

Phomopsis stem canker of sunflower in North America: correlation with climate and solutions through breeding and management^{☆, ☆☆}

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Abstract – Climate change is occurring in the central US and is interacting with agroecological factors to increase biotic stress in sunflower. Certain species of *Diaporthe* cause Phomopsis stem canker in sunflower and other dicotyledonous weeds and crops. The increase in precipitation already observed in the states of North Dakota, South Dakota, and Minnesota have increased the chances of outbreaks of necrotrophic pathogens, like *Diaporthe*. We discuss how climate trends, combined with technological, management, and economic interactions, are correlated with increasing incidence of Phomopsis stem canker in these and adjacent areas in North America. Further, we discuss management options and the role of improved sunflower genetics in reducing Phomopsis stem canker outbreak risk.

Keywords: Sunflower and Climate Change Symposium / *Helianthus annuus* / *Diaporthe* / Phomopsis / yield

Résumé – Le Phomopsis du tournesol en Amérique du Nord : corrélation avec le climat et solutions par amélioration génétique et gestion agronomique. Le changement climatique se fait sentir dans le centre des États-Unis et interagit avec des facteurs agroécologiques pour augmenter le stress biotique du tournesol. Certaines espèces de *Diaporthe* provoquent des attaques de Phomopsis chez le tournesol ainsi que d'autres espèces dicotylédones, cultivées ou adventices. L'augmentation des précipitations déjà observée dans les États du Dakota du Nord, du Dakota du Sud et du Minnesota a accru les risques d'épidémies de pathogènes nécrotrophes, tels que *Diaporthe*. Nous discutons de la façon dont les tendances climatiques, associées aux interactions technologiques, agronomiques et économiques, sont corrélées à l'incidence croissante de Phomopsis dans ces zones et les zones adjacentes en Amérique du Nord. De plus, nous discutons des options de gestion et du rôle de l'amélioration génétique du tournesol dans la réduction du risque d'épidémies de Phomopsis.

Mots clés : Symposium Sunflower and Climate Change / *Helianthus annuus* / *Diaporthe* / Phomopsis / rendement

The Sunflower and Climate Change Symposium gathered sunflower researchers from around the world to discuss how climate has shaped or will shape sunflower production in their regions and develop strategic research agendas to counteract

negative effects of changing climate on our crops. In North America, changes in climate have shaped or interacted with land use, technology, and management changes over time to result in new challenges to sunflower production. Our case study centers on a biotic stress challenge: the increase in incidence of Phomopsis stem canker (caused by species of *Diaporthe*).

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1 Climate change: interactions with producer decision-making and agroecology

One way we monitor climate in real time is through evaluation of changes in yearly averages. In the United States,

