Chapter 9
Challenges and Opportunities in Managing Diseases in No-Till Farming Systems

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Abstract Under NT management, there are several pathogens that often increase, such as *Rhizoctonia solani* and *Fusarium* spp., or decrease, such as *Gaeumannomyces graminis* and *Pratylenchus neglectus*. While NT farming can lead to more inoculum in residue, soil, weeds, or volunteers, and changes in the microclimate that may affect disease development, there are management approaches that can reduce disease. Some of the most effective approaches include crop rotation, planting resistant varieties, and use of fungicides and herbicides, as well as managing stubble residue and mechanical disruption during planting. Additional research is needed for many crops that have potential to yield more in NT than in CT systems, and in South America and Asia where NT is implemented on the greatest area of land.

Keywords No-till · Disease management

9.1 Management of No-Till Farming Systems

For disease management, one of the most important distinctions between no-till (NT) and conventional tillage (CT) farming systems is the plant residue that is left on the surface of the soil from the previous crop. No-till management involves planting directly into residue from the previous crop with no tillage or soil disturbance to form a seedbed before planting (Baker et al. 1996; Paulitz 2006). The method leaves surface residue remaining intact, with at least 30% or 1.12 Mg ha^{-1} of residue remaining according to the USDA's definition (Smiley and Wilkins 1993) and up to 70% retained in some systems (Baker et al. 1996). The intact residue can serve as a source of inoculum for the subsequent crop. The residue is colonized by micro-organisms, some of which can be pathogenic and cause disease under favorable conditions.

Another factor in NT systems important for the emergence of disease is the use of planting methods that minimize soil disturbance. Planting methods have

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implications for pathogens surviving on and below the soil surface and on the physical disruption and dispersal of pathogen vegetative and sexual propagules.

Disease occurs only where there is a susceptible crop, virulent pathogen, and an environment conducive to the survival of the pathogen and its life cycle stages necessary for infection. Changes in the soil microenvironment affect pathogen populations. Tillage affects moisture, temperature, and pore space, which affect plant pathogen survival, reproduction, and abundance.

This chapter focuses on disease management, primarily in systems in which NT practices can out-yield or equal CT because these are the areas where NT is likely to continue to expand in the future. However, the scientific literature is lacking for many of these crops and regions of the world. There are eight countries that comprise 97% of the global no-till acreage reported, with 46.8% of the global NT acreage in South America (Derpsch et al. 2010). However, most research has been conducted in the United States, Canada, and Australia, with very few studies published from South America and Asia. These areas need greater research on disease management because successful practices are regionally specific.

Based on meta-analysis, the largest factors that drive the yield differential in NT systems are the crop species and to a slightly lesser extent, aridity. Oilseed, cotton, and legume NT yields matched CT, while wheat yielded slightly less in NT systems (2.6%), and maize and rice yielded less (>7.5%) (Pittelkow et al. 2015). With only slight differences in wheat production, there have been many research studies conducted to determine how to manage disease in small grain NT production systems. For maize and rice, the yield discrepancy between CT tillage and NT makes the system less cost-effective, which may explain the limited published studies on NT disease management for these crops. For legumes, oilseeds and cotton, disease management research across a wider geographic range may help to make systems even more profitable.

9.2 Challenges of Disease Management

Additional sources of inoculum No-till management has been used in cereal grain production in Australia, Canada, Argentina, and Brazil but is not commonly employed in Europe or in the Pacific Northwest of the United States (Paulitz 2006). A significant barrier to adoption of NT in these areas is the potential increase of residue- and soil-borne pathogens. No-till systems pose challenges in the management of pathogens where substantial inoculum comes from stubble of the previous crop or from the soil. For pathogens that are present on the residue, the rate of residue decomposition affects their ability to survive until the next host crop is planted. Under NT practices, residue decomposes at a lower rate on the soil surface as a result of lower temperatures due to shading and lower water potential due to infiltration (Summerell and Burgess 1988). If burned, partially buried, or managed in a CT system, the residue decomposes more rapidly.

