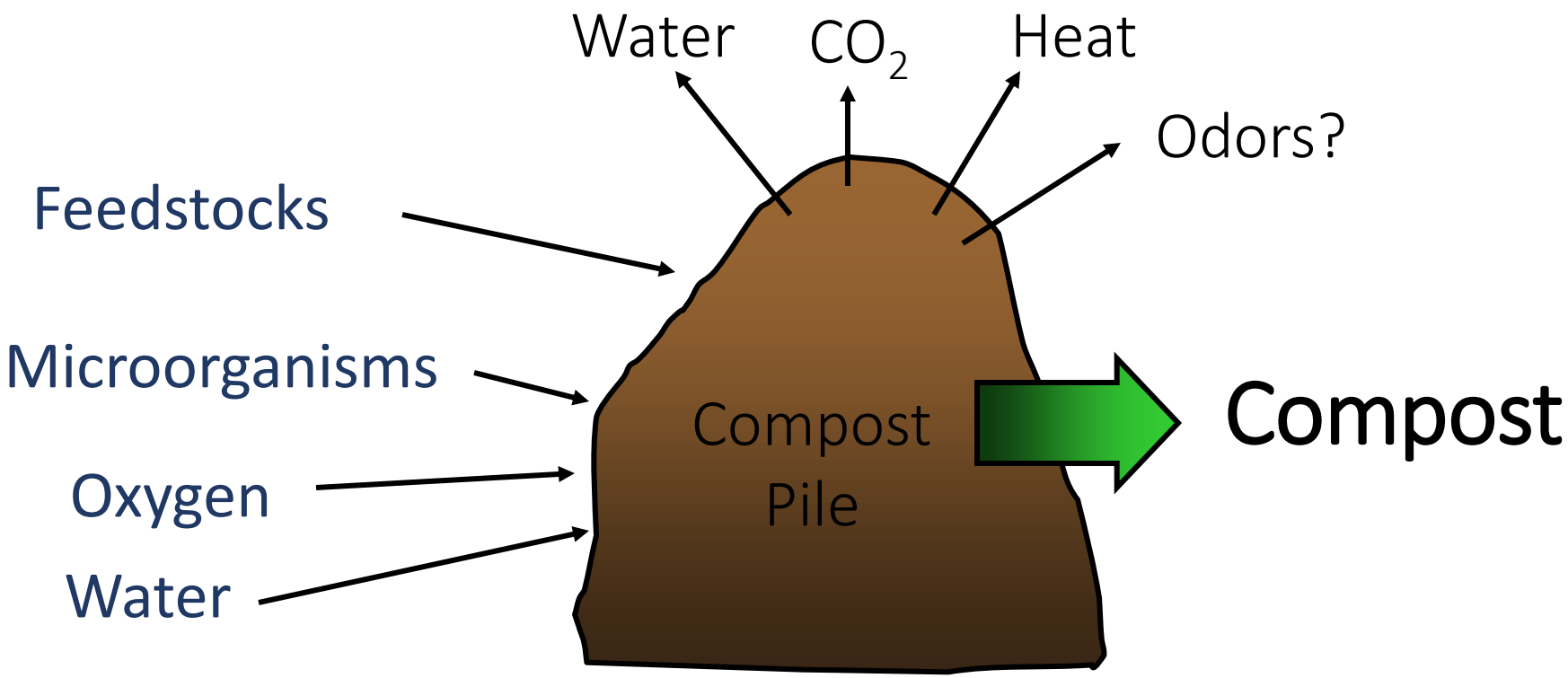


How Many Microbes?

~3 trillion!

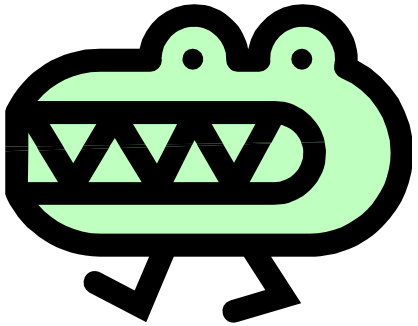
Why Does Composting Happen?

- **Microbes** consume feedstocks to obtain energy & nutrients
- Their activity creates heat
- Heat gets trapped in pile
  - Accelerates process

What Microbes Need

- ***Carbon*** (*sugars*) fuels their metabolism
- ***Nitrogen*** (*protein*) makes enzymes used in decay process
- ***Moisture*** transports and supports life functions
- ***Oxygen***
- ***Hospitable environment***

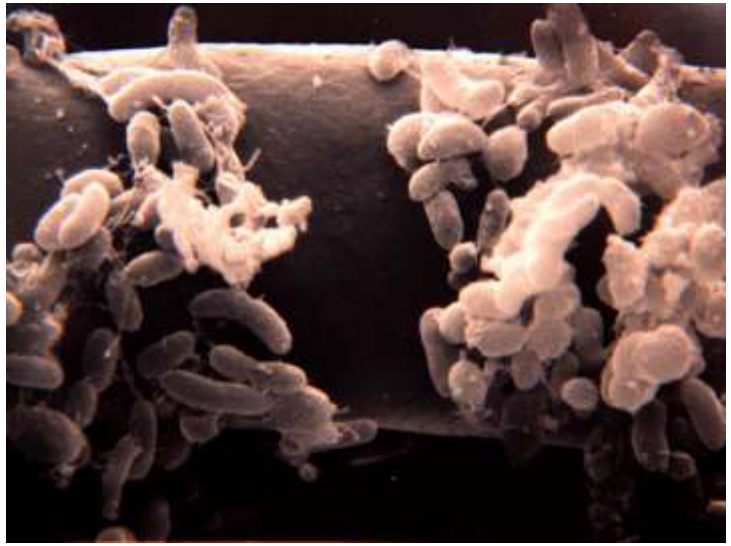
How Microbes ‘Eat’



- Secrete enzymes to dissolve organics
- Enzymes are specialized proteins that break chemical bonds
- Only relatively small organic compounds can cross cell membrane

Microorganisms Involved in the Composting Process

- Bacteria
- Fungi
- Actinomycetes
- Protozoa
- Rotifers



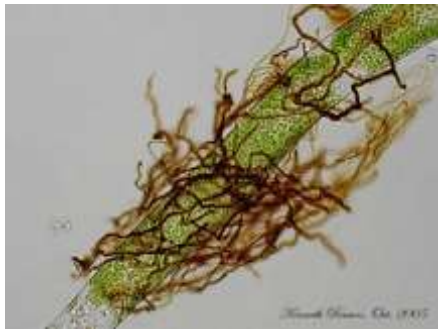
Bacteria

- Smallest living organisms
  - 250,000 – 500,000 fit inside a period!
- 1 teaspoon soil has 100 million – 1 billion
- Consume simple carbon compounds
- 80-90% of microbes in compost pile
- Responsible for most of decomposition and heat generation in compost

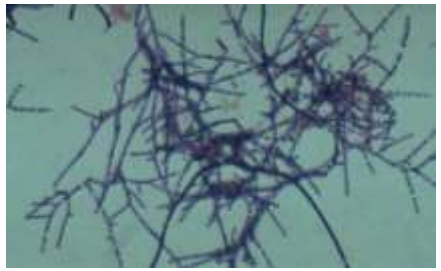
Fungi

- Molds, yeasts, mushrooms
- Numerous during mesophilic phases
- When temperatures are high, most fungi live in outer layer of compost
- Break down tough organic debris
  - Cellulose, hemicellulose, lignin
- Can decompose materials too dry, acidic, or low in nitrogen for bacterial activity

