Hindawi Publishing Corporation
International Journal of Agronomy
Volume 2013, Article ID 561370, 5 pages
http://dx.doi.org/10.1155/2013/561370

Research Article

Soybean (*Glycine max* L.) Response to Fungicides in the Absence of Disease Pressure

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Received 11 April 2013; Revised 29 May 2013; Accepted 31 May 2013

Academic Editor: David Clay

Field studies were conducted during the 2010 and 2011 growing seasons along the Texas Upper Gulf Coast region to study the effects of fungicides on soybean disease development and to evaluate the response of four soybean cultivars to prothioconazole plus trifloxystrobin and pyraclostrobin. In neither year did any soybean diseases develop enough to be an issue. Only NKS 51-T8 responded to a fungicide treatment in 2010 while HBK 5025 responded in 2011. Prothioconazole plus trifloxystrobin increased NKS 51-T8 yield by 23% in 2010 while in 2011 the yield of HBK 5025 was increased 14% over the unsprayed check. No yield response was noted with pyraclostrobin on any soybean cultivar. Only prothioconazole + trifloxystrobin applied to either NKS 51-T8 or DP5335 in 2010 resulted in a net increase in dollars per hectare over the unsprayed check of the respective cultivar. In 2011, under extremely dry conditions, all fungicides with the exception of prothioconazole + trifloxystrobin applied to HBK 5025 resulted in a net decrease in returns over the unsprayed check.

1. Introduction

Fungicide applications and timing have been shown to be critical for the control of foliar diseases on soybean [1]. The control of frogeye leaf spot (*Cercospora sojina*) varied with applications of benomyl at different reproductive stages of the crop [2]. To manage soybean rust (*Phakopsora pachyrhizi*) with fungicides, three strategies include applying fungicides in a predetermined calendar-based schedule, scouting and applying fungicides after the first detection of soybean rust or utilizing a forecast system that monitors disease development in areas that are potential inoculum sources, and applying fungicides ahead of a predicted deposition of spores [1, 3–5].

The older chemistry of foliar fungicides for soybeans included contact fungicides which remain on the leaf surface and if a rain event occurred soon after application, the fungicide could be washed off [6]. With improved chemistry, systemic fungicides are now available and these types of fungicides are absorbed by the leaves and move within the treated plant [6]. Systemic fungicides allow growers to properly manage soybean diseases now more than ever before. Soybeans that have been sprayed with a fungicide retain their leaves for a longer period of time, allowing the pods to fill and increase the size and weight of the beans [6].

Three of the newer fungicides include prothioconazole, trifloxystrobin, and pyraclostrobin. Prothioconazole is a sterol biosynthesis inhibitor fungicide in the triazolinthione class of fungicides [7] that has shown activity against *Cercospora arachidicola* and *Cercosporidium personatum* as well as *Sclerotium rolfsii* and *Rhizoctonia solani* in peanut (*Arachis hypogaea* L.) [8]. In addition, this fungicide provides suppression of *Cylindrocladium* black rot (*Cylindrocladium parasiticum* Crous, Wingfield, and Alfenas), another extremely destructive disease of peanut in some areas of the southeastern USA [9, 10]. Prothioconazole has also shown promise for control of cereal diseases in Europe when applied alone or in combination with strobilurin fungicides [7]. In addition, the activity of this fungicide on foliar diseases is of special interest because populations of both leaf spot pathogens in peanut have displayed noticeable reductions in efficacy of that fungicide [7].

Trifloxystrobin is in the class of strobilurin fungicides, and the mode of action for this class of fungicides is by the inhibition of mitochondrial respiration. Trifloxystrobin has protective, curative, translaminar, and novel redistribution properties [11]. The strobilurin fungicides are very active against many plant pathogenic fungi. On grapes (*Vitis* spp.), excellent control of powdery mildew (*Uncinula necator*) has been achieved. Scab (*Venturia inaequalis*) of pome fruits has been controlled at relatively low-use rates in protective or curative schedules at 75 to 100 gram ai/ha [11]. On pears (*Pyrus* spp.), trifloxystrobin has provided good control of *Stemphylium* black spot [11]. The strobilurin fungicides have very low toxicity to birds, earthworms, beneficial insects, predaceous mites, and mammals (including humans) [12]. Also, they break down quickly in the soil [13].

