

**Working Paper # 15  
(Kertas Kerja # 15)**

**Disease Management in Polyculture Systems**

**Katie Campbell-Nelson**

Research Associate, University of Massachusetts

**December 2009**

**Institute of Indonesia Tenggara Timur Studies  
(East Nusa Tenggara – NTT Studies)  
© IITTS Publications (Open Sources)**

# Disease Management in Polyculture Systems

**Katie Campbell-Nelson**

## **Abstract**

Mixing crops of different species in the same space is known as a polyculture. Polyculture systems vary widely from traditional, small scale agriculture, to commercial and chemical large scale agriculture. Biodiversity of these crop mixtures are their strength in disease management. Host and pathogen diversity promote induced resistance, and provide co-evolutionary pressures to keep disease epidemics in check. Biodiversity of plant and microbe species in a cropping system slow the spread of disease, create disease suppressive microclimates, and offer predation and competition of pathogenic microbes. Alternative plant breeding, cultural practices, and biological controls associated with polyculture systems can be used effectively to manage multiple diseases with varying life history characteristics while maintaining crop efficacy. With increasing economic and environmental costs of many chemical methods of disease control, large scale agricultural systems today can use polyculture principles to manage disease while maintaining yield stability.

## **1. Introduction**

A polyculture is an agricultural system in which crops of different species are grown together in the same space. Polycultures are used in a wide variety of cropping systems from traditional slash-and-burn or swidden fields of Southeast Asia where it is common to see 40 species of crops planted together, to mixed cropping of wheat in Kansas. Because the term ‘polyculture’ covers such a broad range of farming systems, disease management will exhibit a vast array of techniques, however, their principles are all inherently the same. Biodiversity is the underlying principle guiding disease management in a polyculture. This paper discusses the many ways in which biodiversity is used in managing disease touching on several host pathogen relationships within this context to help illustrate how biodiversity contributes to disease suppression.

In traditional polycultures, disease is rarely a factor which occupies the farmers’ management practices. In the Jambi Province of Sumatra where farmers practice swidden rubber polycultures, only 3% of them used burning to reduce the incidence of disease; and they did not use any other methods for managing disease<sup>1</sup>. Most traditional polycultures do not suffer from high amounts of disease, so there is hardly any recognition for the necessity of disease management. An ancient exception to this was the existence of

Roman 'rust gods' who received sacrifices from farmers for a good grain yield<sup>2</sup>. However, as populations come closer together, shifting cultivation is no longer safe from disease by means of isolation, and farmers must begin to use some integrated disease management practices to maintain crop health.

Monocultures, as opposed to polycultures are a more recent approach to agriculture which compliments mechanization and provides the world today with the majority of its' staple crops: rice, maize, and wheat. However, these high yielding monocrops have often succumbed to disease pressures. When agronomists in the 1950's noticed disease in serial cereal (sequential cropping of cereal grains for many growing seasons), they began looking into the benefits of 'inter and intra-crop diversity'<sup>6</sup>. Disease management in a polyculture system requires a different approach to plant breeding, cultural practices, and use of biological control than a monoculture. Rather than suppressing biodiversity, a polycultures encourage it; indeed a different paradigm in management.

Many reasons have been cited for low disease incidence in all types of polycultures:

- Shifting cultivation has the benefit of isolation from other farmers and diseases.
- Fire associated with slash-and-burn agriculture removes sources of inoculum in plant litter.
- Landrace varieties and *multilines* are breeding alternatives for crops which exhibit pathogen resistance when planted in mixtures.<sup>2,6,7</sup>
- Wild vegetation block the movement of spores and insects.<sup>8</sup>
- Resistant plants grown as a barrier to susceptible plants intercept disease inoculum; also known as the 'flypaper effect'.<sup>9</sup>
- Microclimates created by spatial zoning create unfavorable conditions for disease spread and inoculation.<sup>12</sup>
- Mixed cropping systems can delay the onset of disease and reduce the spread.
- Certain crop roots exude toxicants or provide shelter for beneficial miccoryzae promoting soil fungistasis.<sup>10</sup>
- A diversity of plant species promotes microbial diversity which increases competition with disease pathogens above and below ground<sup>10</sup>.
- Existence of resistant hosts and avirulent pathogens along with susceptible hosts and virulent pathogens encourage induced resistance in a crop system<sup>11</sup>.