Actinomycetes



- Cause earthy smell
- Bacteria with filaments (resemble fungi)
- Look like gray spider webs
- Degrade cellulose, lignin, chitin, proteins
  - Bark, woody stems, paper
- Live in wider range of pH than other bacteria
- Some species in thermophilic phase, others in curing phase



Protozoa

- One-celled microscopic animals
- Live in water droplets in compost
- Play minor role in decomposition
- Feed on organic matter, bacteria and fungi

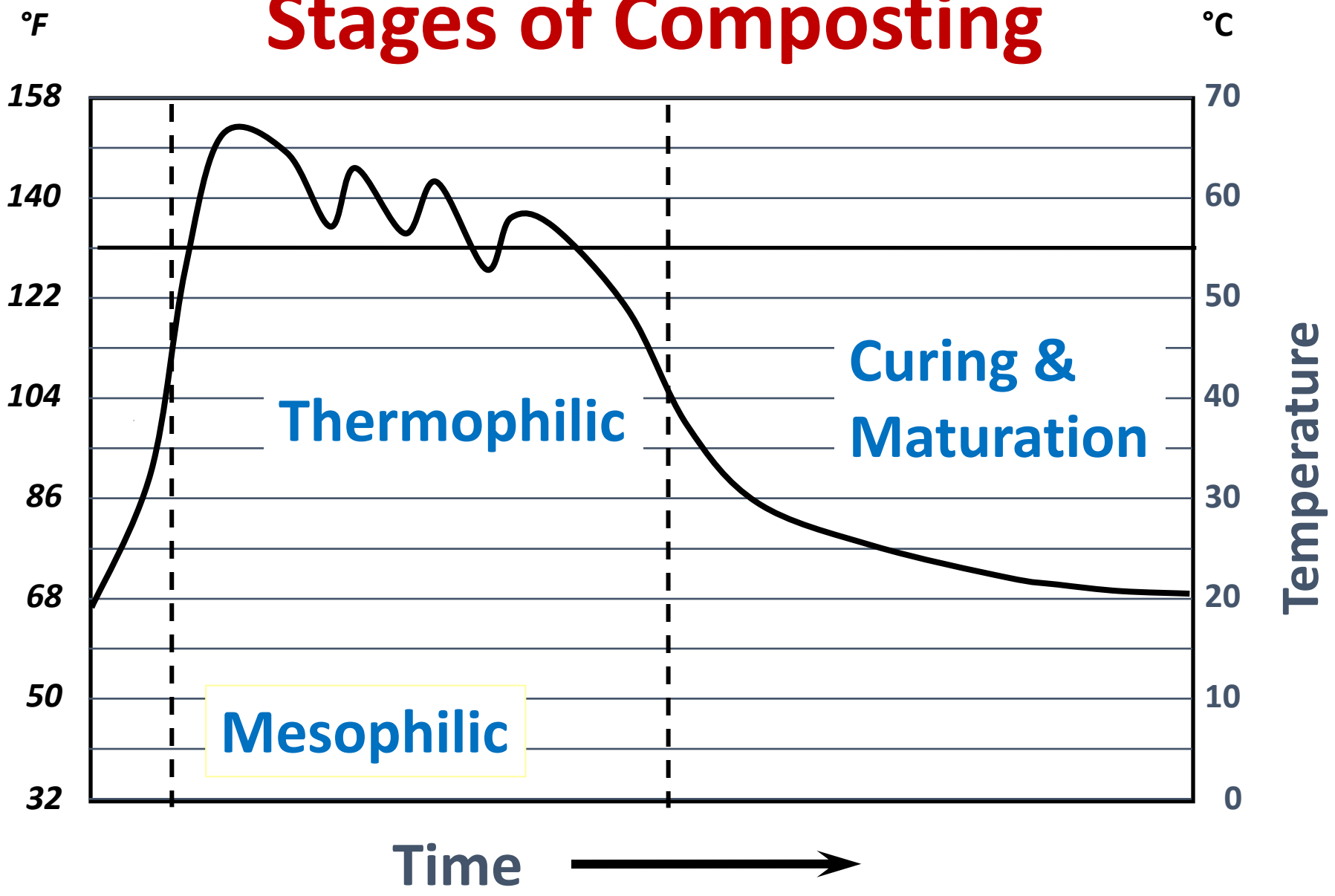
Rotifers

- Microscopic multicellular organisms
- Also found in water drops in compost
- Also eat organic matter, bacteria and fungi

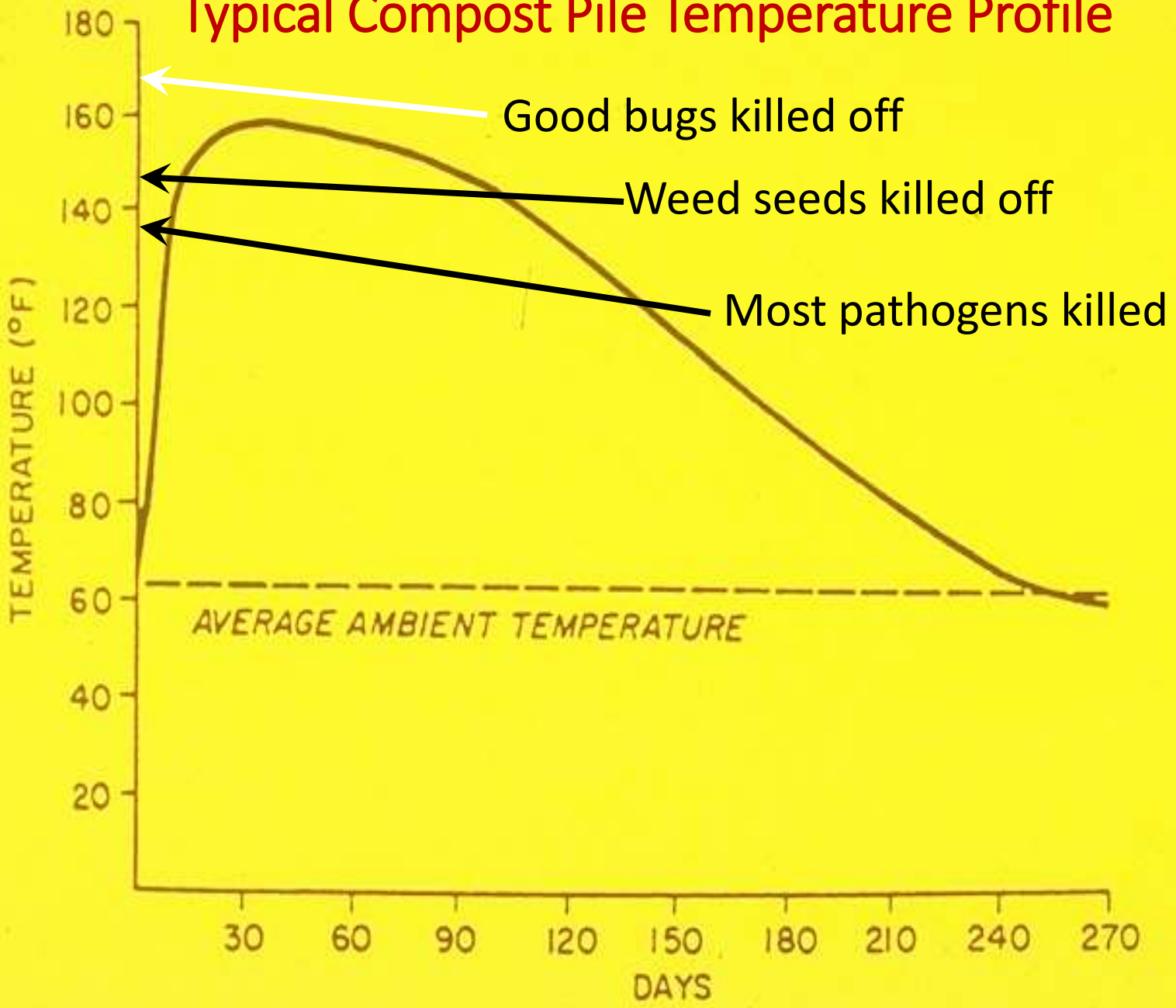
Three Temperature Stages of Composting

- **First:** Mesophilic (68° – 104°F; 20°- 40°C)
- **Second:** Thermophilic (105°-150°F; 40.6° – 65.6°C)
- **Third:** Mesophilic (<105°F; <40.6°C)