Weed and Volunteer Seedlings as source of disease In CT systems, tillage is used to eliminate weeds and volunteer seedlings that harbor pathogens and create a "green bridge" where biotrophic pathogens that depend on living tissue can survive until the next crop. In the Pacific Northwest, barley and wheat plantings are particularly susceptible to root rot when planted into volunteer wheat and barley or weedy pasture (Roget et al. 1987; Smiley et al. 1992). The volunteers and weeds maintain or increase inoculum levels, resulting in higher disease levels in the subsequent crop. Control of volunteers and weedy hosts is important for controlling viral and soil-borne diseases by reducing the amount of primary inoculum (Kirby et al. 2017).

Micro-environment Soil-borne and residue-borne pathogens are heavily influenced by soil moisture and temperature, which are affected by tillage. As Bailey and Duczek (1996) describe, soil has higher moisture and is lower in temperature in NT systems due to the retention of additional crop residue. This can cause diseases to either increase, decrease or remain unchanged. The observed changes in intensity depend on environmental factors and are variable depending on the year and location grown. For example, low leaf disease severities in wheat were observed in dry hot conditions in Saskatchewan between 1987 and 1992, limiting differences due to effect of tillage, but the years following experienced higher moisture promoting higher disease levels and yield loss in tilled systems (Bailey et al. 1992).

9.2.1 Diseases that Are Reduced in No-Till Systems

There are several diseases that generally decrease in NT systems. Pathogens can be reduced in NT managed systems due to greater competition within the microbial communities that develop and diversify over time when soils are not disturbed, and through changes in the environmental factors that affect pathogen life cycles and dispersal. One example of a disease that often declines in NT systems is take-all disease of cereal crops (Baker et al. 1996). Take-all is caused by the fungal pathogen *Gaeumannomyces graminis* (Sacc.) Arx & Oliver var. *tritici.* When compared with burned and CT treatment, the NT treatments with crop rotation and either burning, stubble removal, or no stubble removal in dryland wheat production all had lower levels of take-all disease (Paulitz et al. 2010). This long term decline in take-all has been observed worldwide and is due to antagonistic *Pseudomonas* spp. that accumulate in the rhizosphere and produce antifungal compounds (Weller et al. 2002; Paulitz et al. 2010). But in a dryland wheat study, species that produce antifungal compounds were also increased in burned and plowed treatments, suggesting that the differences in the NT treatments were due largely to the effect of crop rotation. In other studies, take-all disease was generally limited due to the reduced movement of soil (Baker et al. 1996).

Nematode populations are also commonly reduced under NT practices. The root-lesion nematode *Pratylenchus neglectus* (Rensch) Filipjev Schuurmanns & Stekhoven population was lower in winter wheat-spring barley-canola NT systems where stubble was left standing or mechanically removed, as compared to

CT. However there was also no difference in two of the five years (Paulitz et al. 2010). Root damage caused by another parasite, the cereal cyst nematode (*Heterodera avenae* Woll.), was also found to be reduced, or no different, in NT systems around the world (Roget et al. 1996). Damage from cereal cyst nematode was reduced in three studies in southern Australia (Rovira and Simon 1982; Roget and Rovira 1985; Roget et al. 1996), with no difference in a fourth study (de Boer et al. 1991). Reduced disease from nematodes was attributed to less root damage in the NT treatments. Roget et al. (1996) concluded that it was unlikely that juveniles were trapped in weedy hosts or volunteers, but that the reduction was likely due to limited movement of nematodes and cyst dispersal from lower soil disturbance.

Common root rot caused by *Bipolaris sorokiniana* (Sacc. in Sorok.) Shoem. generally declined under NT compared with CT across several studies in North America, though no differences were observed in some years and locations (Bailey and Duczek 1996). While inoculum was reduced, the inoculum density did not affect disease severity. The authors suggested that the reduction in disease in NT systems could be due to reduced sporulation due to exposure to freezing temperatures, to which the fungus is sensitive. Other causes of lower disease could be the shallower planting depth used in NT, as more root rot occurs with deeper seeding, or the lower temperatures and higher moisture of NT since *B. sorokiniana* causes greatest disease severity under high temperature and low moisture (Bailey and Duczek 1996).

