# Ecology of Disease

Theme: AGRICULTURE
PLANT DISEASE

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# Plants

- Plant Kingdom = majority of life-forms on Earth
- Contribute directly/indirectly to all human foods
- Only higher organisms that can produce sugars, proteins and fats from solar energy
- Diseases may destroy crops, reduce yield, render them unfit for consumption
- worldwide problem (annual loss in USA ~$9billion)
- greater problem in developing countries

| Crop | % crop lost to disease |
|---|---|
| Cereals | 9.2 |
| Potatoes | 21.8 |
| Fruits | 12.6 |

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# Historical Impact

Plant diseases have significantly impacted human history (esp. with intensification of cropping systems) e.g.

- 1770s – Decimation of Russian cavalry (Peter the Great)
- 1870s – Downy mildew in European vineyards
  - wine production losses ~$50 billion
  - controlled by Bordeaux mixture (mixture of lime and copper sulphate)
- 1900's Irish potato famine
  - potato blight fungus
- 1943 great Bengal famine
  - brown spot on rice
- 1900's ruin of chesnut timber industry
  - chesnut blight
- 1860's coffee rust fungus

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# Coffee rust in Asia

- *Coffea arabica* (arabica coffee)
- *Coffea canephora* (robusta coffee)
- originated as understorey plant in forests on mountains in Ethiopia
- first used as drink for medicinal purposes and in religious rituals
- crop of tropics (surpassed only by oil in value as world commodity)
- popular drink in Europe in 1600s
- 17th century coffee houses throughout Europe
- Dutch major coffee suppliers

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# Coffee rust in Asia

- Ceylon developed into the greatest coffee-growing region in world
- Ceded to British in 19th century
- British expanded plantations, stripping island of forests
- By 1870s, Ceylon was exporting ~ 100 million pounds of coffee a year
- Appearance of "coffee leaf disease" in 1867 (fungus *Hemileia vastatrix*)
- No effective fungicides
- Spores resistant to desiccation, capable of long-distance movement
- In less than 20 years, many coffee plantations were destroyed

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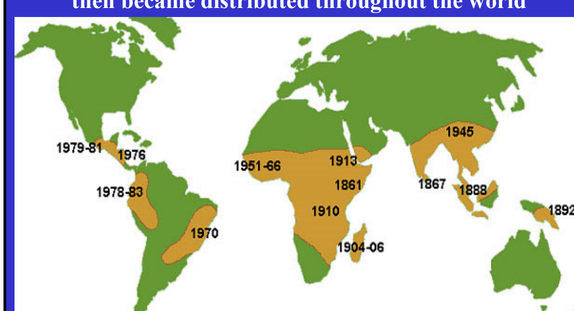
# Coffee rust in Asia

fungus had made its way from native Ethiopia to Ceylon, then became distributed throughout the world

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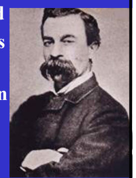
## Coffee rust in Asia

- British sent in plant pathologist H Marshall Ward
- Recommended use of fungicides (but sulphur ones available were not very effective)
- Studied life-cycle and identified spore germination stage as vulnerable stage
- Warned about the dangers of monoculture

  (continuous plantings over whole island had created perfect environment for epidemic)
- Vigour and productivity of coffee plantations declined to point where they were no longer economically viable

SOLUTION – GROW TEA INSTEAD



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## Plant Pathology

- Study of plant disease involves:
  - aetiology (causative agents)
  - life-cycle (transmission/development)
  - epidemiology (dispersal in populations)
  - pathogenesis (mechanisms of disease)
  - manifestations (how plant affected)
  - diagnosis (detection)
  - treatment (therapy)
  - prevention/control (prophylaxis/intervention/management)
  - ecology (interactions between pathogen – plant – environment)

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## Ecology of Plant Disease

- natural ecology disrupted by agriculture
- conditions favouring disease inherent in agriculture
  - natural controls have been removed
- diseases more destructive due to human activity
  - parallels between plant/animal/human diseases
  - urbanisation → ↑ population density → outbreaks
  - epidemics are the cost of crowding