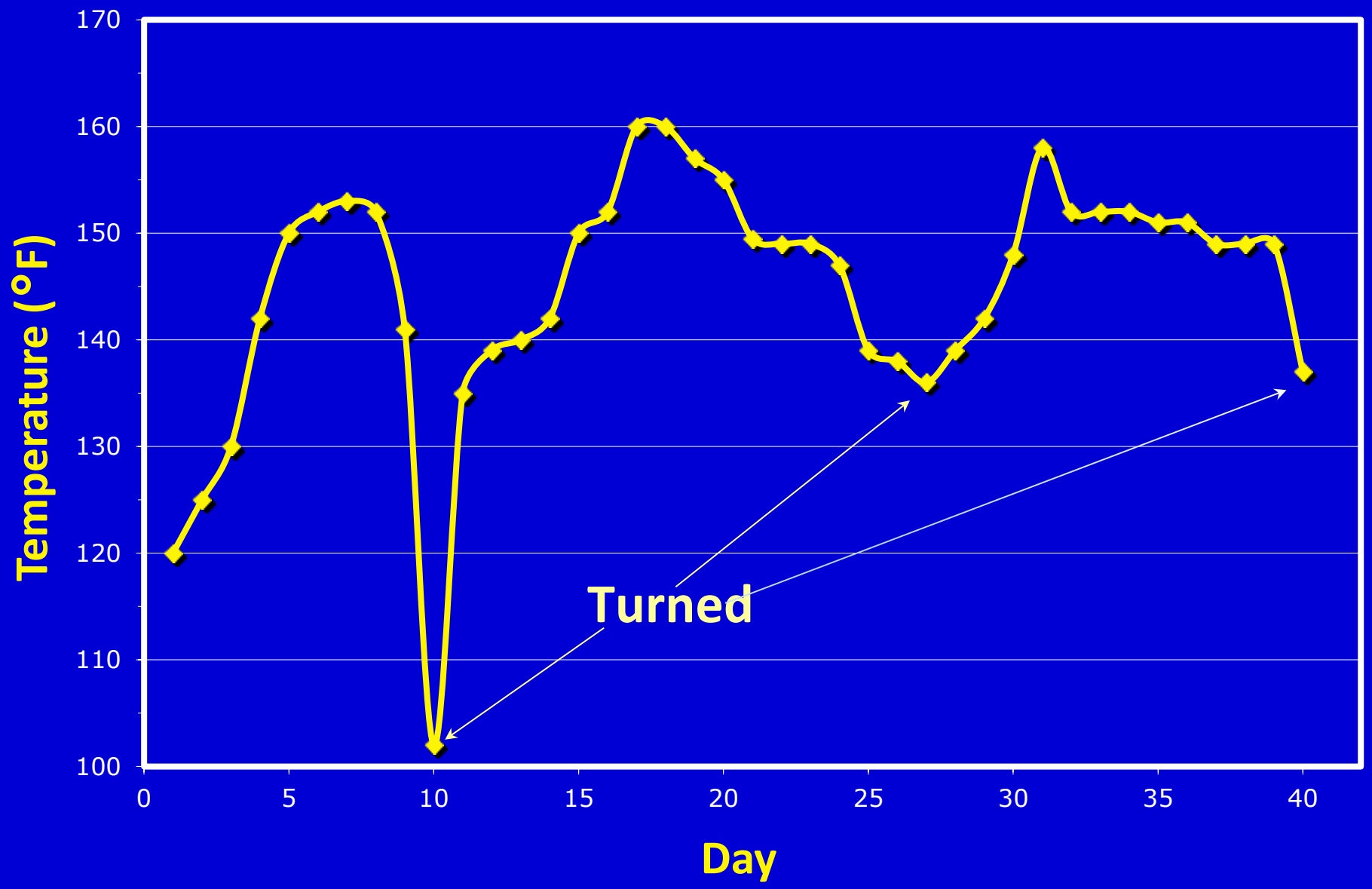
Stages of Composting



Typical Compost Pile Temperature Profile



Daily Temperature Variance in a Composter

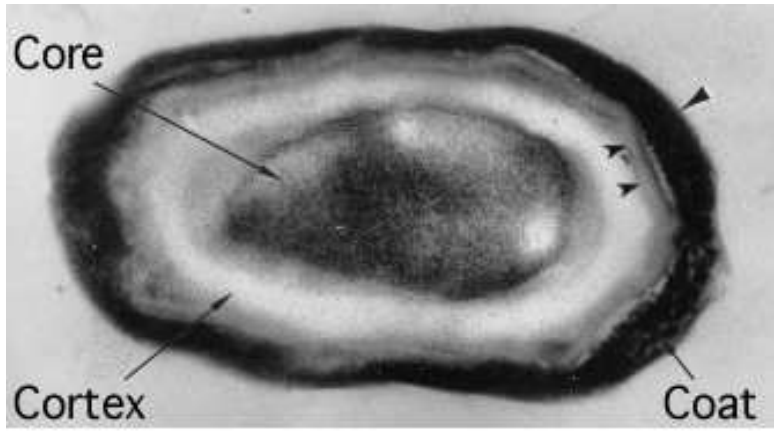


Stage 1 Activity

- Bacteria break down cellulose into glucose (sugars, protein, starch)
- Makes temperatures in pile rise
- Produce endospores as pile heats up

Endospores

- Bacteria develop tough coating
- Resists heat, drying, UV radiation, chemicals
- Can survive next, hotter phase then return to active state when cool again



Stage 2 Activity

- Thermophilic bacteria, fungi take over
- Heat-intolerant microbes go dormant
- Pathogens (human, plant) destroyed
- Complex carbohydrates fully broken down
- Some proteins are decomposed
- Hemicelluloses (more resistant) decay

All this activity makes temperature continue to rise!

Stage 3 Activity

- Mesophilic microbes return to active state
- Proteins and carbs diminish
- Metabolic activity decreases
- Temperatures in pile drop
- Lignin (most resistant plant component) decayed by actinomycetes, fungi

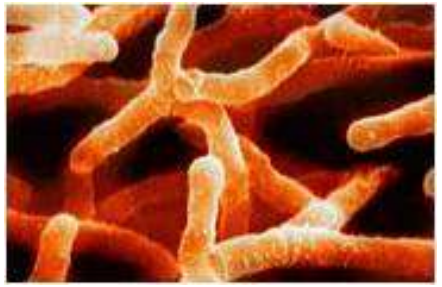
Stage 3 *continued*

- Physical decomposers support microbes
  - Matter gets exposed to bacteria as arthropods forage
  - Allows microbial populations to increase

Earthworms, mites, spiders, ants, snails, sow bugs, slugs, nematodes, springtails, centipedes, etc.