Charcoal rot, caused by *Macrophomina phaseolina* (Tass.) Goid. is the most common root disease of soybeans in Brazil (Wrather et al. 1997) and is most severe under hot and dry conditions. Almeida et al. (2003) found a greater proportion of infected roots in CT treatments compared to NT in dry conditions (<840 mm annual rainfall) and no difference under wet conditions. They attributed the differences observed to the lower water loss and soil temperature in the NT system due to residue coverage and lower light penetration. In moist areas that have frequent droughts, NT could reduce the chance of crop losses due to charcoal rot.

Fusarium crown rot, which was found to be higher in asparagus in Michigan when disked in the spring and fall compared to NT (Putnam and Lacy 1977). In this instance, disease levels may have been reduced in NT due to a reduction in mechanical damage due from tilling that can allow pathogens to more easily infect plants through open wounds.

9.2.2 Diseases that Are Increased in No-Till Systems

There are also several diseases that often increase in severity under NT practices. Among these, Rhizoctonia root rot, caused by the fungal pathogen, *Rhizoctonia solani* (Kühn) is the most common soil-borne disease that increases under NT management (Baker et al. 1996). It is widespread across crops, including many cereal, legume, and vegetable crops (Fig. 9.1). Rhizoctonia root rot is typically a minor disease of cereals in CT systems, but can be devastating in NT systems when planted into cereal stubble (Stubbs et al. 2004). Bare patches in wheat, barley and durum

Fig. 9.1 Rhizoctonia solani lesions on common bean plants. (Photograph courtesy of H. F. Schwartz, Colorado State University, Bugwood.org)

caused by Rhizoctonia root rot were first observed in the United States in 1984 in Oregon, Idaho, and Washington and was only found in fields planted using conservation tillage practices, including NT direct drilling into stubble, sowing with minimal tillage, or tillage the day of planting (Weller et al. 1986). Many studies in southern Australia have also demonstrated an increase in Rhizoctonia in NT systems (MacNish and Lewis 1985; Rovira 1987; de Boer et al. 1991). Subsequent studies in wheat have shown that *R. solani* populations and resulting disease were higher in NT (Paulitz et al. 2010). However, when left in continuous NT management for 7–10 years, Rhizoctonia rot diminished (Kirby et al. 2017). This may result from natural disease suppression as microbial communities become more diverse over time without disturbance.

In vegetable NT systems, young seedlings are directly exposed to *R. solani* from the surface residue causing poor stands and deformed plants. Moldboard plowing compared to reduced tillage methods reduced *R. solani* populations by 75% after corn, 16% after legumes, and 12% after vegetables (Sumner et al. 1986a, b). Among many vegetables tested, Sumner et al. (1986a, b) also found diseases of snap bean and lima bean were caused by *R. solani* and an unidentified basidiomycete, when following corn in NT systems. They found root and hypocotyl cankers as well as postemergence damping off to be less common in CT treatments (Sumner et al. 1986a, b). However, large populations of *R. solani*, do not necessarily result in disease development or reduced yield. For example, despite higher *R. solani* concentrations in NT systems, there were no major yield losses during the course of a 6 year study, which was attributed to potential compensation from adequate moisture levels or microbial suppression (Paulitz et al. 2010). And although Rhizoctonia root rot was more severe in NT spring barley compared with moldboard plowed, there was no relationship with yield; barley yield was actually higher in the NT managed treatments due to less loss of water in the tilled plots prior to planting (Smiley and Wilkins 1993). The trend was not isolated to particular years or locations; Smiley and Wilkins (1993) found the yield was highest in treatments with the highest consecutive years of NT management across locations.

Fig. 9.2 *Fusarium* head blight of wheat. (Photograph courtesy of Donald Groth, Louisiana State University AgCenter, Bugwood.org)

Other common fungal pathogens of NT systems are *Fusarium* spp., which also cause significant damage to many crop species, including wheat (Fig. 9.2). In Germany, France, Switzerland and Croatia, higher disease incidence of Fusarium head blight in wheat following maize has been observed in NT and reduced tillage systems (Basch et al. 2008; Vrandečić et al. 2019). Disease caused by *Fusarium* spp. is likely higher under reduced tillage due to changes in soil moisture, temperature, and seeding depth (Bailey and Duczek 1996). In vegetables, reduced tillage increased root rot with symptoms from *Fusarium* (Abawi and Crosier 1992).