All of these disease suppressive characteristics in polycultures can be used to manage diseases. The main strength for disease management in a polyculture lies in the diversity of hosts, pathogens, and pathogen competitors and predators. Following is a discussion of these characteristics and some examples of how they are used as well as a look into some specific pathogen host relationships in polycultures.

**2. Biodiversity and Disease Resistance:**

Natural biodiversity may be inherently disease suppressive, but not inherently effective at controlling disease in agricultural crops. Diverse plant communities must be managed to be effective at disease control. The right plants grown together can achieve the desired effects of a changed microclimate, slowing disease spread and inoculation, or providing root toxicants and microbial niches. Over time, plants grown together evolve with their associated pathogens to create new varieties or races which are effective at maintaining yields.

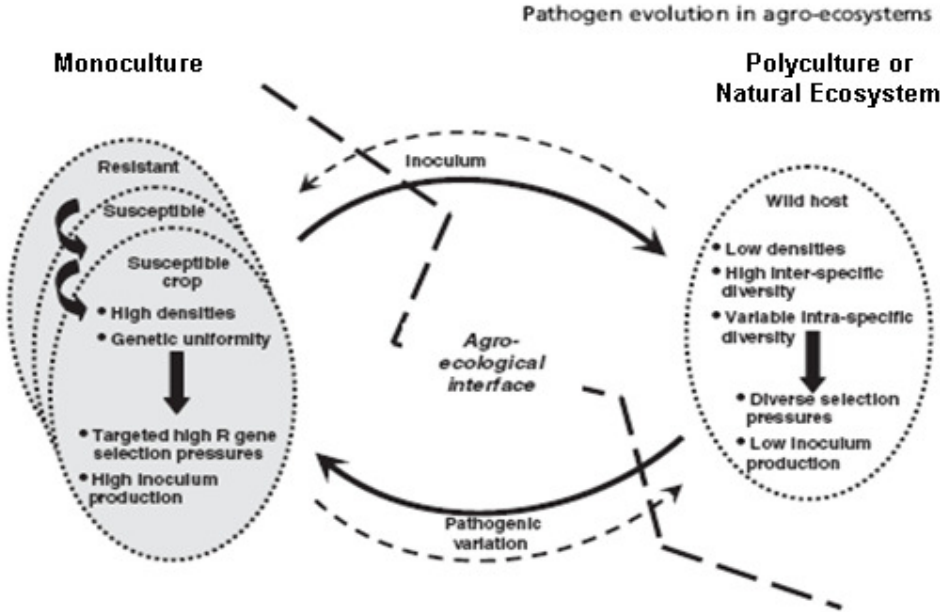


Figure 1. Interactions at the agroecological interface between crops (landrace and *multiline*) and wild plants leading to an interchange of inoculum and pathogen variation. Adapted from: Pathogen evolution across the agro-ecological interface: implications for disease management.<sup>8</sup>

In order to understand how cultural and biological methods work to control disease in a polyculture, we must first understand the basis for biodiversity in the system through crop breeding and natural genetic recombination of pathogen species. In a situation where variation of species and potential for disease transmission occurs there is selection pressure for evolutionary change in pathogens and hosts. Figure 1. illustrates how pathogenic variation and inoculum are transmitted between a monoculture and a polyculture with inter and intra-crop diversity .

In Figure 1 above, induced resistance is an important mechanism for disease control, and illustrates how a monocrop would fail to induce resistance. “Induced resistance occurs when spores of an avirulent pathogen land on a resistant host and elicit a resistance mechanism that is effective against virulent spores of the pathogen”.<sup>11</sup> Induced resistance can take several years to be expressed throughout the cropping system. In mixtures, the range of host susceptibility and pathogen virulence encourage induced resistance. Host specificity of a pathogen also contributes to its ability to evolve new strains or races. The more host specific the pathogen, the less chance it will have to sexually reproduce new races.