Summary: Succession of Microbial Communities During Composting

- **Mesophilic bacteria** break down soluble, readily degradable compounds (sugars and starches)
- **Thermophilic bacteria** break down proteins, fats; work with actinomycetes to begin breaking down cellulose and hemicellulose
- Actinomycetes and fungi are important during curing phase in attacking most resistant compounds



Key Process Variables for Controlling the Composting Process

1. Initial FEEDSTOCK mix
2. Pile MOISTURE
3. Pile AERATION
4. Pile SHAPE and SIZE
5. Pile TEMPERATURE
6. Composting retention TIME

1. Feedstocks: Your Raw Materials

Chemical Composition

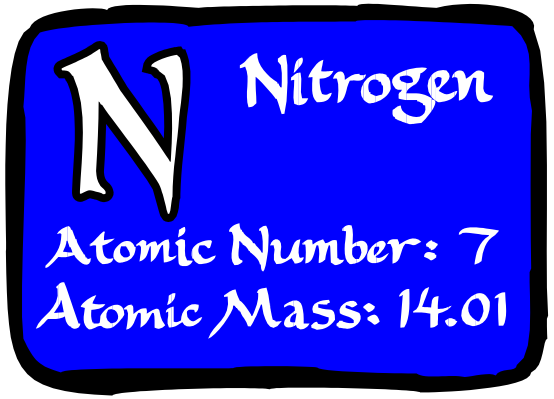
- Organic matter, nutrients, degradability

Physical Characteristics

- Moisture, bulk density, heterogeneity

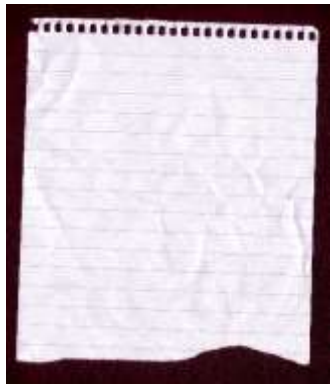
What is Organic Matter?

- Derived from living organisms
- Always contains carbon
- Source of energy for decomposers
- Contains various amounts of other elements
  - Nitrogen
  - Phosphorous
  - Oxygen, Hydrogen
  - Sulfur
  - K, Mg, Cu, Cl, etc.



Types of Organic Carbon

- Sugars, starches (1st to break down)
- Proteins, fats (readily decomposable)
- Cellulose, hemicellulose, chitin (slower to degrade)
- Lignin and lignocellulose (most resistant to decay)

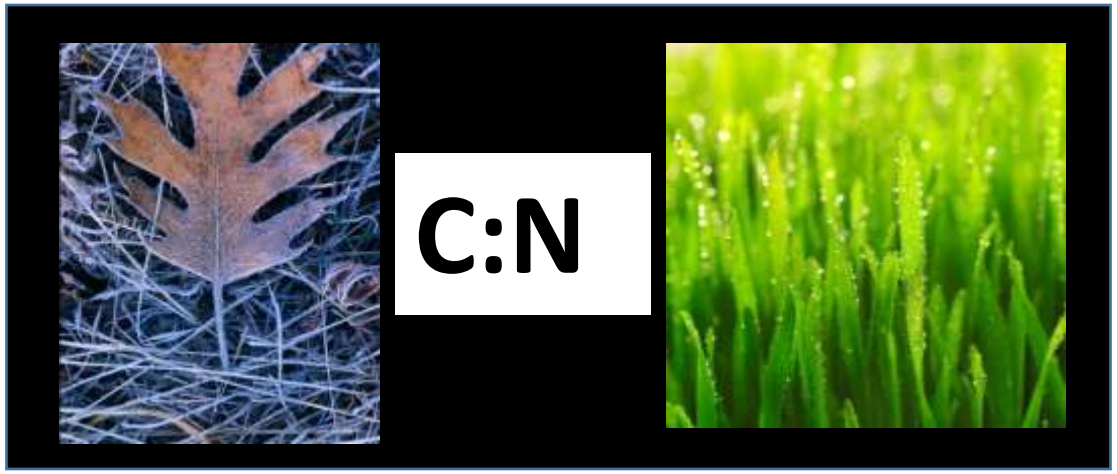


Nitrogen

- Second most important element
- Found in
  - Amino acids
  - Proteins
- Sources include
  - Fresh plant tissue (grass clippings, green leaves, fruits and vegetables)
  - Animals wastes (manure, meat, feathers, hair, blood, etc)

Carbon to Nitrogen Ratio (C:N)

- Ratio of total mass of elemental carbon to total mass of elemental nitrogen
- Expressed as *how much more carbon than nitrogen*, with N = 1
- Does NOT account for availability, which is affected by:
  - Degradability
  - Surface area
  - Particle size



C:N Ratio

- **“Ideal”** starting range: **25:1 - 35:1**

- **High C:N**

  > 40:1 slows composting process (N limited)

- **Low C:N**

  < 20:1 results in net N release (as ammonia)

Example of Feedstock C-N Ratios

Carbon Sources (est.)

• Bark	100-130
• Cardboard	200-500
• Leaves	30-80
• Mixed paper	150-200
• Newspaper	560
• Peanut shells	35
• Peat moss	30-65
• Pine needles	250
• Sawdust	100-230
• Triticale, oat, rye straw	70-90
• Wood chips	200-700
• Wheat straw	140-150

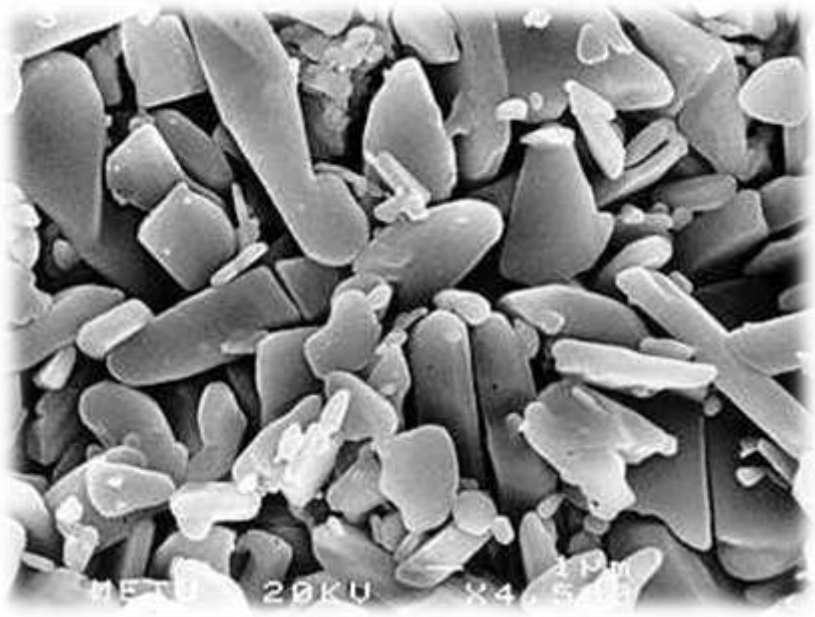
Nitrogen Sources (est.)

