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Plot size can influence yield benefits from fungicides on corn

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ABSTRACT

Use of foliar fungicides on corn has increased over the last decade. Part of the reason for this increase is due to physiological benefits on plants from QoI (strobilurin) containing fungicides. However, there remains controversy over how significant yield and economic benefits are from strobilurin fungicides. A potential source of this controversy might be explained by experimental plot size. To better understand grower-relevant yield benefits from fungicides, three hundred and fourteen commercial-strip trials (8.1 ha fungicide treated and 8.1 ha untreated) were conducted on growers' farms across four years, and twenty-five small plot (37.2 m^2 or less) trials were conducted across the corn belt in 2010. Yield benefits from fungicides were much greater in the commercial-strip trials than in the small plot trials. In 2011, twenty-six large plot trials (ranging from 557 to 1394 m^2), were established with efforts made to reduce border and alley effects. Two corn hybrids were evaluated at each of the 26 trial locations, and the results indicated that corn yield benefits from Quadris® fungicide (a solo formulation containing 22.9% azoxystrobin) applied at the V4-V8 growth stage, Quilt Xcel® fungicide (a premix formulation containing 13.5% azoxystrobin and 11.7% propiconazole) applied at the R1 growth stage, or a combination of the two, provided yield benefits similar to those from the commercial-strip trials. The financial gain/loss from the use of fungicides was determined. Using the highest cost estimates for fungicide and applications, Quilt Xcel fungicide applied at the R1 growth stage provided estimated yield benefits of $105, $219, $241, and $278/ha ($19, $65, $74, and $89/A) over the untreated checks in the commercial-strip trials conducted in 2009, 2010, 2012, and 2013, respectively. The average economic benefit to growers over the four year period was $211 ± 37/ha ($62 ± $15/A). Variability in economic benefit not only includes costs associated with fungicides but also includes annual commodity price, disease pressure, and location effects. This study supports the hypothesis that plot size influences assessment of yield effects of fungicides. Yield responses from the small plot, large plot, and commercial-strip trials resulted in increases of 378 kg/Ha (6 Bu/A), 701 kg/Ha (11 Bu/A), and 1132 kg/Ha (18 Bu/A) over the untreated, respectively.

1. Introduction

Due to several driving factors, fungicide use on maize has increased significantly over the past twenty years. First, gray leaf spot, caused by *Cercospora zeae-maydis* Tehon & E. Y. Daniels, became more prevalent in the 1980's and 1990's (Lipps et al., 1996; Lipps, 1987, 1998) concomitant with the adoption of reduced tillage practices in the US (Lipps, 1987, 1998). Gray leaf spot is one of the most yield-limiting fungal diseases of corn (Munkvold et al., 2001) and as a necrotrophic pathogen, the fungus overwinters in corn residues that remain in the field with reduced tillage. Second, with the threat of Asian soybean rust establishing in the US in the early 2000's, the US Environmental Protection Agency (EPA) granted Quarantine Section 18 registrations for several fungicide active ingredients including: cyproconazole, metconazole, myclobutanil, tebuconazole, propiconazole, prothioconazole, tetraconazole, flusilazole, flutriafol, pyraclostrobin, tebuconazole and pyraclostrobin, propiconazole and trifloxistrobin, flusilazole and femoxadone, metconazole and pyraclostrobin, propiconazole and azoxystrobin, and cyproconazole and azoxystrobin (Mueller and Eckermann, 2006). Several of these active ingredients and combinations of active ingredients were not registered in the US prior to this event. Many of the fungicides containing these active ingredients

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eventually received EPA federal registrations (Section 3 registrations) with corn on their labels. A third and more controversial reason for increased use of fungicides on corn has been due to industry promotion of physiological benefits that quinone outside inhibitor (QoI, also known as strobilurin) fungicides provide on some crops, including corn, above and beyond disease control.

Azoxystrobin, the active ingredient in Quadris® fungicide, and one of the two active ingredients in Quilt Xcel® fungicide, increases many of the beneficial antioxidant enzymes in plants and decreases some of the damaging reactive oxygen species (ROX). Azoxystrobin decreases super oxide ($O^{-}{}_2$) production in wheat while increasing both super oxide dismutase and peroxidase (Wu and von Tiedemann, 2001), which subsequently reduces ozone injury (Wu and von Tiedemann, 2002b). Azoxystrobin also reduces super oxide levels in barley (Wu and von Tiedemann, 2004), which is highly correlated with physiological leaf spot (Wu and von Tiedemann, 2002b; Wu and von Tiedemann, 2004), a malady that causes abiotic necrotic lesions and often decreases yield in parts of Europe (Jabs et al., 2002; Wu and von Tiedemann, 2002a). Azoxystrobin has also been found to increase super oxide dismutase, peroxidase, catalase, ascorbate peroxidase, glutathione reductase, and protein content in spring barley (Wu and von Tiedemann, 2002b). Other strobilurin fungicides have been shown to increase nitrate reductase levels in plants (Glaab and Kaiser, 1999; Wu and von Tiedemann, 2002b; Ruske et al., 2003), resulting in increased protein content (Wu and von Tiedemann, 2002b). Strobilurin fungicides also can reduce transpiration (Grossmann et al., 1999; Nason et al., 2007) and delay senescence in plants (Grossmann and Retzlaff, 1997; Gerhard et al., 1999; Beck et al., 2002). Therefore plants tend to utilize water more efficiently (Giuliani et al., 2011) and the leaves stay green longer (Below and Uribelarrea, 2009; Byamukama et al., 2013). Longer green leaf duration in corn is positively correlated with increased corn grain yields (Tollenaar and Daynard, 1978; Gregersen et al., 2013). The translation of many of these physiological benefits in terms of greener plants, stronger stalks, reduced lodging, and yield benefits have all supported grower adoption of fungicide use on corn.