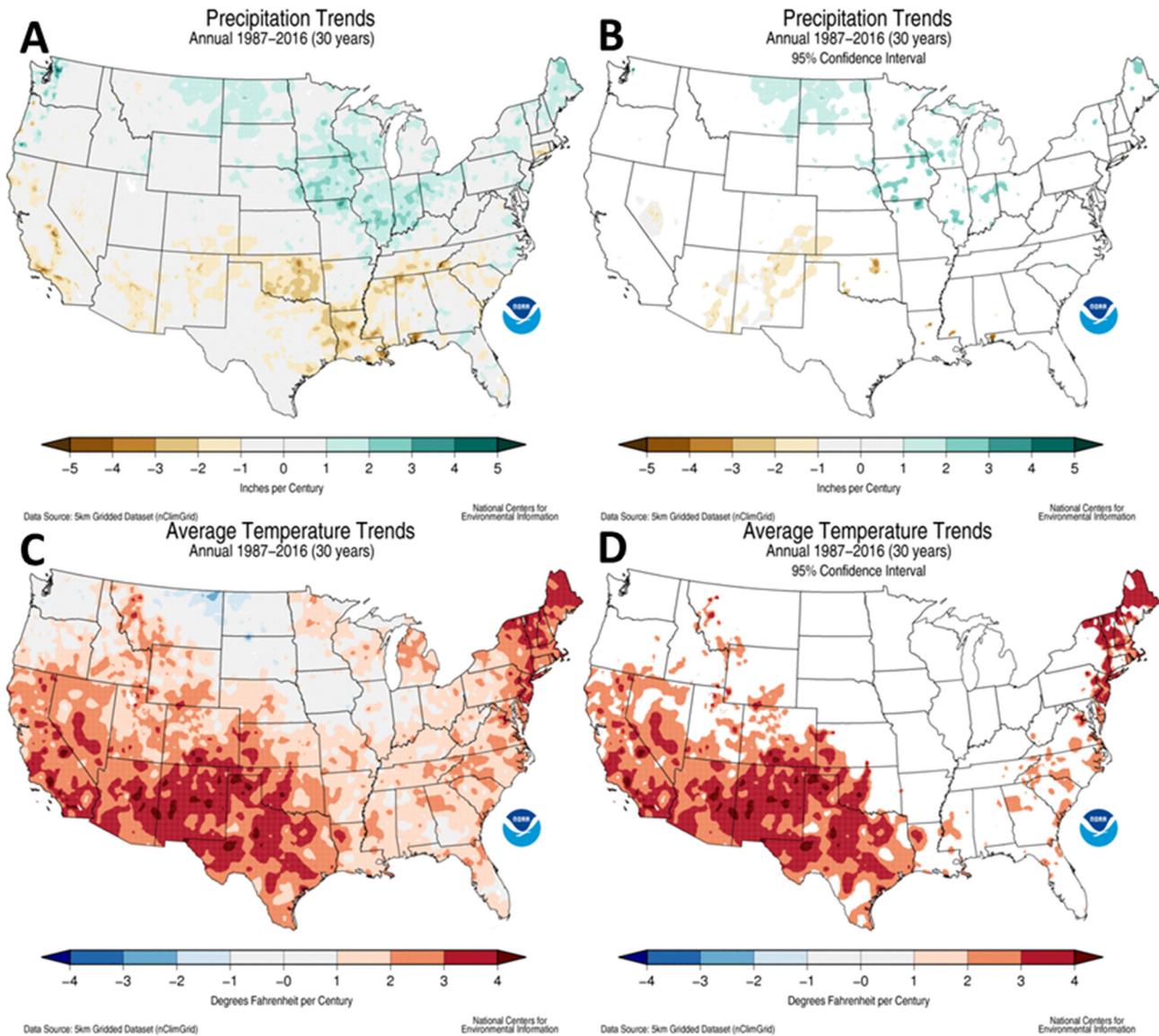


Fig. 1. Annual precipitation and temperature trends for the 30-year period of 1987 to 2016. 1 inch = 25.4 mm and 1 Fahrenheit degree = 0.56 Celsius degree. (A) Overall trends for precipitation, (B) trends for precipitation that are a significant departure from initial values for the period at the 95% statistical confidence level, (C) overall trends in temperature, and (D) trends for temperature that are a significant departure from initial values for the period at the 95% statistical confidence level. Figures available from [NOAA-NCEI \(2018\)](#).

a database has been assembled that allows us to evaluate these changes graphically, with statistical support (e.g. [Fig. 1](#); [NOAA-NCEI, 2018](#)). In the past three decades, climate has trended significantly wetter in the north central states, a major sunflower growing region, while it has trended significantly hotter in the southern sunflower growing region of Colorado, Kansas, and Texas ([Fig. 1](#)). Southeast Colorado and adjacent areas have turned significantly drier, as well. Some warming has occurred over this period in parts of the north central states, that while not statistically significant in this analysis, has resulted in changes in temperature extremes. These developments have led the U.S. Department of Agriculture to update its Plant Hardiness Zone Maps ([USDA-ARS, 2018](#)).

These changes in climate have combined with other factors to change land use in the north central US and eastern prairie provinces in Canada. Advances in soybean breeding resulted in

the development of early maturing soybean varieties that are tolerant of colder climates (e.g. [Helms and Nelson, 2015](#)), the need for which is partially offset by more favorable climate. The acceptance by producers of adapted soybean varieties is also driven by favorable production systems, such as Roundup Ready® technology (glyphosate herbicide tolerance), which has simplified weed control dramatically. An increase in exports, particularly to China, has allowed soybean prices to remain high over much of the last two decades, despite an increasing land area devoted to the crop and increasing yields due to improved genetics and agronomy ([Gale et al., 2015](#); [USDA-NASS, 2019](#)). As soybean hectares increase, the area of other crops has decreased, including sunflower ([Fig. 2](#)).