• Alfalfa	13
• Clover	23
• Coffee grounds	20
• Food scraps	15-25
• Garden debris	20-60
• Grass clippings	15-25
• Alfalfa, timothy hay	15-25
• Cow manure	20
• Pig manure	5-7
• Poultry manure	5-10
• Horse, llama, donkey, alpaca manure	15-25
• Blood or bone meal	3-4

Ideal Starting Range is 25:1 - 35:1

Physical Factors Affecting Decomposition

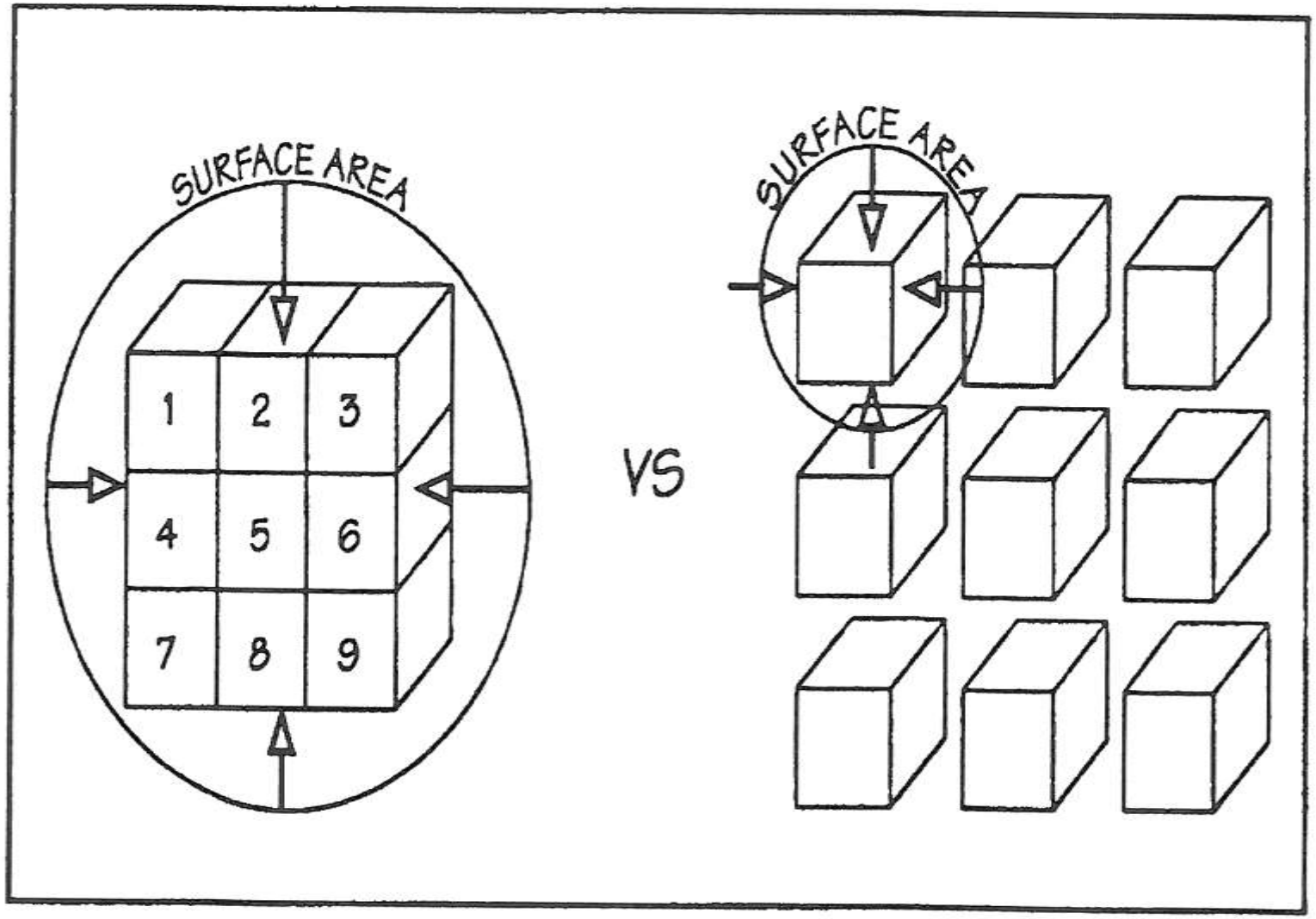
- Particle Size
- Structure
- Porosity
- Free Air Space
- Bulk Density



Particle Size and Shape

- Decomposition happens on surface
- Smaller particles = more surface area
- Very fine particles prevent air flow
- Rigid particles provide structure & help aerate

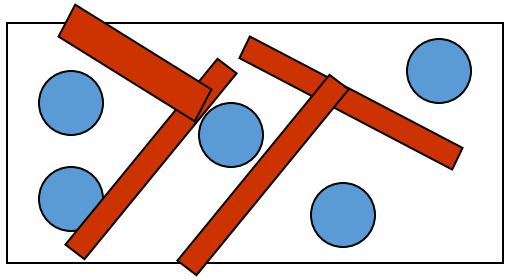
Particle Size



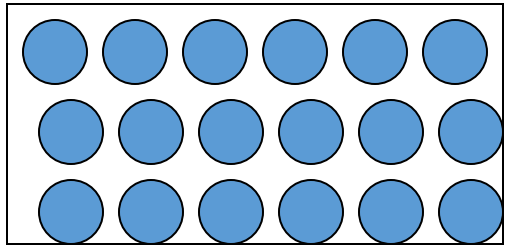
Source: Mid-Scale Composting Manual

Adapted from T. Richard

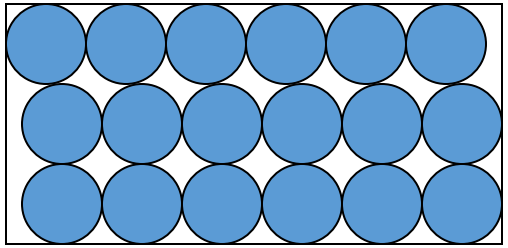
Particle Size and Porosity Effects on Aeration