Pyraclostrobin is also a strobilurin-type fungicide that has shown activity against many different fungi of soybean and peanut including *C. arachidicola* [14, 15]. This fungicide is absorbed rapidly by leaf tissue and has demonstrated translaminar movement through layers of the leaf but is not redistributed throughout the plant like a true systemic fungicide [16, 17]. Selected rates of pyraclostrobin have superior activity against *C. arachidicola* and *C. personatum* of peanut as well as soil-borne diseases such as southern stem rot (*Sclerotium rolfsii* Sacc.) [18].

Soybean diseases along the upper Texas Gulf Coast usually are variable and not widespread and may not become major production issues in a given year (author's personal observations). However, growers continue to inquire about the use of fungicides in soybean and their economic value. Therefore, the objective of this study was to determine foliar disease control and the response of commonly grown soybean cultivars to fungicides.

2. Materials and Methods

2.1. Research Sites. Soybean fungicide studies were conducted in 2010 and 2011 at two different locations in growers' fields in Victoria County, TX, USA. In 2010, studies were conducted at the Keith Johnson Farm (28.78°N, 96.87°W) while in 2011 studies were conducted at the Larry Stary Farm (28.85°N, 96.74°W). Soil type at both locations was a Houston black clay (fine, smectitic, and thermic Udic Haplustepts) with a pH range of 7.4 to 7.7. Conventional tillage systems were used at both locations, and both were maintained under rainfed conditions. Fertilizer was applied by growers as needed according to Texas A&M AgriLife Extension recommendations for soybean. Plots were maintained weed-free throughout the growing season using a preemergence application of either a premix of *S*-metolachlor plus metribuzin (Boundary, Syngenta Crop Protection, Greensboro, NC, USA) at the rate of 1.12 kg ai/ha or pendimethalin (Prowl H_2O, BASF Corp, Florham Park, NJ, USA) plus imazethapyr (Pursuit, BASF Corp., Florham Park, NJ, USA) at 1.06 kg ai/ha plus 0.07 kg ai/ha, respectively, depending on location. Grass and broadleaf weed escapes were controlled with postemergence applications of clethodim (Select, Valent USA Corp., Walnut Creek, CA, USA) at 0.21 kg ai/ha and acifluorfen (Blazer, BASF Corp., Research Triangle Park, NC, USA) at 0.84 kg ai/ha or lactofen (Cobra, Valent USA Corp., Walnut Creek, CA, USA) at 0.22 kg ai/ha, respectively. Postemergence herbicide applications included Agridex (Helena Chemical Co., Memphis, TN, USA) at the rate of 0.25% v/v. The number of postemergence herbicide applications varied from year to year depending on weed emergence problems.

Table 1: Monthly rainfall during the growing season at study locations.

Month	2010	2011	20-year average
		Mm	
March	40.1	6.1	52.8
April	129.3	0	74.4
May	120.4	35.6	125.7
June	155.7	25.2	121.2
July	247.1	6.9	83.8
August	29.2	13.5	78.2
Total	721.8	87.3	536.1

2.2. Soybean Cultivars and Fungicide Treatments. Soybean cultivars (early Group V) selected for the study were those that had shown promise in previous studies or had produced well in growers fields in the area [19]. The cultivars planted in both years included HBK 5025, NKS 51-T8, and DP 5335. Pioneer 95Y01 was planted in 2010 but, due to a lack of availability in 2011, Pioneer 94Y90 was planted instead. HBK 5025 was the only conventional soybean cultivar planted. All others were Roundup Ready cultivars. Soybean seed was planted with a vacuum planter (Monosem ATI, Inc., Lenexa, KS, USA) to provide a uniform seeding rate of 33 seed/m (55,847 seeds/ha) on a pair of rows with 97 cm centers. Planting dates were March 25, 2010 and March 29, 2011. Treatments consisted of a factorial arrangement of the four soybean cultivars with three fungicide treatments (untreated, prothioconazole at 0.04 kg/ha + trifloxystrobin at 0.15 kg/ha, and pyraclostrobin at 0.11 kg/ha). Each study was replicated three times.