Changes in climate have not been as favorable to sunflower as it has been to other crops in the north central US. Sunflower can be susceptible to diseases caused by necrotrophic pathogens

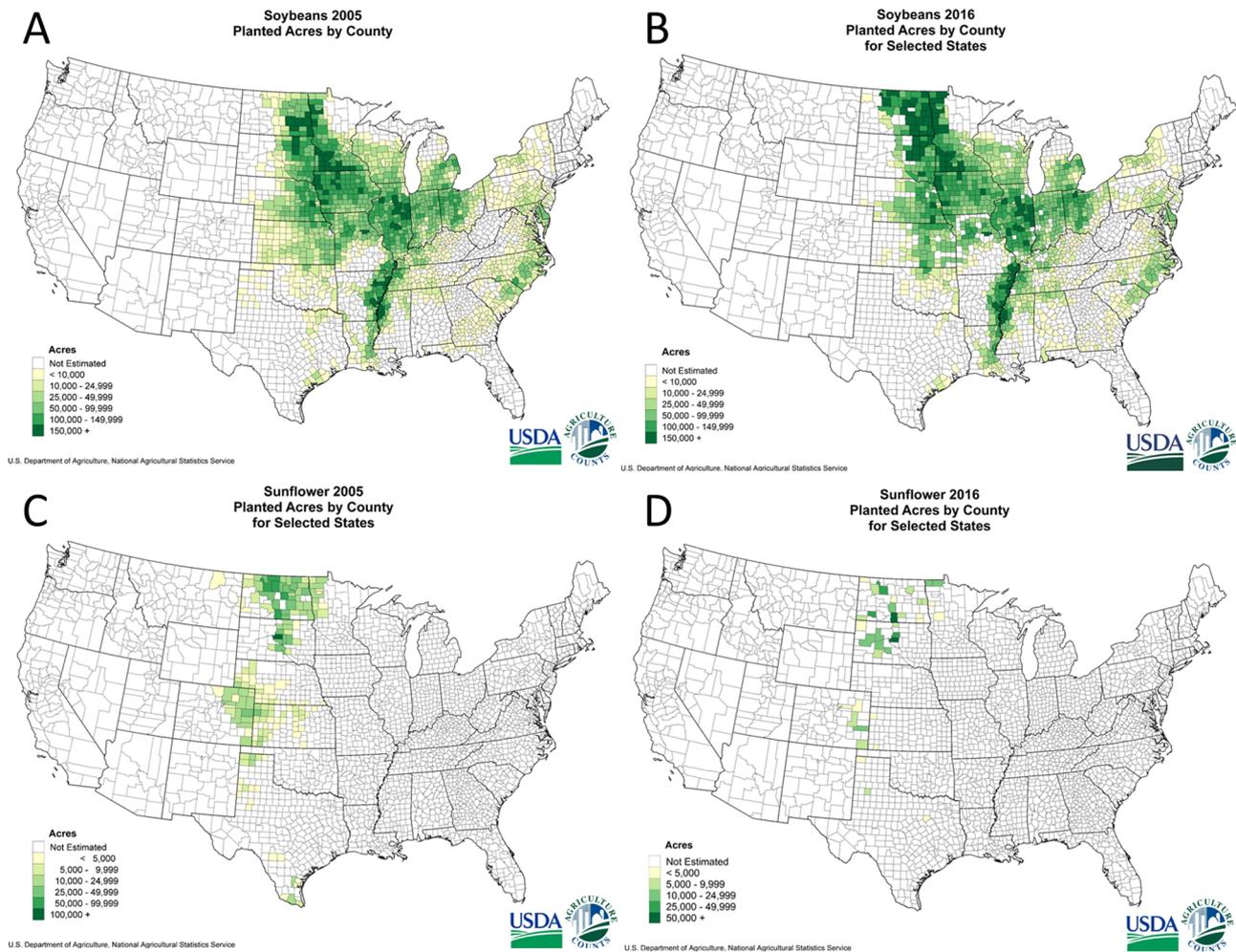


Fig. 2. Production area shifts for soybeans and sunflower 2005–2016, represented as acres per county. 1 acre=0.4 ha. Note that color scale differs by year and commodity. (A) Soybeans 2005, (B) soybeans 2016, (C) sunflower 2005, and (D) sunflower 2016.

under humid conditions in late summer (Gulya *et al.*, 1997). One of these, *Phomopsis* stem canker, has increased in incidence over the previous two decades, as captured in the National Sunflower Association (USA) Sunflower Survey data (Fig. 3; Gulya *et al.*, 2019). A gradual upward trend has been seen in the percentage of sunflower fields infested with the disease, broken only by brief interludes of drought.

