Climate Change Effects on Insects and Pathogens

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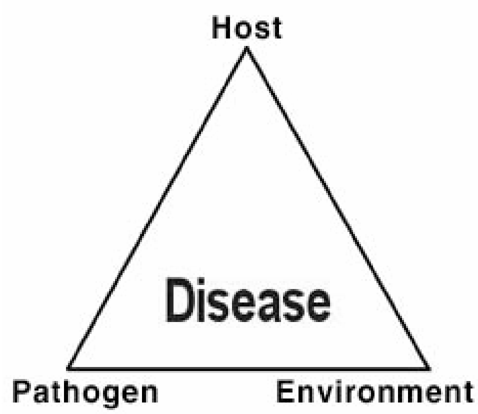
General Background

Plant pathogens, crop hosts and the environment

The study of plant disease often begins with a discussion of the "plant disease triangle".



The three legs of the triangle – host, pathogen, and environment – must be present and interact appropriately for plant disease to result. If any of the 3 factors is altered, changes in the progression of a disease epidemic can occur. The major predicted results of climate change – increases in temperature, moisture and CO_2 – can impact all three legs of the plant disease triangle in various ways. Precisely predicting the impact of climate change on plant disease is tricky business.

How rising temperatures will affect pathogens and disease

Temperature has potential impacts on plant disease through both the host crop plant and the pathogen. Research has shown that host plants such as wheat and oats become more susceptible to rust diseases with increased temperature; but some forage species become more resistant to fungi with increased temperature (Coakley et al 1999). Many mathematical models that have been useful for forecasting plant disease epidemics are based on increases in pathogen growth and infection within specified temperature ranges. Generally, fungi that cause plant disease grow best in moderate temperature ranges. Temperate climate zones that include seasons with cold average temperatures are likely to experience longer periods of temperatures suitable for pathogen growth and reproduction if climates warm. For example, predictive models for potato and tomato late blight (caused by *Phytophthora infestans*) show that the fungus infects and reproduces most successfully during periods of high moisture that occur when temperatures are between 45^{o} F (7.2^{o} C) and 80^{o} F (26.8^{o} C) (Wallin et al 1950). Earlier onset of warm temperatures could result in an earlier threat from late blight with the potential for more severe epidemics and increases in the number of fungicide applications needed for control.

How changes in moisture will affect pathogens and disease

Moisture can impact both host plants and pathogen organisms in various ways. Some pathogens such as apple scab, late blight, and several vegetable root pathogens are more likely to infect plants with increased moisture – forecast models for these diseases are based on leaf wetness, relative humidity and precipitation measurements. Other pathogens like the powdery mildew species tend to thrive in conditions with lower (but not low) moisture.

More frequent and extreme precipitation events that are predicted by some climate change models could result in more and longer periods with favorable pathogen environments. Host crops with canopy size limited by lack of moisture might no longer be so limited and may produce canopies that hold moisture in the form of leaf wetness or high canopy relative humidity for longer periods, thus increasing the risk from pathogen infection (Coakley et al 1999). Some climate change models predict higher atmospheric water vapor concentrations with increased temperature – this also would favor pathogen and disease development.

How rising CO_2 levels will affect pathogens and disease

Increased CO_2 levels can impact both the host and the pathogen in multiple ways. Some of the observed CO_2 effects on disease may counteract others. Researchers have shown that higher growth rates of leaves and stems observed for plants grown under high CO_2 concentrations may result in denser canopies with higher humidity that favor pathogens. Lower plant decomposition rates observed in high CO_2 situations could increase the crop residue on which disease organisms can overwinter, resulting in higher inoculum levels at the beginning of the growing season, and earlier and faster disease epidemics. Pathogen growth can be affected by higher CO_2 concentrations resulting in greater fungal spore production. However, increased CO_2 can result in physiological changes to the host plant that can increase host resistance to pathogens (Coakley et al 1999).