### **3. Plant Breeding for Polycultures:**

Plant breeding approaches in polyculture must match the diversity of pathogenicity in a system in order to maintain efficacy over time. Traditional polyculture farmers save seed and plant cuttings from the same bioregion for many growing seasons, even centuries; plants from these sources are referred to as landraces. Landraces typically have a range of susceptibility to disease and exhibit horizontal gene resistance rather than vertical resistance found in many plants bred for large scale agricultural production.

A plant breeding approach with results similar to landraces used by some plant breeders today are called *multi-lines*. *Multilines* express genotype differences in disease resistance characteristics, but they are phenotypically similar. “After about eight generations of backcrossing, a series of lines is produced, each carrying a different resistance gene but identical in all other respects. This is intra-specific genetic diversity for disease resistance.”<sup>6</sup> Multilines are difficult to produce due to many generations of backcrossing required. They can be grown in combination with landraces or other crop species to provide inter- and intra-species diversity for improved disease resistance. Some multilines

bred today are slightly susceptible to a pathogen races to apply negative selective pressure on virulent pathogens. “Mixtures support more diverse pathogen populations than do pure stands, and that diversity is positively related to the degree of disease control provided by the mixture”.<sup>13</sup> Variation and enhanced pathogen transmission potential provide more opportunity for evolution<sup>8</sup>. If host and pathogen are able to evolve symbiotically, disease of epidemic or economically important proportions are rare.

Genetic diversity is not only important to annual cropping systems which use the breeding methods for *multilines* and landraces, but also for perennial cropping systems. A polycyclic silviculture is a method of forestry which may better control disease problems by frequent harvests at which time diseased trees can be thinned out. Cutting fewer trees more often simulate falling trees in a forest, which allows for a quick regeneration time, in which mature trees are left to start new seedlings making for a genetically diverse stand.<sup>5</sup> Genetic diversity among trees encourages more disease resistance.

#### **4. Spatial Mixing and Disease Management:**

Spatial mixing of crops falls under the category of cultural practices in terms of disease management, and is typically most effective for diseases with a shallow dispersal gradient<sup>13</sup>. Inter and intra-species diversity along with lower individual species density is common in natural ecosystems, and is used in polycultures to reduce incidence of disease. Dilution and barrier effects<sup>13</sup> are disease suppressive by slowing the spread of pathogens to susceptible plants. A study on winter wheat cultivar mixtures<sup>11</sup> for simultaneous management of leaf rust *Puccinia triticina* and tan spot *Pyrenophora tritici-repentis* concluded that severity of both diseases were reduced when one cultivar resistant to leaf rust was grown with another cultivar resistant to tan spot; though the mixture was more effective at suppressing leaf rust which has a shallow dispersal gradient. In another study in South East Asia, “maize grown in rows 2 or 3 meters apart, intercropped with soybeans, groundnuts, upland rice, or mung beans suffer relatively little from downy mildew, normally a major maize disease”<sup>9</sup>.

Spatially zoning crops by combining plants of different heights for varying canopy coverage creates microclimates which can be effective at suppressing disease inoculation and spread. In an experiment of rice mixtures in China, canopy microclimate data

indicated that “height differences between taller glutinous and shorter hybrid varieties resulted in temperature, humidity, and light conditions that were less conducive to blast (*Magnaporthe grisea*) in mixtures than in monocultures”<sup>12</sup>. Another study showed that growing peas on cereal crops (rather than matted on the ground) increases airflow which reduces humidity, resulting in suppression of waterborne pathogens<sup>9</sup>. Spatial zoning is also used to control shading for crops such as coffee and cocoa, which are healthier in shade than in full sun where they are susceptible to disease.