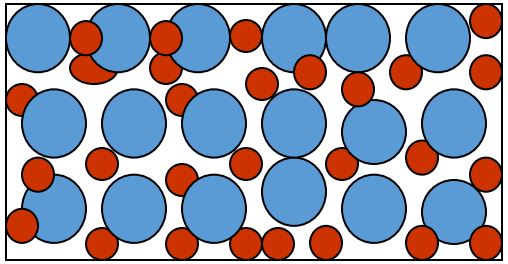
Loosely packed, well structured



Loosely packed, uniform particle size



Tightly packed, uniform particle size

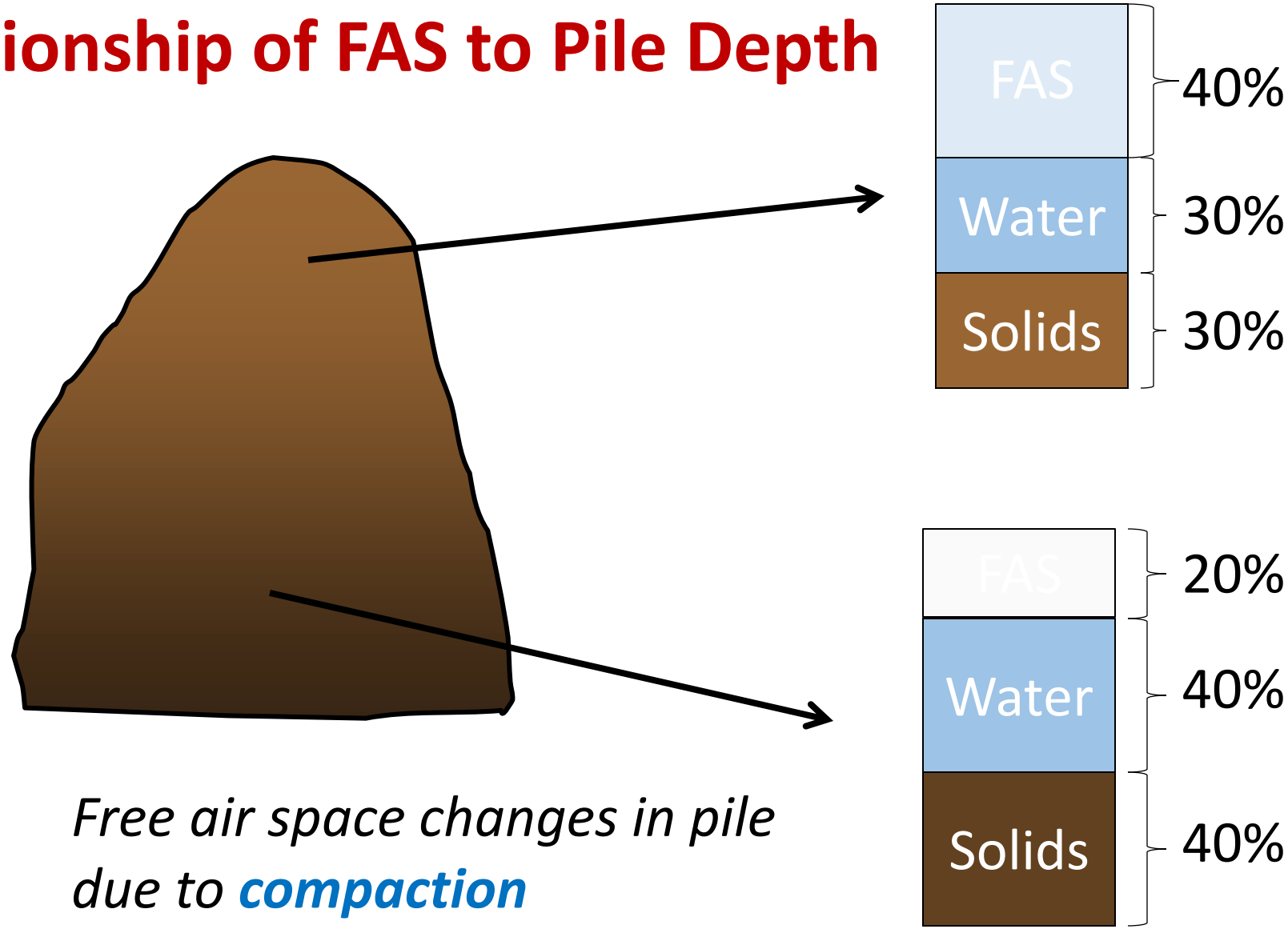


Tightly packed, mixed particle sizes

Porosity and Free Air Space

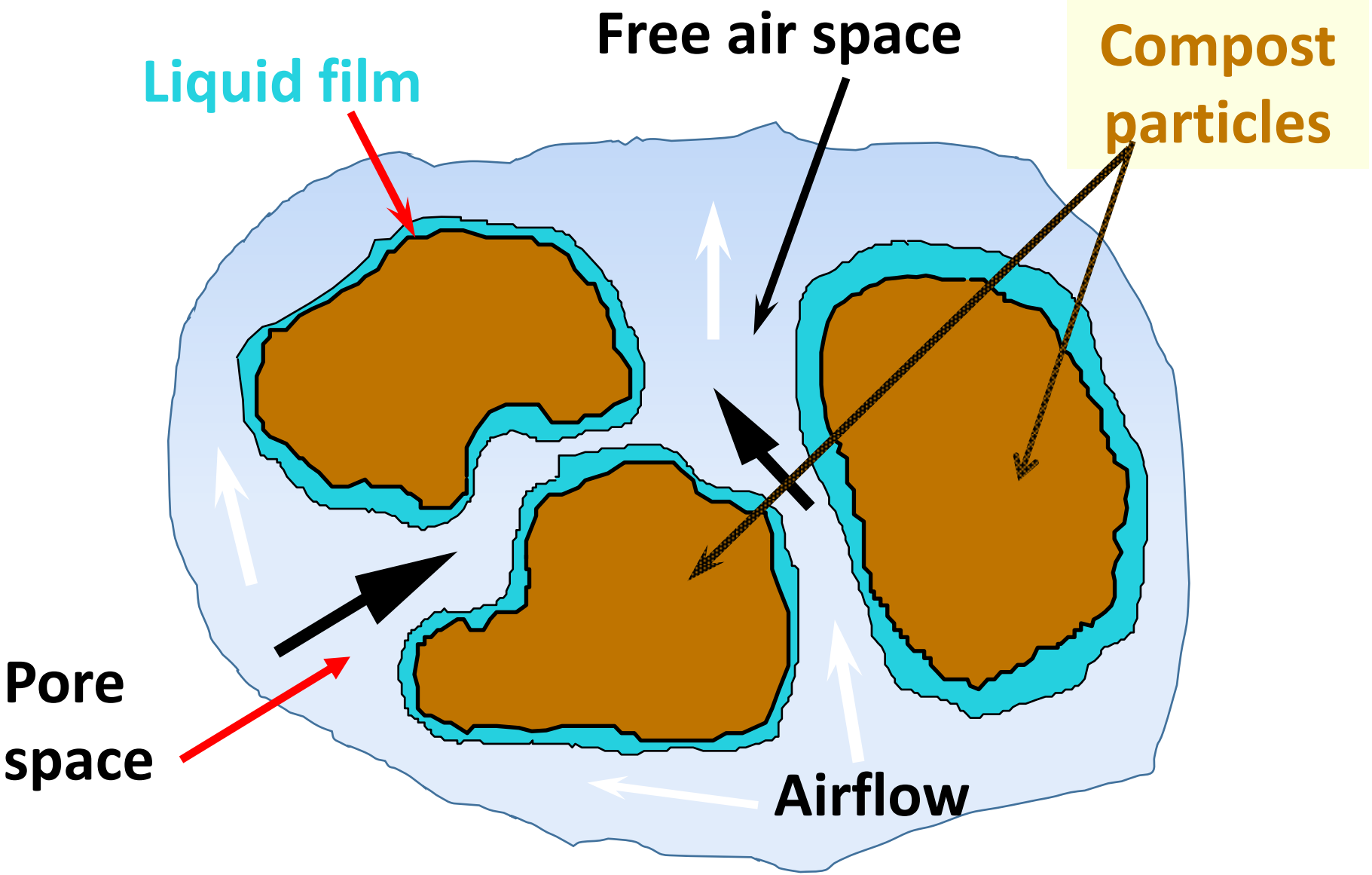
- Porosity = non-solid portion of pile
- Determined by size and type of particles, and height of pile
- Free Air Space (FAS) = portion of pore space not occupied by liquid
- May vary in pile
- Start > 50% free air space