How climate change could impact plant disease management practices

While physiological changes in host plants may result in higher disease resistance under climate change scenarios, host resistance to disease may be overcome more quickly by more rapid disease cycles, resulting in a greater chance of pathogens evolving to overcome host plant resistance. Fungicide and bactericide efficacy may change with increased CO_2, moisture, and temperature. The more frequent rainfall events predicted by climate change models could result in farmers finding it difficult to keep residues of contact fungicides on plants, triggering more frequent applications. Systemic fungicides could be affected negatively by physiological changes that slow uptake rates, such as smaller stomatal opening or thicker epicuticular waxes in crop plants grown under higher temperatures. These same fungicides could be affected positively by increased plant metabolic rates that could increase fungicide uptake. It is not well understood how naturally-occurring biological control of pathogens by other microbial organisms could change as populations of microorganisms shift under changed temperature and moisture regimes – in some cases antagonistic organisms may out-compete pathogens while in others pathogens may be favored. Exclusion of pathogens and quarantines through regulatory means may become more difficult for authorities as unexpected pathogens might appear more frequently on imported crops.

How this will affect farmers

Although the specific impacts of climate change on plant disease are difficult to predict given our current knowledge, it seems possible to make several generalizations for farmers in the northeastern US: a) increased winter temperatures will likely mean higher populations of pathogens survive to initially infect plants; b) increased temperatures will likely result in northward expansion of the range of some diseases because of earlier appearance and more generations of pathogens per season; c) more frequent and more intense rainfall events will tend to favor some types of pathogens over others (Coakley et al 1999). Two pathogens important in the northeastern US, Stewart's wilt and late blight, illustrate some of these effects.

Stewart's wilt, a bacterial (*Erwinia stewartii*) disease of generally sporadic importance in sweet corn in the northeast, is vectored by the corn flea beetle (*Chaetocnema pulicaria*). Survival of the vector through winter is considered key to the severity of Stewart's wilt infections the following year. Currently, a forecast model based on winter temperatures is used to predict severity for Stewart's wilt. The model assumes the survival of the corn flea beetle is higher in warmer winters than colder winters (Castor et al 1975). Climate change resulting in more winters that allow larger populations of flea beetles to survive would be expected to increase the frequency of growing seasons with severe Stewart's wilt.

Stewart's wilt (transmitted by the corn flea beetle) frequency may be increased by climate change (flea beetle from Shelton - http://www.nysaes.cornell.edu/ent/factsheets/pests/cornfb.html; Stewart's wilt from Petzoldt)

Farmers in the northeastern US now attempt to control Stewart's wilt by planting resistant varieties and using in-furrow or foliar insecticides to control the flea beetle vector (Stivers 1999, Fournier 1999, Whitney et al 2000, Baniecki and Dabaam 2000). Farmers would incur increased costs as a result of increased frequency of insecticide treatment and the accompanying negative environmental impacts would mount. Resistant varieties are the most effective method for Stewart's wilt control, yet few varieties offer high levels of resistance and some popular varieties offer only moderate or low levels of resistance (Stivers 1999a, Fournier

1999, Whitney et al 2000, Baniecki and Dabaam 2000a). Higher levels of Stewart's wilt in more growing seasons could impact farmers' variety selection forcing them to choose varieties based on Stewart's wilt resistance rather than market qualities such as taste, texture, and appearance. Farmers' profitability could thus be impacted by the varieties they would be forced to grow to combat Stewart's wilt.

Late blight (*Phytopthora infestans*) infects both potatoes and tomatoes in the northeastern US. It can be a devastating disease for both crops and farmers, with complete crop loss a possibility if control measures are not employed. Infection is triggered by high moisture conditions within a fairly specific temperature range. Annually, 5-20 fungicide applications from as early as June through August are used in the northeastern US (Stivers 1999b, Hoffman 1999. Baniecki and Dabaam 2000b). This represents a significant expense to farmers and a significant environmental risk. Work in Finland, which is considered to be in a similar late blight risk zone to the northeastern US (Hijmans 2000), has predicted that for each 1 C warming late blight would occur 4 to 7 days earlier, and the susceptibility period extended by 10 to 20 days (Kaukoranta 1996). This would likely translate into an additional 1 to 4 additional fungicide applications for northeastern US potato farmers – increasing both farmer costs and environmental risk.