In studies conducted in NT vegetable systems, several additional pathogen species were associated with root disease. Abawi and Widmer (2000) found lower yield in snap beans in New York due to disease in reduced tillage compared to intensive tillage. In addition to *Fusarium* and *Rhizoctonia, Thielaviopsis* was also attributed to increased root rot in NT vegetable production (Abawi and Crosier 1992). Southern blight caused by *Sclerotium rolfsii* Sacc. survives saprophytically on residue on or near the soil surface. Yield losses due to southern blight were greater in reduced tillage systems compared to deep tillage in carrot and tomato in tropical regions, and in lettuce in Australia (Sumner et al. 1986a, b). Cercospora leaf spot (*Cercospora cruenta* Sacc.) and rust of cowpea (*Uromyces* spp.) and early bight of tomato, caused by *Alternaria solani* (Ell. & Mart.) L.R. Jones and Grout, were found to be more severe in reduced tillage than with moldboard ploughing (Sumner et al. 1986a, b). The authors attributed the higher disease levels more to the overall plant health due to access and uptake of nutrients and tillage compaction rather than a change in the pathogen community.

9.2.3 Diseases Not Affected by Tillage

Root diseases caused by pathogens that survive for long periods of time in the soil and are not impacted by disturbance may remain unaffected by NT, or even decrease in severity due to competition with other microbes and more limited dispersal. In vegetable production systems, *Pythium* spp. are usually not affected by conservation tillage methods; possibly because *Pythium* spp. can survive for several months as oospores in the soil (Sumner et al. 1986a, b). The inoculum is likely not increased substantially by the presence of residue on the surface. Fusarium in vegetable production in the southeast US was also not affected by tillage practice, with rotation more important in management of *Fusarium* spp. (Sumner et al. 1986a, b).

9.2.4 Disease Variability in No-Till Systems

There are many cases of disease that are influenced by environmental conditions. Take-all severity has been somewhat variable by region (Roget et al. 1996), with reductions observed in Britain (Brooks and Dawson 1968; Lockhart et al. 1975; Bockus et al. 1994), increases in the northwest United States (Moore and Cook 1984), and either no effect or increase in southern Australia (Kollmorgen et al. 1987; de Boer et al. 1991). Some of this variability is due to temperature or moisture differences. In Kansas, the soil temperatures in plots with residue left to shade the soil surface were 8–10 °C cooler than unshaded plots and had the higher severity of take-all with lower wheat grain yields (Bockus et al. 1994). Higher soil moisture of NT systems also facilitates greater microbial activity and faster decomposition of infected residue and limitation of *G. graminis* (Garrett 1938). However, while higher soil moisture reduces take-all disease in some environments, temperature was the driving factor in take-all disease development in Kansas (Bockus et al. 1994). In areas where high temperatures exist with high summer rainfall, take-all may also be more severe under NT management, which reduces the soil temperature enough to allow the pathogen to survive in the presence of adequate moisture.

9.3 Management Options to Address Disease Challenges

The management practices to address disease challenges in NT are similar to those used in CT. But, as emphasized by Baker et al. (1996), correct identification of the pathogen is essential as the management measures for a pathogen may differ in efficacy between NT and CT.

9.3.1 Crop Rotation

The order of rotation is the most important factor in reducing disease in dryland production in both NT and CT systems. If a crop is not rotated, the severity of disease may also become higher over time due to the evolution of more aggressive pathogen strains (Bailey and Duczek 1996).

Root disease severity in vegetable crops, including lima bean, cowpea, cucumber, and spinach, have exhibited higher disease levels due to conservation tillage practices. Disease levels of reduced and CT tillage treatments were the same, however, when grown in a different crop rotation (Sumner et al. 1986a, b). This indicates that increases in disease due to reduced tillage could be mitigated by changing the crop rotation.

Rotations of multiple years before planting similar crop species, such as broadleafs and cereals, are needed to achieve disease reduction (Bailey and Duczek 1996). Although other management techniques can reduce the severity of Fusarium head blight in cereals, the disease reduction is not sufficient without altering the rotation sequence so that wheat does not follow maize (Vogelgsang et al. 2011). In some cases, longer rotations may be needed when pathogens remain viable for long periods of time. The fungal pathogen, *B. sorokiniana,* which causes root rot in wheat, has spores that remain viable up to 4 years (Bailey and Duczek 1996). Rotations are very effective in limiting disease, but may require multiple years and do not allow flexibility to plant the most profitable crop.