Relationship of FAS to Pile Depth



Free air space changes in pile due to ***compaction***

Pile Structure/Porosity



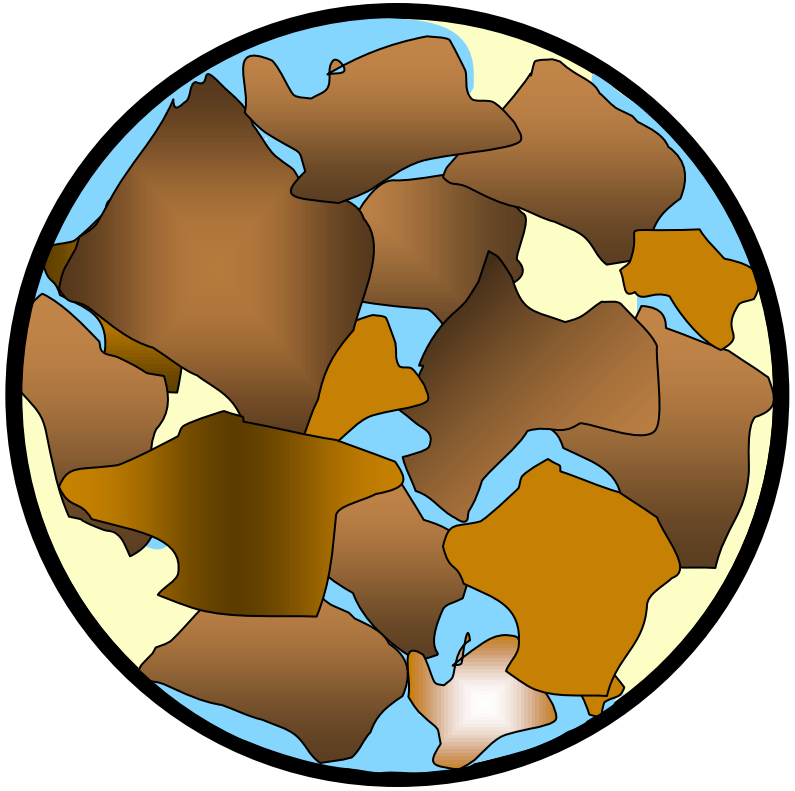
Bulk Density

- Highly correlated with Free Air Space (FAS)

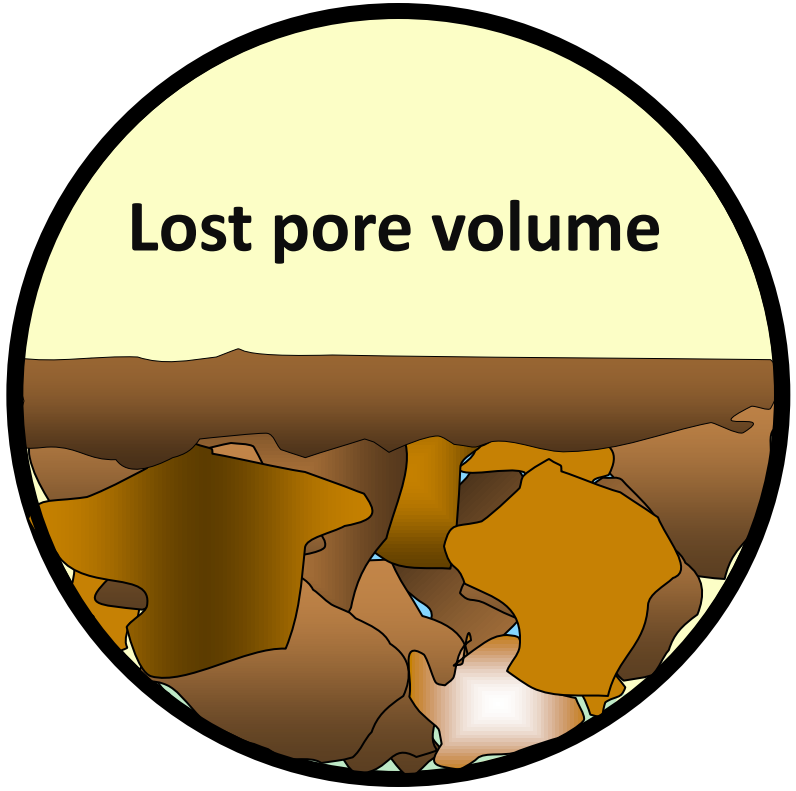
- Measure of weight per unit volume
  - Pounds/cubic foot, tons/cubic yard, kg/L
  - Compost : ~44 lb/ft^3, ~1200 lb/yd^3

Lower bulk density usually means greater porosity and free air space

Non-Compacted
Low Bulk Density



Compacted
High Bulk Density



Bulk Density

- <800 pounds per cubic yard
- Light and fluffy

- 800 – 1,000 pounds per cubic yard
- About right

- 1,000 – 1,200 pounds per cubic yard
- Heavy, hard to aerate, loss of pore space

- >1,200 pounds per cubic yard
- Too dense, very difficult to aerate

Feedstock Summary

- Each feedstock has certain attributes
  - Carbon, nitrogen, moisture, bulk density, rigidity, pH, homogeneity, consistency, putrescibility, pathogenicity, tip fee
- The RECIPE is how feedstocks are combined
- Composting system and site are designed and managed based on types, amounts of feedstocks
- Regulations are always partly based on feedstock

2. Pile Moisture

- Required by microbes for life processes, heating and cooling, place to live
- Optimum is 45-60% moisture
- > 65% can become anaerobic
- < 40% fungus can dominate
  - difficult to re-wet
- < 35% dust problems

Moisture Range

65%
- Too wet
- Wet, heavy, pores filled with water

< 50%
- A little dry
- Process slows

< 40%
- Too dry
- Process slows appreciably

< 35%
- Really dry
- Process nearly stops, rewetting difficult

Moisture

Composting consumes water

- Better to start on high end
- Adding water is difficult
- 25 gallons per ton raises moisture content ~10%

3. Pile Aeration

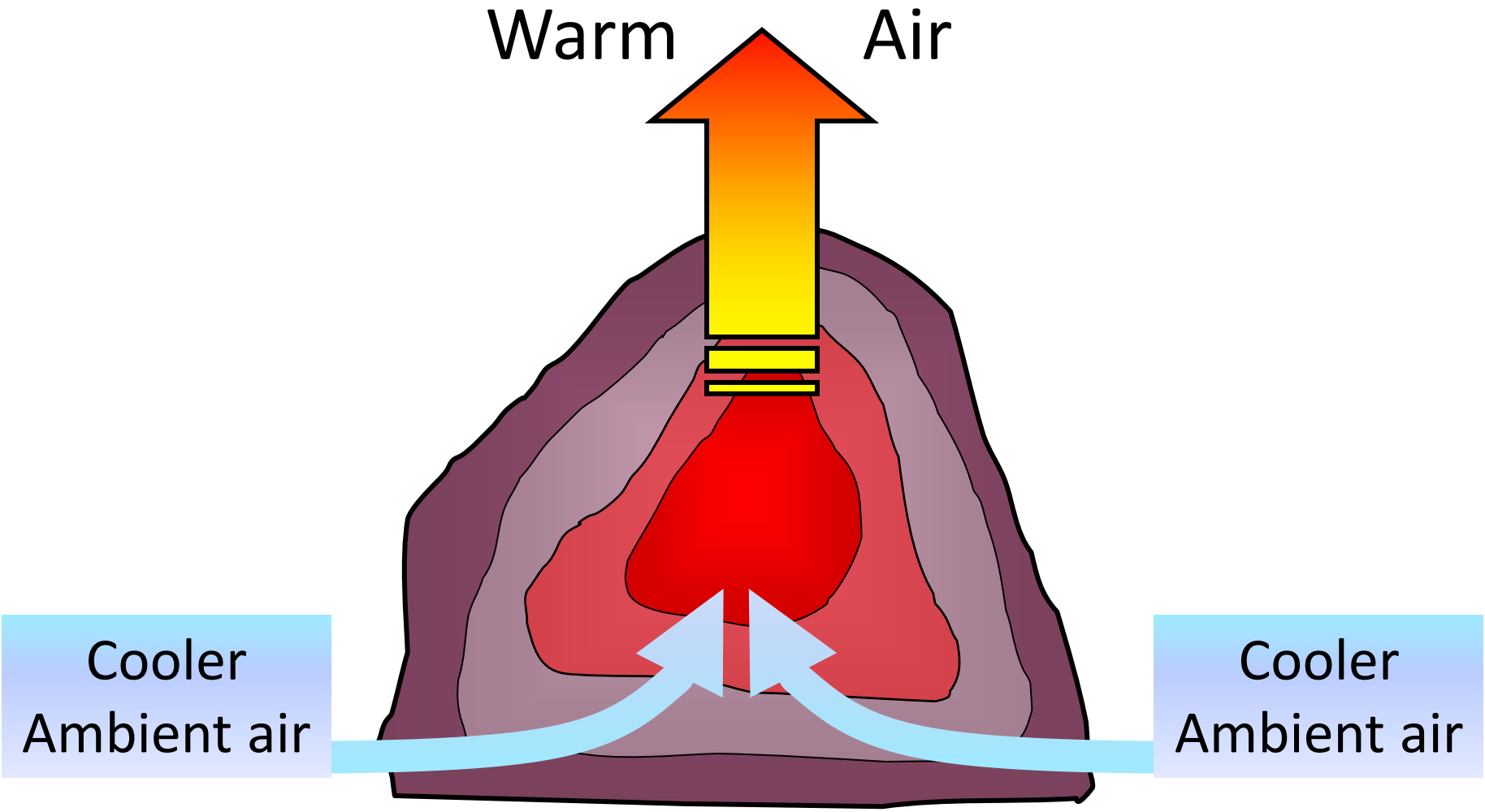
- Aeration supplies oxygen
- Ambient air is 21% oxygen
- O_2 consumption increases with temperature
- Compost organisms can survive 5% oxygen
- Below 10% oxygen in pile, bacteria can start switching to anaerobic respiration
  - Produces hydrogen sulfide (rotten egg smell)