Late blight severity and control costs may be increased by climate change. (Late blight from Fry)

Insects and the environment

Insects are cold-blooded organisms - the temperature of their bodies is approximately the same as that of the environment. Therefore, temperature is probably the single most important environmental factor influencing insect behavior, distribution, development, survival, and reproduction. Insect life stage predictions are most often calculated using accumulated degree days from a base temperature and biofix point. Some researchers believe that the effect of temperature on insects largely overwhelms the effects of other environmental factors (Bale et al 2002). It has been estimated that with a 2^{o} C temperature increase insects might experience one to five additional life cycles per season (Yamamura & Kiritani 1998). Other researchers have found that moisture and CO_2 effects on insects can be potentially important considerations in a global climate change setting (Hamilton 2005, Coviella and Trumble 1999, Hunter 2001).

How rising temperatures affect insects

Climate change resulting in increased temperature could impact crop pest insect populations in several complex ways. Although some climate change temperature effects might tend to depress insect populations, most researchers seem to agree that warmer temperatures in temperate climates will result in more types and higher populations of insects.

Increased temperature could increase *pest insect populations*

Researchers have shown that increased temperatures can potentially affect insect survival, development, geographic range, and population size. Temperature can impact insect physiology and development directly or indirectly through the physiology or existence of hosts. Depending on the development "strategy" of an insect species, temperature can exert different effects (Bale et al 2002). Some insects take several years to complete one life cycle – these insects (cicadas, arctic moths) will tend to moderate temperature variability over the course of their life history. Some crop pests are "stop and go" developers in relation to temperature – they develop more rapidly during periods of time with suitable temperatures. We often use degree-day or phenology based models to predict the emergence of these insects and their potential to damage crops (cabbage maggot, onion maggot, European corn borer, Colorado potato beetle). Increased temperatures will accelerate the development of these types of insects – possibly resulting in more generations (and crop damage) per year.

"Migratory" insects (corn earworm in northern parts of the northeast) may arrive in the Northeast earlier, or the area in which they are able to overwinter may be expanded. Natural enemy and host insect populations may respond differently to changes in temperature. Parasitism could be reduced if host populations emerge and pass through vulnerable life stages before parasitoids emerge. Hosts may pass though vulnerable life stages more quickly at higher temperatures, reducing the window of opportunity for parasitism. Temperature may change gender ratios of some pest species such as thrips (Lewis 1997) potentially affecting reproduction rates. Insects that spend important parts of their life histories in the soil may be more gradually affected by temperature changes than those that are above ground simply because soil provides an insulating medium that will tend to buffer temperature changes more than the air (Bale et al 2002).

Lower winter mortality of insects due to warmer winter temperatures could be important in increasing insect populations (Harrington et al. 2001). Higher average temperature might result in some crops being able to be grown in regions further north – it is likely that at least some of the insect pests of those crops will follow the expanded crop areas. Insect species diversity per area tends to decrease with higher latitude and altitude (Gaston & Williams 1996, Andrew & Hughes 2005), meaning that rising temperatures could result in more insect species attacking more hosts in temperate climates (Bale et al 2002). Based on evidence developed by studying the fossil record some researchers (Bale et al 2002) conclude that the diversity of insect species and the intensity of their feeding have increased historically with increasing temperature.

Increased temperature could decrease *pest insect populations*

Some insects are closely tied to a specific set of host crops. Temperature increases that cause farmers not to grow the host crop any longer would decrease the populations of insect pests specific to those crops. The same environmental factors that impact pest insects can impact their insect predators and parasites as well as the disease organisms that infect the pests, resulting in increased attack on insect populations. At higher temperatures, aphids have been shown to be less responsive to the aphid alarm pheromone they release when under attack by insect predators and parasitoids – resulting in the potential for greater predation. (Awmack et al 1997).

How changes in precipitation will affect insects

There are fewer scientific studies on the effect of precipitation on insects than temperature. Some insects are sensitive to precipitation and are killed or removed from crops by heavy rains - in some northeastern US states, this consideration is important when choosing management options for onion thrips (Reiners and Petzoldt 2005). For some insects that overwinter in soil, such as the cranberry fruitworm and other cranberry insect pests, flooding the soil has been used as a control measure (Vincent et al 2003). One would expect the predicted more frequent and intense precipitation events forecasted with climate change to negatively impact these insects. Other insects such as pea aphids are not tolerant of drought (Macvean and Dixon 2001). As with temperature, precipitation changes can impact insect pest predators, parasites, and diseases resulting in a complex dynamic. Fungal pathogens of insects are favored by high humidity and their incidence would be increased by climate changes that lengthen periods of high humidity and reduced by those that result in drier conditions.