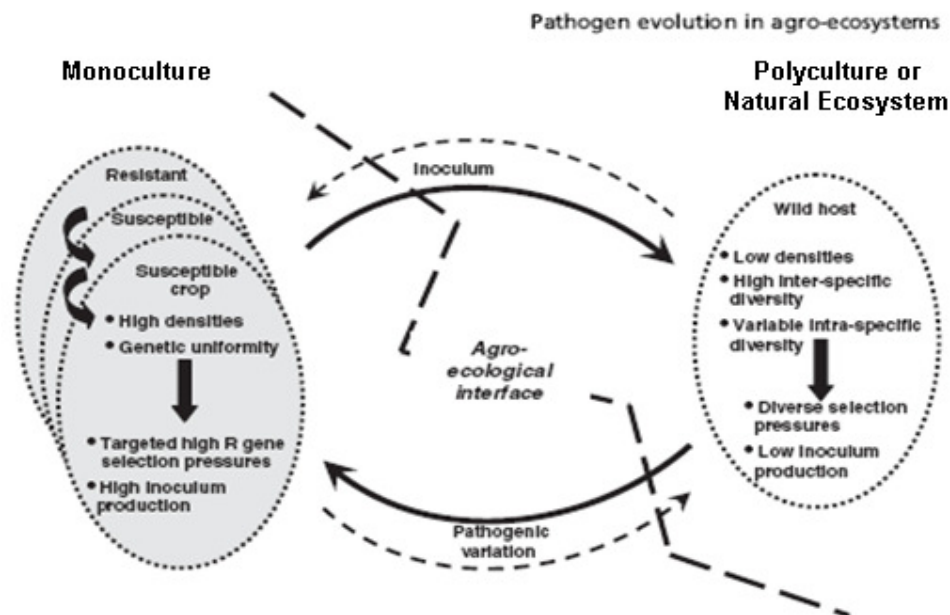


Figure 2. Upland rice and corn intercropped in a slash and burn field of Timor, Indonesia (2007). Corn rows are far enough apart to hinder the spread of downy mildew from one row to the next.

### 5. Microbial Competition and Predation:

Most studies on using crop mixtures to control disease have found positive results on management of windborne pathogens, but little conclusive evidence shows that mixtures are effective at controlling residue- and soil-borne disease. However, this is not to say that soil and residue borne diseases cannot be effectively managed in a polyculture, just that this aspect of disease management has been more difficult to study and more research is necessary. Therefore, a discussion of microbial competition and predation in the context of species diversity for disease management is still worth while.

Microbial competition and predation in the soil rhizosphere has potential for managing pathogens which parasitize roots. The use of microbial diversity to manage disease falls into the category of biological control. Host diversity in polycultures encourages microbial diversity by offering a variety of niches for them to inhabit. Many fungal species including some *Bacillus*, *Streptomyces*, and *Pseudomonas* are effective competitors and predators of virulent pathogen fungi<sup>10</sup>. Once introduced, these disease suppressive effects of soil microbes are often long lasting because the bacterial populations continue to grow and establish new generations in an environment with a diverse rhizosphere. Mycorrhizal root fungi often out-compete disease fungi for space near plant roots. Some plant roots even exude enzymes to attract mycorrhizae. Some roots exude toxins to detract virulent pathogens.

One example of a parasitic fungus commercially used for managing soil disease is *Trichoderma harzianum*<sup>10</sup>. *Trichoderma* is a hyphal fungus which helps control disease in several ways:

- It penetrates the *Rhizoctonia solani* (fungus causing damping-off) cell wall with apresoria-like structures and parasitizes it.
- *Trichoderma* stimulates plant growth,
- *Trichoderma* releases an antibiotic into soils surrounding plant roots or into the plant itself.
- After colonizing near young roots of a plant, *Trichoderma* offers preventative disease control for the life of the plant.