Despite sunflower being native to North America and cultivated for thousands of years by Native Americans (Heiser, 1951), the first report of *Phomopsis* stem canker of sunflower occurred in the former Yugoslav republics in 1980. Sporadic outbreaks occurred in the USA shortly after the Yugoslav reports (Masirevic and Gulya, 1992), but the disease had not received much notice by agronomists and plant breeders in the US until around 2010 (Mathew *et al.*, 2015; Gulya *et al.*, 2019). The disease is maintained in decomposing plant litter in the soil and can be seed transmitted. Spores from the fungal perithecia can be spread by wind and rain over short distances, and inoculum can build up over years under ideal environmental conditions in a given area. Crop rotation strategies to counteract inoculum buildup are difficult to implement

because nearby fields are often sources of inoculum (Masirevic and Gulya, 1992).

Sunflower is not the only crop to be affected by *Phomopsis* stem canker, as it can infest many dicotyledonous weed and crop plants. However, there are a large number of species in the *Diaporthe* genus and different species have been isolated from different crops, suggesting specialization by the pathogen. Until recently, it was believed that only *Diaporthe helianthi* Muntañola-Cvetkovic, Mihaljevic, and Petrov was pathogenic to sunflower, but recent investigations have also isolated at least ten other species of *Diaporthe* from sunflower, including *D. gulyae* Shivas, Thompson and Young (Thompson *et al.*, 2011, 2015; Mathew *et al.*, 2015). In 2017, *D. stewartii* Harrison was found to infect sunflower in Polk County, Minnesota (Olson *et al.*, 2017). Recently, *D. gulyae* was also isolated from soybean in North Dakota and South Dakota, in regions where both sunflower and soybean are grown (Mathew *et al.*, 2018; Gilley *et al.*, 2019). This expands the land area producing inoculum for this pathogen greatly, and may explain, in part, the recent increases in incidence in sunflower (Fig. 3; Gulya *et al.*, 2019).

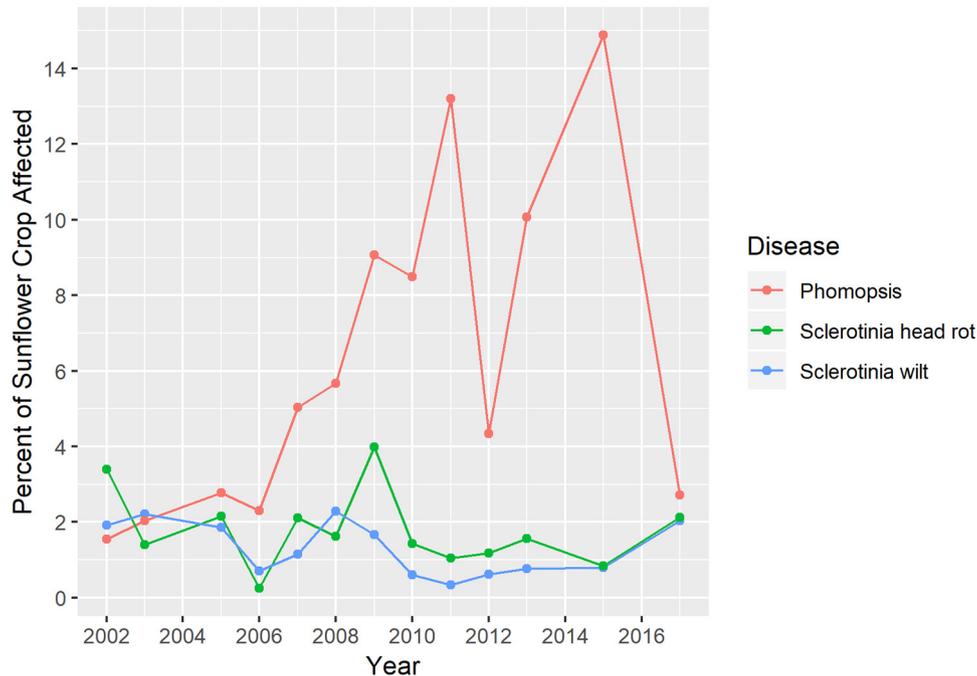


Fig. 3. Percentage of sunflower crop affected by three necrotrophic diseases, Phomopsis (caused by *Diaporthe* spp.), and Sclerotinia head rot and Sclerotinia wilt/basal stem rot (caused by *Sclerotinia sclerotiorum*). The percentage was calculated by multiplying the percentage of fields with each disease by the average within-field percent incidence excluding unaffected fields, from survey data across North America. Data from National Sunflower Association (2018) and calculations from Gulya *et al.* (2019).