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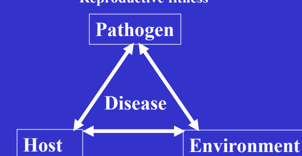
## The Disease Triangle

(interactions determine disease distribution/abundance/severity)

- Presence of pathogen
- Virulence and aggressiveness
- Dispersal efficiency
- Reproductive fitness




Host:
- Susceptibility
- Growth stage and form
- Population density and structure
- General health

Environment:
- Temperature
- Moisture (rainfall, dew, leaf wetness period, soil water content)
- Soil organic matter content
- Wind
- Herbicide damage

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## Pathogen

- Aetiological agents for plant diseases:
  - Fungi: 60-70%
  - Viruses: 10-15%
  - Bacteria: 5-10%
  - Nematodes: 1-5%
  - Miscellaneous parasitic plants (dodder, mistletoe...)

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## Pathogen

- Occurrence (presence/absence)
  - contacts, barriers, quarantine, ...
- Virulence (ability to cause disease)
  - pathogenicity, aggressiveness
- Adaptability (fitness)
  - competition
  - adapt to changing environment (reproductive efficiency)
  - evolve to overcome host resistance (new races)
- Dispersal (distribution)
  - epidemics □ rapid, large areas
- Survival (e.g. over-wintering)
  - spores, paratenic hosts, reservoirs
- Infectivity (success of transmission)
  - number of infective propagules
  - priming (effect of environment)

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## Environment

- Host + Pathogen $\neq$ Disease
- NEEDS conducive environment
- Plant diseases are more common and severe in humid to wet areas
- Environment = atmosphere + soil
- Can be manipulated to exclude pathogen
  - e.g. wheat varieties bred to grow in drier environments

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## Environment

- Moisture (most important for fungal and bacterial diseases)
  - Rainfall (duration, intensity, dispersal)
  - Humidity
  - Dew
  - Leaf wetness (important for foliar pathogens)
  - Irrigation
- Moisture affects fungal:
  - spore formation
  - spore liberation
  - spore germination
  - penetration of host by the germ tube
- Moisture affects bacterial:
  - survival
  - multiplication
  - penetration

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## Environment

- Temperature
  - minimum temperature for growth
  - maximum temperature for growth
  - optimal temperature for pathogen ($\neq$ host)
    - early spring or autumn
    - ↑ number infection cycles
    - can be a "trade off"

| Species | Min | Opt | Max |
|---|---|---|---|
| *Erwinia amylovora* | 0.5°C | 28-30°C | >37°C |
| *Xanthomonas axonopodis* pv *citri* | 10°C | 28-30°C | 36°C |
| *Agrobacterium tumefaciens* | 0°C | 25-30°C | 37°C |

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## Environment

- Wind
  - Spread of the pathogen
    - rapid epidemic spread
    - wind-blown rain
  - Host wounding
    - whiplash
    - most important for bacterial pathogens
  - Acceleration of drying
    - prevents infection

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## Host

- Susceptible or resistant?
  - interaction with pathogen
- Growth stage and form
  - young v. old
  - microclimate (canopy closure, ..)
- Health status
  - stress, nutrition, ...
- Population structure
  - plant density (crowding)
    - crop microclimate
    - competition between plants
  - biodiversity
    - mixed culture v. monoculture

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## Monoculture

- "Industrial agriculture" (cultivars, clones)
  - Farm = factory with:
    - "inputs" – pesticides, fertilizer etc.
    - "outputs" – the crop
  - Economy of scale
    - Cultivation easier
    - Decreased overheads
    - Increased productivity

→ MONOCULTURE

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## Monoculture

- Advantages
  - uniform product
  - reduced contamination
  - ease of production
    - planting
    - management
    - harvest
- Dangers
  - increased vulnerability
    - diseases
    - pests (insects)
    - weather
  - pathogen dispersal
  - soil depletion
  - increased dependence on multinationals
    - seed, pesticides

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## Monoculture – Southern corn leaf blight

- By 1970, most diseases of corn thought to be under control
  - “corn breeding”
- TCMS – Texas cytoplasm male sterility
  - don’t need to detassel
  - widespread by 1970
    - 85% hybrid corn was TCMS
- BUT susceptible to Southern corn leaf blight
  - combination of pathogen, widespread susceptible hosts and favourable weather conditions throughout 1970s
  - epidemic – estimated annual losses of $1 billion.