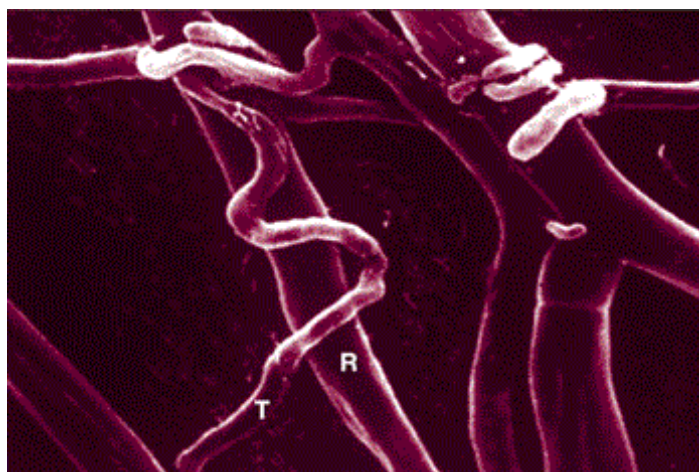


Figure 3. The *trichoderma* (T) strain is in the process of parasitizing a hypha of *R. solani* (R). The coiling reaction is typical of mycoparasitic interactions<sup>14</sup>.

A small amount of microbial rich soil (usually high in organic matter like compost) if introduced to an environment with diversity of host soil niches like that of a polyculture, will establish new microbial communities and continue to inhabit that soil for many years.

Another method in which plant mixtures can be used to control soil borne pathogens, are by way of root exudates. Root exudates from one plant may affect disease attack on roots of another plant. This is the reason for reduced incidence of *Fusarium udum* wilt of pigeon pea when grown with sorghum, as sorghum produces a toxin to *Fusarium*<sup>9</sup>. Other plant roots like marigolds exude a substance toxic to nematodes. A perennial polyculture in which roots are constantly present in the soil fosters a better long term microbial community than annual crops whose root systems are either removed by tilling or killed by harvest. Fire is another way in which soil and residue borne disease can be managed.

#### **6. Fire and Disease Suppression:**

Using fire to manage disease in a polyculture is another cultural method of control. Forest areas cleared for a swidden field are burned after about a month when the wood is dry to provide nutrients in the form of ash, and to eliminate sources of inoculum for some fungi. Burning old tree stumps is phytosanitary in the Jambi rubber growing region; removing the source of white rot fungus from the area<sup>1</sup>. In other agricultural systems, burning decreases disease severity of '*Phoma* and *Ascochyta* blights in alfalfa seed production fields, stripe rust in Kentucky bluegrass seed production fields, ergot in perennial ryegrass cultivation, rice stem rot, rice sheath blight, and *Cephalosporium* stripe of wheat.'<sup>3</sup>

Native Americans of California burned ground cover in oak forests to control the *Penicillium* and *Aspergillus* fungi that infect acorns. Fire helped maintain distance between possibly infected plant parts<sup>4</sup>. Time of burning is an important factor in disease management. In a temperate climate, burning is done to recycle nutrients when leaves fall after the plant has contributed nutrients to the leaves. In the tropics, burning is done at the end of dry season to remove potential inoculum before the most susceptible time of year for disease spread; rainy season. Although the use of fire has been used in agriculture for centuries, the effects of fire on pathogen populations are still largely unknown. Perhaps fire plays the same role as winter does to a pathogen population such as *Puccinia triticina* (leaf rust pathogen) in the United States by hindering the sexual recombination of

pathogens. If used at the correct time, fire could be used to maintain non-sexual recombination of pathogens, weakening their virulence over time. Burning is also most effectively used to control diseases which survive on litter like: *Pyrenophora tritici-repentis* (tan spot pathogen) or in the first few inches of soil like: *Gaeumannomyces graminis* var. *tritici* (take-all pathogen).<sup>3</sup>

### **Further Research and Conclusions:**

Further research is necessary in the use of fire for disease management in polycultures. Although in the interest of reducing carbon footprints, it is understandable that burning is not a popular research subject these days. The role of soil microbial diversity and disease management is another area of study requiring more research. However, the technology for gauging microbial diversity in soils is still fairly inaccurate.