It is noteworthy to mention that another major necrotrophic pathogen is common to both soybean and sunflower, *Sclerotinia sclerotiorum* (Lib.) de Bary. This pathogen causes three diseases in sunflower, a basal stem rot/wilt through direct mycelial penetration of roots, and a mid-stem and head rot caused by airborne ascospores (Gulya *et al.*, 1997). In soybean, only ascospore infection of flowers has been observed (Bolton *et al.*, 2006). *Diaporthe*- and *Sclerotinia*-associated diseases are favored under conditions of frequent rainfall or free moisture, with a temperature optimum about 25 °C (Gulya *et al.*, 1997). Despite the similarities in environmental suitability, unlike Phomopsis, Sclerotinia has been a notorious disease of sunflower, soybean, and other crops in North America for a long time, and efforts such as the National Sclerotinia Initiative (USA) and private breeding have reduced the genetic susceptibility of these crops to *Sclerotinia sclerotiorum*. This is evident in Figure 3 by the low incidence of *Sclerotinia* associated disease over the last decade. In contrast, cultural and genetic efforts to manage Phomopsis stem canker in North American sunflower have only begun circa the last 10 years, and lack of immediate genetic progress across current commercial hybrids contributes to increased incidence under favorable conditions (Fig. 3; Gulya *et al.*, 2019). In soybean, *Diaporthe*-associated diseases have received attention from researchers (Backman *et al.*, 1985), but there is little information available on the resistance genes currently deployed in commercial soybean cultivars.

An additional contributing factor to increased Phomopsis incidence in sunflower is failure of the Roundup Ready® glyphosate-tolerance system to control some species of weeds that also host species of *Diaporthe*. Glyphosate tolerance in kochia (*Kochia scoparia* L.) has already

developed in North Dakota and South Dakota, which is a concern because very few other chemistries control this weed effectively (Heap, 2018). Recently, Ghimire *et al.* (2018) isolated *D. gulyae* from kochia and lambsquarters (*Chenopodium album* L.) and showed that the weed-derived isolates could infect sunflower. Since North Dakota and South Dakota are among the states where Phomopsis stem canker of sunflower is the most prevalent, the additional reservoir of inoculum from a difficult-to-control, common weed that is present in many different types of crops may be contributing to inoculum availability.

2 Management of Phomopsis under our current climate conditions

Perhaps one of the easiest means of controlling fungal diseases is through application of fungicides. Experimental trials to control Phomopsis with fungicides have thus far not provided a simple solution for producers, mainly because the timing of fungicide treatment must coincide with the conditions most favorable for development of the disease. This may necessitate fungicide treatment many times a season and under conditions that are not favorable for aerial application of fungicide (Samuel Markell, pers. comm., 2018). Despite these difficulties, research is underway to develop disease prediction models, as well as rate and timing recommendations, that could assist sunflower producers in attempts to treat fields with fungicides.

The recent findings of Ghimire *et al.* (2018) underline the importance of weed control in managing this disease. Beyond the yield impacts caused by weed presence in fields, their role

Table 1. Performance of new USDA Phomopsis-resistant sunflower inbred line releases as testcrosses, compared to those of previously released USDA lines and commercial hybrids adapted to North America, four environments, 2011–2016.

Hybrid	Yield (kg ha ⁻¹)	Oil (g kg ⁻¹)	Lodging (score) ^a	Phomopsis (%) ^b
New USDA testcrosses				
CMS HA 412HO/RHA 485	2629 ab ^c	449 a	2.6 a	9.9 ab
CMS HA 467/RHA 485	2339 ab	422 ab	2.6 a	8.5 ab
CMS HA 412HO/RHA 486	2614 ab	418 b	2.8 a	0.0 a
CMS HA 467/RHA 486	2898 ab	374 d	2.5 a	0.0 ab
CMS HA 487/RHA 464	2532 ab	402 bc	1.1 a	24.8 b
CMS HA 487/RHA 468	2565 ab	395 c	2.5 a	39.2 b
Previous USDA testcrosses				
CMS HA 412HO/RHA 373	2345 b	408 bc	2.8 a	54.9 bc
CMS HA 412HO/RHA 377	2094 b	418 b	3.0 a	70.7 c
CMS HA 412HO/RHA 464	2235 b	423 b	1.8 a	13.4 ab
CMS HA 412HO/RHA 468	2493 ab	429 ab	2.8 a	12.1 ab
CMS HA 467/RHA 464	2008 b	369 d	2.3 a	44.7 b
CMS HA 467/RHA 468	2363 b	388 cd	2.5 a	36.0 b
Commercial hybrids				
Croplan 3080	2582 ab	422 b	2.7 a	50.5 b
Croplan 7717 HO/CL/DM	2872 ab	407 bc	2.0 a	26.2 b
Mycogen 8H449CLDM	2991 a	439 ab	2.8 a	38.0 b
Nuseed Camaro II	2884 ab	410 bc	2.3 a	23.1 b
Pannar 7813NS	2784 ab	395 c	2.6 a	47.6 b
CV (%)	16.0	2.1	29.9	34.7
Correlation (Pearson)				
Yield		0.37***	-0.41***	-0.39***
Oil			0.05	-0.29***
Lodging				0.17**