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## Southern corn leaf blight

- Fungal pathogen
  - *Bipolaris maydis*
  - two races
    - Race O (old)
    - Race T
      - Pathogenic on TCMS
- Hosts
  - corn, sorghum and teosinte
  - overwinters
    - on crop debris, primarily on the soil surface, as mycelium, conidiospores and chlamydospores


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## Southern corn leaf blight

- Conidiospores
  - windblown or splashed by water to fresh plant tissue in the spring
  - spores germinate on leaf surface and infect host directly through stomata
- Disease development favoured by:
  - warm ( 20-30°C) moist weather
  - presence of free moisture on leaf
- Fungus very prolific
  - able to complete life-cycle in 60-72 hrs under favourable weather conditions

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## Southern corn leaf blight

- Phytotoxins
  - Race O
    - non-specific to cytoplasm types
    - produced in small amounts
  - Race T
    - specifically affects corn containing TCMS


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## Southern corn leaf blight

- TCMS carries two cytoplasmically inherited traits
  - male sterility <u>and</u> disease susceptibility
  - two traits are inseparable and are associated with an unusual mitochondrial gene
    - T-*urf*13 encodes a 13-kD polypeptide (URF13)
  - interaction between fungal toxins and URF13 results in permeabilization of inner mitochondrial membrane
    - accounts for specific susceptibility to fungi

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## Monoculture

- Disease in natural ecosystems
  - In nature the potential host is genetically diverse as are the pathogen populations
    - barriers to dissemination
  - Epidemics are rare in the absence of a major disturbance
    - e.g. introduction of virulent pathogen

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## Mixed culture


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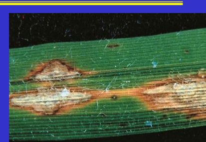
## Mixed culture

- Rice blast
  - number 1 disease of rice
  - can contribute up to 99% of losses in production due to disease
  - caused by the fungus *Magnaporthe grisea*
  - has the ability to overcome host resistance



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## Mixed culture

- Hypothesis (Zhu *et al*. Nature 2000)
  - Crop diversity/heterogeneity limits disease
  - Method
    - Grew mixed rice varieties over a 2 year period
  - Results
    - susceptible varieties gave 89% better yield and rice blast disease was 94% less severe than when grown in monoculture
    - Fungicidal sprays not necessary
  - Conclusions
    - Intraspecific crop diversification provides an ecological approach to disease control

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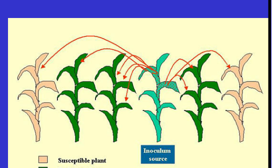
## Mixed culture

How does diversification work?

- Dilution effect
  - Increasing the distance between susceptible plants reduces/slows the rate of plant-to-plant spread
- Barrier effect
  - The presence of resistant plants in the canopy provides a physical barrier against spore dispersal, interrupting spore movement
- Induced resistance
  - Induced resistance occurs when biochemical host defences are triggered by inoculation with an avirulent race, thus slowing the infection processes of virulent pathogen races
- Changes in crop microenvironment
  - Different plant heights and canopy structures may contribute to a different microclimate




In a mixture, the number of released spores creating new infections can be reduced considerably by lowering the density of susceptible plants (dilution effect). Moreover, some of the spores released from an infected plant are captured by a resistant plant and consequently, removed from the epidemic process (barrier effect).

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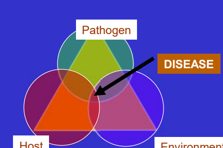
## What's examinable?

AGRICULTURE
- intensive production
- monoculture
- genetic diversity
- plant diseases/pathology

DISEASE TRIANGLE
- Pathogen
  - dispersal
  - survival
- Host
  - susceptibility/resistance, health status
  - population structure/density
- Environment
  - moisture
  - temperature
  - wind

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