9.3.2 Genetic Resistance

For pathogens that have a very wide host range, or infect all economically important crops for a region, crop rotation may not be a feasible method of disease control. One example of this is in the control of charcoal rot on soybeans in Brazil. Charcoal root rot affects both corn and soybeans, as well as cotton, peanut, sunflower, sorghum, and other vegetable crops (Almeida et al. 2003). In these instances, disease resistant cultivars often offer the most cost-effective solution.

In perennial grain cropping systems, yearly rotation is also not possible. Perennial grain crops are being developed to restore capacities of native grasslands, preventing erosion and maintain water and nutrients. But the perennial nature of the system poses a challenge in elimination of the annual rotation schedule. In these instances it is important that the crops selected for development have broad genetic diversity (Jensen et al. 2016) and strong genetic resistance to disease (Turner et al. 2013). Genetic resistance is being combined with other management techniques and a diverse soil microbial community that develops over time, to reduce diseases in perennial grain crops.

Genetic resistance is also available for ubiquitous, aerially dispersed pathogens and their diseases where rotation is not effective (Paulitz 2006), for some long-living pathogens that infect roots (Kirby et al. 2017), and is an important tool for reducing mycotoxin accumulation in maize and cereal grains (Campa et al. 2005). Genetic resistance provides a control strategy that does not require additional costly inputs or additional labor in management. For many soilborne pathogens, however, genetic resistance is not available, and growers are more reliant on cultural practices.

9.3.3 Chemical Control of Disease

In combination with crop rotation and genetic resistance, chemical control provides a solution for high value crops grown in environments conducive to high disease pressure. Baker et al. (1996) suggest using chemical control to complement rotation. This chemical control includes both fungicides to manage disease and herbicides to manage weedy or volunteer plants that could harbor pathogens of insect vectors of pathogens.

9.3.3.1 Fungicide

For foliar fungicides to be cost effective, grain prices must be sufficiently high (Bailey and Duczek 1996) and environmental conditions conducive to disease development. Often when moisture conditions are optimal for high yield potential, they are also likely to produce high disease pressure from numerous fungal and bacterial pathogens.

To avoid applying chemicals when environmental conditions are not conducive for disease development, modeling programs have been designed that are specific to crop, pathogen and disease, and location. An example is the FusaProg developed in Switzerland, which incorporates cropping factors, previous crop, soil and straw management, and cultivar susceptibility with growth stage and weather conditions in a model that predicts the toxin content of wheat prior to harvest (Musa et al. 2007). In Canada there is a similar program called DONcast (Schaafsma and Hooker 2007) and in France and Belgium there is a program called Qualimètre® (Froment et al. 2011). These programs allow growers to determine a threshold of tolerance to determine when to apply fungicides optimally.

One limitation to these tools is the need to calibrate them to each location and design models specific for local conditions. When the DONcast model was applied to the Czech Republic, the most predictive parameters included the previous crop, total precipitation and average temperature in April, and total precipitation and average temperature 5 days before anthesis; but in other regions additional factors like cultivar, fungicide use, climate factors during different times in the growing season, leaf wetness, and growth stage were more relevant (Van Der Fels-Klerx and Booij 2010). When considering other crops, there are different parameters to consider as well. In maize the best fitting model developed for Argentina and the Philippines included predictors of insect damage, and weather at four time periods (Campa et al. 2005); in Italy the optimal model included longitude, maturity class, sowing date, and growing weeks (Battilani et al. 2008).

9.3.3.2 Herbicide

Chemical application to control weeds and volunteer crops also require a significant investment to the producer and will be driven largely by the value of the crop and the potential for crop losses due to disease. Volunteer crops and weedy hosts facilitate a 'green-bridge' of living tissue that can harbor pathogens and insect vectors until the next crop germinates. In CT systems, the field would be tilled prior to planting to remove weeds, including volunteers, and prepare the seedbed. To avoid this overlap of susceptible plants in NT systems, herbicide can be applied to kill the weeds and volunteer seedlings. After a herbicide treatment, delaying planting by at least 21 days after spraying prevented transmission of bacteria in continually cropped cereals (Baker et al. 1996).