When considering the agronomic applications of a polyculture for disease control, many factors must be taken into consideration:

- Number of species being planted together
- Microclimate and canopy effect of species mixture
- Plant species interactions for microbial niches
- Perennial or annual nature of the crops
- Climate of the farming area
- Pathogens found in the region or area being farmed
- Crop and wild hosts present, and their levels of resistance to varying pathogens
- Genetic diversity among host and pathogen species and among host cultivars
- Type of farm practices for planting, cultivating, and harvesting
- Crop yield stability over time

Every farming system will be different, and applying polyculture principles of disease management will require experimentation. “Experimentation with simple mixtures of susceptible and resistant genotypes can be very helpful for testing whether three basic mechanisms (dilution, barrier, and induced resistance) are active for that system”.<sup>13</sup> In cooperation with planting and cultivating a polyculture, other agricultural methods such as crop rotation, cover cropping, and fallow periods are important components to a sustainable disease management system.

More and more wheat farmers in Kansas are growing cultivar mixtures for the management of disease<sup>11</sup>. Thousands of farmers in China are now growing rice mixtures without the use of fungicides<sup>12</sup>. With the increasing economic and environmental costs of many chemical methods for disease control, and the failure of monocultures to maintain disease resistance over time, large scale agricultural systems today can use polyculture principles learned from traditional agricultural systems to manage disease while maintaining yield stability for the sustainability of their crop production systems.

## **7. References**

1. Ketteringsa QM, Wibowob TT, van Noordwijk M, Penot E. Farmers' perspectives on slash-and-burn as a land clearing method for small-scale rubber producers in Sepunggur, Jambi Province, Sumatra, Indonesia. *Forest Ecology and Management* 1999; 120: 157-169.
2. Schumann GL. *Plant Diseases: Their Biology and Social Impact*: APS Pr; 1991. 397p.
3. Cox CM, Garrett KA, Bockus WW. Meeting the challenge of disease management in perennial grain cropping systems. *Renewable Agriculture and Food Systems* 2004, 20(1): 15-24.
4. Anderson MK. *Tending the Wild; Native American Knowledge and the Management of California's Natural Resources*: Univ Cali Pr; 2005. 526p.
5. Sachs JD. *Slash-and-Burn Agriculture: the Search for Alternatives*: Univ Columbia Pr; 2005. 463p.
6. Geno L, Geno B. *Polyculture Production Principles, Benefits and Risks of Multiple Cropping Land Management Systems for Australia*: Rural Industries Research and Development Corporation; 2001. 115p.
7. Kang MS, Priyadarshan PM. *Breeding Major Food Staples*: Blackwell Pub; 2007. 437p.
8. Burdon JL, Thrall PH. Pathogen evolution across the agro-ecological interface: implications for disease management: *Evolutionary Applications*; 2008: 57-65.
9. Altieri MA. *Agroecology: The Science of Sustainable Agriculture*: Westview Pr; 1995. 433p.
10. Wolfe, D. *Tales from the Underground: a Natural history of Subterranean Life*. Basic Books; 2001. 221p.

11. Cox CM, Garrett KA, Bowden RL, Fritz AK, Dendy SP, Heer WF. Cultivar Mixtures for the Simultaneous Management of Multiple Diseases: Tan Spot and Leaf Rust of Wheat. *Phytopathology* 2004, 94(9): 961-968.
12. Zhu Y, Chen H, et al. Genetic Diversity and Disease Control in Rice. *Nature* 2000, 406: 718-722.
13. Castro, A. 2001. Cultivar Mixtures. *The Plant Health Instructor*.  
[http://www.apsnet.org/education/AdvancedPlantPath/Topics/CultivarMixtures/how\\_do\\_pg2.htm](http://www.apsnet.org/education/AdvancedPlantPath/Topics/CultivarMixtures/how_do_pg2.htm).
14. Harman GE, Howell CR, Viterbo A, Chet I, Lorito M. *Trichoderma* species — opportunistic, avirulent plant symbionts. *Nature Reviews Microbiology* 2004, 2: 43-56.