How rising CO_2 levels affect insects

Generally CO_2 impacts on insects are thought to be indirect - impact on insect damage results from changes in the host crop. Some researchers have found that rising CO_2 can potentially have important effects on insect pest problems. Recently, free air gas concentration enrichment (FACE) technology was used to create an atmosphere with CO_2 and O_2 concentrations similar to what climate change models predict for the middle of the 21st century. FACE allows for field testing of crop situations with fewer limitations than those conducted in enclosed spaces. During the early season, soybeans grown in elevated CO_2 atmosphere had 57% more damage from insects (primarily Japanese beetle, potato leafhopper, western corn rootworm and Mexican bean beetle) than those grown in today's atmosphere, and required an insecticide treatment in order to continue the experiment. It is thought that measured increases in the levels of simple sugars in the soybean leaves may have stimulated the additional insect feeding (Hamilton et al. 2005).

Although not observed in the FACE study, other researchers have observed that insects sometimes feed more on leaves that have a lowered nitrogen content in order to obtain sufficient nitrogen for their metabolism (Coviella and Trumble 1999, Hunter 2001). Increased carbon to nitrogen ratios in plant tissue resulting from increased CO_2 levels may slow insect development and increase the length of life stages vulnerable to attack by parasitoids (Coviella and Trumble. 1999).

How this will affect farmers

It is likely that farmers will experience extensive impacts on insect management strategies with changes in climate. Entomologists expect that insects will expand their geographic ranges, and increase reproduction rates and overwintering success. This means that it is likely that farmers in the northeastern US will have more types and higher numbers of insects to manage. Based on current comparisons of insecticide usage between more southern states and more northern states, this is likely to mean more insecticide use and expense for northeastern farmers. New York conditions currently require 0-5 insecticide applications against lepidopteran insect pests to produce marketable sweet corn (Stivers 1999a); Maryland and Delaware conditions require 4-8 insecticide applications (Fournier 1999, Whitney et al. 2000); Florida conditions require 15-32 applications (Aerts et al, 1999). It is apparent that for sweet corn pests, warmer temperatures translate to increased insecticide applications to produce a marketable crop. Insecticides and their applications have significant economic costs for growers and environmental costs for society. Additionally, some classes of pesticides (pyrethroids and spinosad) have been shown to be less effective in controlling insects at higher temperatures (Musser & Shelton 2005).

Entomologists predict additional generations of important pest insects in temperate climates as a result of increased temperatures, probably necessitating more insecticide applications to maintain populations below economic damage thresholds. A basic rule of thumb for avoiding the development of insecticide resistance is to apply insecticides with a particular mode of action less frequently (Shelton et al 2001, Georghiou and Taylor 1986). With more insecticide applications required, the probability of applying a given mode of action insecticide more times in a season will increase, thus increasing the probability of insects developing resistance to insecticides.

In New York a network of pheromone traps in sweet corn fields has been used to monitor corn earworm (*Helicoverpa zea*) throughout the central and western part of the state for over 10 years (Seaman personal communication). Corn earworm is thought not to overwinter in upstate New York and is generally considered to be a late season, migratory pest of sweet corn, so trapping was initiated in mid-July. The graphs in Figure 1 compare the trap catches in 1995 with those in 2003 in Eden Valley, NY.