Breaking the "green bridge" period before planting when volunteer cereals or weedy hosts of *R. solani* are growing is one of the most effective practices in decreasing Rhizoctonia rot in barley (Smiley et al. 1992). Roget et al. (1987) showed that Rhizoctonia rot in direct-drilled wheat was lower and grain yields were higher when volunteer pasture comprised largely of barley and ryegrass was sprayed 3–6 weeks prior to planting. *R. solani* can colonize dead or dying weeds and volunteers and contribute to higher levels of infection if planted too quickly after spraying (Smiley et al. 1992). When volunteer barley was killed by spraying the canola crop, the canola was infected with *R.solani* and began dying within 2 weeks (Paulitz et al. 2010). The timing of killing weed and previous crop is thus crucial for control of disease when the crop can host the same diseases.

Besides herbicide chemical weed control, non-chemical controls can be used to manage weeds and volunteers including flame weeding, steam weeding, knife rolling, or hand weeding (Baker et al. 1996). These methods require additional labor or specialized equipment, but are valuable in systems where herbicide use is not possible.

9.3.4 Stubble and Residue Management

Management of standing stubble and crop residue is particularly important in NT agriculture, providing a method to reduce the population sizes of some residue-borne pathogens. For example, burning stubble reduced *Fusarium psuedograminearum* and *F. culmorum* in winter wheat-spring barley-canola NT system to levels no different from CT tillage (Paulitz et al. 2010). The authors of this study also found that inoculum was higher when stubble was mechanically removed or left standing, but that stubble removal had no effect on *R. solani* inoculum concentration. Burning has also been used successfully to control *Sclerotium oryzae* (Catt.) in rice, Blind seed disease of grasses, and Cephalosporium stripe of wheat (Skoglund et al. 1999).

Although burning has been shown to be effective in reducing infected residue, some concern exists that burning could reduce total carbon which would could be detrimental for maintaining and improving soil quality (Basch et al. 2008). But Chan et al. (2002) found that burning did not affect the total carbon as much as tillage, which explained 80% of the variation. Particulate organic carbon and mineralizable nitrogen were also reduced more by tillage than by burning. These results indicated that tilling can have a much greater negative effect on soil health than burning.

Another method of reducing stubble involves chopping residues finely for faster decomposition. When wheat follows maize in rotation, *Fusarium* spp. that cause head blight were reduced by planting less susceptible wheat varieties and by fine chopping maize residues (Oldenburg et al. 2007). However, although disease was reduced, the levels of mycotoxin still exceeded European standards and altering the rotation sequence was also recommended (Vogelgsang et al. 2011). Methods to break up residue can thus have some effect on disease severity, but may require use in combination with other control approaches.

9.3.5 Mechanical Disruption of Soil and Root Pathogens

Without intensive tilling, there are other management practices that can be used to control diseases. Planting techniques that disturb the soil 0.05 m below the seeding depth using a thin implement at the time of planting, have been effective at reducing Rhizoctonia and take-all; using a modified seed drill designed with narrow sowing points for minimal soil disturbance resulted in lower disease levels than the standard NT drills that disturb the soil at a shallower depth (Roget et al. 1996). When this specialized planting technique was combined with a chemical fallow treatment, disease levels were comparable to CT methods (Roget et al. 1996). Jarvis and Brennan (1986) also found that direct drilling with a modified combine drill with tines that penetrated to 0.10 m reduced Rhizoctonia rot severity. While this practice disturbs the soil slightly below the location of the seed, it does not mix or stir the soil yet provides enough disturbance to disrupt the hyphal growth of *R. solani* to reduce disease incidence.

9.4 Conclusions

Diseases caused by pathogens like *Rhizoctonia* and *Fusarium* are known to increase in NT systems, but these pathogens and their diseases can be managed through rotation, genetic resistance, and use of chemicals, with other important disease reductions achieved through management of stubble residue and mechanical disruption during planting. So far, there are no disease problems of NT agriculture that are insurmountable or untreatable (Baker et al. 1996). However, the research to support the adoption of NT agriculture is specific to region and crop. Additional research is needed for cotton, oil seeds, vegetables, and legumes that have potential to yield more in no-till than in CT systems, and for targeted environments in South America and Asia where no-till is implemented on the greatest area of land.

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