Maintaining adequate oxygen will reduce odor complaints!

Aeration

- Controlled by
  - Porosity *(particle size)*
  - Compaction *(pile height and density)*
  - Moisture
- Without blowers, rely on diffusion and convection

Convective Aeration



4. Pile Shape and Size

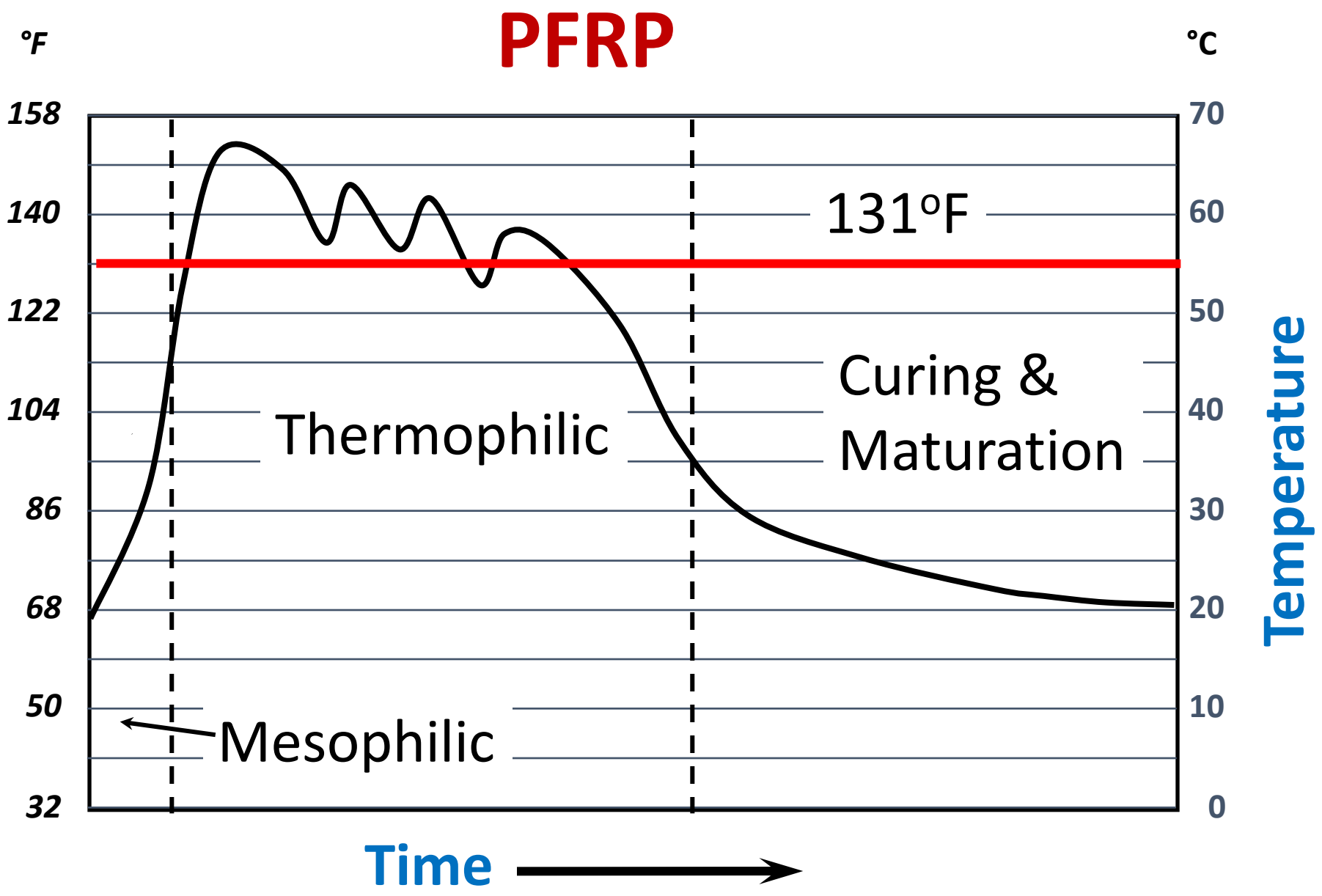
- Smaller piles allow for greater air flow, especially to center of pile
- Larger piles retain temperatures
- Too large compacts bottom of pile
- You can have a bigger pile if
  - Have good structure (sticks)
  - Higher C:N
  - Lower bulk density
  - If regulations allow it
- Equipment should match pile size

5. Temperature

- Higher temps result in **faster** breakdown
- > 160°F (71°C) lose microbial diversity, composting actually **slows**
- Most seeds and pathogens killed at temps 140°F (55°C) or higher

PFRP

- *Process to Further Reduce Pathogens*
- Time and temperature requirements to assure pathogen reduction
- Aerated static pile and in-vessel
  - 131°F (55°C) or higher for 3 days
- Turned windrow
  - 131F (55°C) or higher for 15 days or more with 5 turnings


PFRP
°F
°C
158
140
122
104
86
68
50
32
70
60
50
40
30
20
10
0
131°F
Thermophilic
Curing &
Maturation
Mesophilic
Temperature
Time

6. Time

- Mesophilic
  - A few days to 2 weeks
- Thermophilic
  - 3 weeks to several months
- Curing and maturation
  - 1 to several months
  - Eliminates inhibitors to seed germination and crop growth

When Might the Pile Be Done?

- Does not maintain heat after turning
- About ½ to 1/3 of its original volume
- Can’t recognize the original materials
- It is a dark color
- Smells earthy (not like ammonia or rotten eggs)
- Stability (activity diminished) vs maturity (will grow plants)
- Testing for doneness (lab and facility tests)

Summary
Key Initial Parameter for Thermophilic Composting

Condition	Reasonable Range	Preferred Range
Moisture %	40 – 65	50 - 60
C:N	20:1 – 60:1	25:1 – 35:1
Oxygen %	Greater than 5	Greater than 10
Temperature F	113 – 160	120 - 150
pH	5.5 – 9.0	6.5 – 8.0
Particle Size	1/8 – 2 inches	Depends on feedstocks and use for compost
Bulk Density	Less than 1200	800 - 1000