Corn earworm adult

Corn earworm larva

(Corn earworm from Seaman)

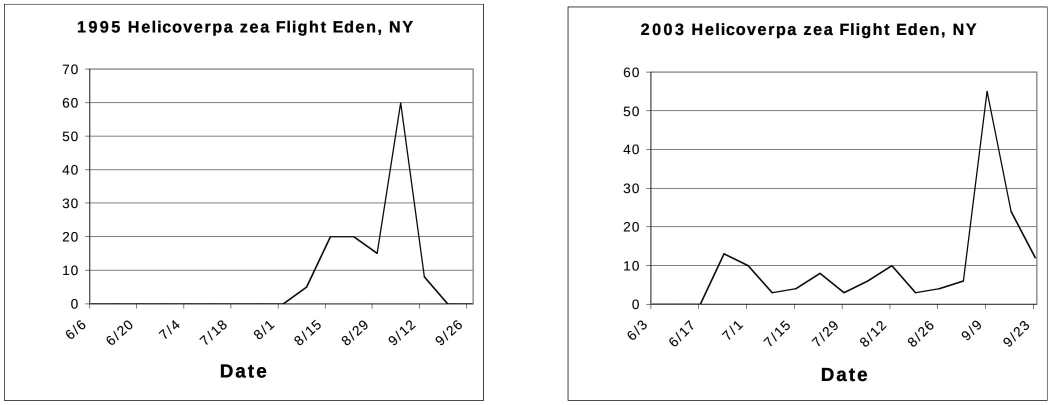


Figure 1: trap catch data indicating possible over wintering of corn earworm in western NY

During the early years of the trap network, CEW traps remained empty until mid-late August. After an unexpected early season infestation in Eden in 1999 trapping was initiated in early June, and typically, low levels of moths are caught through the early season, increasing when the migratory flight arrives. It is yet to be determined if the earlier arrival of corn earworm indicates it is overwintering in Eden, but since CEW management recommendations are based on trap catches, it is clear that control of this pest is already costing farmers more than it did nine years ago.
A number of cultural practices that can be used by farmers could be affected by changes in climate – although it is not clear whether these practices would be helped, hindered, or not affected by the anticipated changes. Using crop rotation as an insect management strategy could be less effective with earlier insect arrival or increased overwintering of insects. However, this could be balanced by changes in the earliness of crop planting times, development, and harvest. Row covers used for insect exclusion might have to be removed earlier to prevent crop damage by excessive temperatures under the covers – would the targeted early insects also complete their damaging periods earlier or be ready to attack when the row covers were removed?

What farmers can do to adapt

Farmers should keep in mind that climate change is likely to be a gradual process that will give them some opportunity to adapt. Although changes in our northeastern US climate are almost certainly happening, it is not precisely understood how these changes will affect crops, insects, diseases, and the relationships among them. If climate is warmer will increases in yield offset losses to pests, or will losses to pests outweigh yield advantages from warmer temperatures? It is likely that new pests will become established in more northerly areas and be able attack plants in new regions. It is likely that plants in some regions will be attacked more frequently by certain pests. A few pests may be less likely to attack crops as change occurs. It is likely that we will not know the actual impacts of climate change on pests until they occur. Clearly, it will be important for farmers to be aware of crop pest trends in their region and flexible in choosing both their management methods and in the crops they grow. Farmers who closely monitor the occurrence of pests in their fields and keep records of the severity, frequency, and cost of managing pests over time will be in a better position to make decisions about whether it remains economical to continue to grow a particular crop or use a certain pest management technique. If more fungicide or insecticide applications are required in order to successfully grow a particular crop, farmers will need to carefully evaluate whether growing that crop remains economical. Those farmers who make the best use of the basics of integrated pest management (IPM) such as field monitoring, pest forecasting, recordkeeping, and choosing economically and environmentally sound control measures will be most likely to be successful in dealing with the effects of climate change.

Summary

• The precise impacts of climate change on insects and pathogens is somewhat uncertain because some climate changes may favor pathogens and insects while others may inhibit a few insects and pathogens.

The preponderance of evidence indicates that there will be an overall increase in the number of outbreaks of a wider variety of insects and pathogens.

• The possible increased use of fungicides and insecticides resulting from an increase in pest outbreaks will likely have negative environmental and economic impacts for agriculture in the northeastern US.

• The best economic strategy for farmers to follow is to use integrated pest management practices to closely monitor insect and disease occurrence. Keeping pest and crop management records over time will allow farmers to evaluate the economics and environmental impact of pest control and determine the feasibility of using certain pest management strategies or growing particular crops.

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