^a Lodging was scored on a 1 to 9 scale with 1 indicating no lodged or leaning plants, 9 indicating all plants completely lodged. Hybrids with the highest and lowest lodging scores were significant at $p=0.06$.

^b Heavy, natural infestation at all four environments. Diseased plots were used for yield data.

^c Common non-superscript letters denote hybrids that are not significantly different at the $p < 0.05$ level.

, * Significant at the 0.01 and 0.001 probability levels, respectively.

in spreading the *Diaporthe* pathogen further increases the importance of good weed control in sunflower fields and adjacent areas. With glyphosate no longer an effective weed control tool for many glyphosate-tolerant crops, use of other effective herbicide classes, such as pre-emerge chemistries in combination with pre-plant burndown treatments, a few post-emergence herbicides such as dicamba or fluroxypyr (in monocot crops), tillage, or perhaps, new weed control technologies are needed to reduce this important risk factor for disease development (Lawrence and Creech, 2016; Thompson, 2018).

As is often the case with necrotrophic pathogens, host-plant resistance can be a useful way to reduce disease, but the complex inheritance that underlies the resistance phenotype can be a barrier to balanced breeding for yield and quality. Recent work by Talukder *et al.* (2014) showed that in North Dakota, South Dakota, and Minnesota, resistance to *D. helianthi* (natural field incidence with pathogen confirmed in a laboratory assay) had very low

genotype-by-environment interaction and high broad-sense heritability. It also had a moderate broad-sense genetic correlation with Sclerotinia head rot resistance ($r=0.45$). However, recent mapping work has indicated that the resistance phenotype is quantitative, due to a few large effect loci and many moderate- to small-effect loci that exist in genomic clusters (Viguié *et al.*, 2000; Bert *et al.*, 2002; Brent Hulke and Nolan Kane, in preparation, 2019). Recent breeding progress has resulted in parental lines with good resistance without much assistance from genomics-assisted methods. However, the yields of the most resistant materials do not consistently surpass that of high-yielding, more susceptible commercial hybrids (Tab. 1). Yield can be affected by Phomopsis in two ways, first by premature ripening of the seeds and second by lodging of diseased stems, while oil content is only affected by premature ripening. In the experiment described in Table 1, most of the damage was from premature ripening, with little damage from lodging. If autumn weather conditions favored lodging

in that experiment, further losses would have occurred in the susceptible commercial hybrids. Nonetheless, the use of genomics in breeding to optimize yield increases with disease resistance will be an important goal, since a successful commercial hybrid must do well both under disease pressure and without disease.

3 Conclusions

Producer decision-making has already been changing (either actively or passively) to the changes in climate already observed. Compounding the effects of climate change, technological innovations, changing management recommendations, economic developments, and the interactions thereof, can provide us certainty that our agricultural landscapes will continue to change in the upcoming decades. The Intergovernmental Panel on Climate Change report (Hoegh-Guldberg *et al.*, 2018) predicts that at 1.5 to 2.0 °C of average global warming, the central US will see further increases in heavy precipitation events, an overall increase in precipitation, and increases in consecutive dry days. This suggests that precipitation could occur in high intensity periods with intervening drought periods, resulting in an overall increase in average precipitation. Similar trends are expected in Northern and Central Europe. Under these potential scenarios, crop production systems will need to be resilient to rapidly changing weather patterns and the crops themselves adapted to stresses caused by extremes in weather which are rarely observed today. Sunflower has the potential to be a key oilseed crop because it is adaptable to a wide range of conditions, but it can be improved to be a better player in crop rotations of the future. Susceptibility to necrotrophic pathogens such as *Diaporthe* is a weakness, and proactive research to mitigate diseases in a changing climate is critical. Innovations in genetics research through optimization of yield and disease resistance will make sunflower better adapted to scenarios that are expected to be more common in the future.

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