Although physiological effects from strobilurin fungicides on plants are well documented, there remains skepticism that these benefits provide economic value unless disease pressure is high (Munkvold et al., 2001; Paul et al., 2011; Wise and Mueller, 2011; Bradley, 2012). Conflicting results in yield benefits from fungicides between fungicide manufacturers and other researchers have further added to the controversy. However, there are some fundamental differences in trial methodology that potentially could account for some of these differences. Within industry, products are often evaluated in large on-farm strip trials (often referred to as commercial-strip trials). The intent for these trials is to allow growers to see how products perform on their farms versus no treatment and/or other fungicide treatments. Most non-industry research focused on evaluating fungicides for yield benefits have been conducted using small plot trials that are standard for fungicide efficacy testing. Although this plot design is generally sufficient for evaluating fungicide efficacy, small plot trials are often not appropriate for determination of yield benefits for a variety of reasons including border and alley effects (Geater et al., 2004; Wang et al., 2013; Rebetzke et al., 2014). There also is a greater impact on yields from missing plants or inconsistent plant stands in small plots than in large plots. For example, missing 3 plants in a small plot (say stand count of 50 = 6% missing plants) has a much greater impact on yield than does missing 3 plants in a large plot (say stand count of 1000 = 0.3% missing plants).

The objective of the current study was to evaluate the QoI containing fungicides Quadris (Flowable formulation containing 2.08 lb. a.i. of azoxystrobin per gallon) and Quilt Xcel (SC formulation containing 1.02 lb. a.i. propiconazole and 1.18 lb ai azoxystrobin per gallon) for yield effects in commercial-strip trials, small-plot trials, and in large plot trials where border and alley effects were managed, to determine which testing method generates yield results and economic impact reflective of what growers might expect on their farms.

2. Materials and methods

2.1. Commercial-strip trials

From 2009 to 2013 excluding 2011, Syngenta field scientists conducted commercial-strip trials on growers' farms to evaluate Quilt Xcel fungicide for yield effects on corn. Strip trials were not conducted in 2011 due to focused efforts on conducing large plot trials with efforts to minimize border and alley effects (See section 2.3). Each trial consisted of approximately 8.1 ha (20 acres) of corn treated with Quilt Xcel fungicide and 8.1 ha (20 acres) of untreated corn. These trials were non-replicated, but growers were asked to use sections of the field for both the fungicide treated and untreated plots that were as similar to one another as possible, with the same agronomic practices for fertilization and weed control. Growers were also asked to provide yield data from both the fungicide treated and untreated sections of their field at the end of the season. Yield data were collected using growers commercial yield monitors.

A meta-analysis of the data was conducted to determine the overall mean difference between the fungicide-treated and untreated strips. Typically meta-analysis methods are conducted for replicated trials where the within-trial sampling variance is used to weight the results of each trial on the overall mean calculation (Madden and Paul, 2011; Paul et al., 2011). As our trials were non-replicated, each trial was instead assumed to have equal weight. The model was fit using PROC MIXED of SAS, the difference between the treatment and control was set as the response variable, trial was considered a random effect, and year was considered a fixed effect so an overall mean and 95% confidence interval of the mean was found for each year. Using this analysis method, the standard normal test statistic (Z) is used to determine whether the difference in treatments is significantly different from zero.

2.2. Small-plot trials

Syngenta field scientists and university plant pathologists conducted replicated small-plot trials in 2010 across many of corn growing states including: Georgia, Illinois, Indiana, Iowa, Kentucky, Minnesota, Missouri, Nebraska, New York, Ohio, Tennessee, and Wisconsin. Two experiments were conducted to evaluate Quadris and Quilt Xcel fungicides for efficacy against corn diseases and measure effects on yields under moderate to high disease pressure (experiment 1) and minimal disease pressure (experiment 2). The objectives of these trials were similar; the main difference was the level of disease pressure present. Eleven trials were established for experiment 1 with hybrids susceptible to gray leaf spot and/or common rust, in locations with a history of disease, and where corn was grown the previous growing season. Fourteen trials were established for experiment 2 growing hybrids with high genetic disease resistance, in locations with a history of low disease pressure, and where corn was not grown the previous growing season. To further maintain disease free plots, Bravo® fungicide (containing the active ingredient chlorothalonil) was used as needed. Bravo fungicide has broad spectrum activity against key fungal pathogens of corn, but imposes no known physiological effects. Trials were established using a randomized complete block design (RCBD) with four to six replications per treatment. The treatments included an