2.3. Plots and Rainfall. Individual plots consisted of four rows (rows spaced 97 cm apart) and 6.3 m long. The middle 2 rows of each plot in each study were sprayed with fungicide, and data were collected from these areas. Rainfall for the upper Texas Gulf Coast can be best described as experiencing vast extremes during the two-year study. Seasonal rainfall (March through August) was above average (722 mm) in 2010 and below average (87 mm) in 2011 (Table 1). The drought of 2011 was extremely widespread over the entire state and severely affected crop yields. Soybeans were harvested the first week of August in each year.

2.4. Fungicide Application. Fungicides were applied with a CO_2 propellant backpack sprayer equipped with three D2-23 hollow-cone spray nozzles (TeeJet Spraying Systems Co., Wheaton, IL, USA) per row in 140 L of water/ha at a pressure of 504 kPa. Fungicides were applied two times during the growing season at R3 and R5 which were 59 and 79 days after planting (DAP) in 2010 and 64 and 84 DAP in 2011.

2.5. Net Returns per Hectare. Net returns were calculated based on current soybean market price [20] and costs of fungicide (J. Pollock; Wilbur-Ellis Co., El Campo, TX, USA, personal communication) and fungicide application cost of \$12.35/ha/application (S. Fischer, Helena Chemical Co., Placedo, TX, USA, personal communication). No other costs (land preparation, seed costs, etc.) were considered since all other factors did not change over fungicide sprays or soybean cultivar.

2.6. Data Analysis. The treatment design was a factorial arrangement using a randomized complete block design with fungicides and soybean cultivars as factors. An analysis of variance was performed using the ANOVA procedure for SAS (SAS Institute, 1998, SAS user's guide, SAS Inst., Cary, NC, USA) to evaluate the significance of fungicide and soybean cultivar on soybean yield and net return per hectare. The Fishers Protected LSD at the 0.05 level of probability was used for separation of mean differences.

3. Results

In neither year did any foliar diseases including anthracnose (*Colletotrichum dematium*), frogeye leaf spot (*Cercospora sojina*), *Cercospora* leaf blight (*Cercospora kikuchii*), pod and stem blight (*Diaporthe phaseolorum* var. *sojae*), or Asian soybean rust (*Phakopsora pachyrhizi*) develop into uniform infections to be evaluated or be an issue. This is not unusual for this soybean production region but is somewhat surprising since above normal rainfall occurred in 2010. Recently, Asian soybean rust has only been an issue in one year (2007), and infection did not occur until early- to mid-July, and this was too late in the growing season to have an economic impact (author's personal observation). The 2010 growing season was exceptionally wet with the region receiving record rainfall including 406 mm in July (http://cwp.tamu.edu/). Typically, disease epidemics are favored by moderate temperatures and long periods of high relative humidity over several days [21].

3.1. Soybean Yield as Influenced by Fungicides and Cultivars. In 2010 under higher than normal rainfall, especially for April, June, and July (Table 1), soybean yields were excellent. Since seed filling begins approximately 80 days after planting [22] and moisture availability is very important to pod development, the above average rainfall in June and even July accounted for the high soybean yields. Demand for water and nutrients is large throughout the rapid seed filling period with the soybeans acquiring approximately 50% of the N, P, and K by redistribution from vegetative plant parts and about 50% by soil uptake and nodule activity [23].

Overall, HBK 5025 produced the highest yield (>5000 kg/ha) with/without any fungicide treatment (Table 2). The use of a fungicide did not improve the yield of any soybean cultivar over the untreated check with the exception of the use of prothioconazole + trifloxystrobin on NKS 51-T8 which increased soybean yield over the unsprayed NKS 51-T8 by 23% (Table 2).

Environmental conditions in 2011 were quite different with extremely high temperatures and lack of rainfall (Table 1). Stress can reduce soybean yield by reducing the number of pods, seeds, and seed mass [24, 25]. Both determinate and indeterminate soybean cultivars have reduced growth rates under drought stress and resume normal growth rates when such stress is removed [25]. No cultivar produced over 1400 kg/ha. Again, no response was noted with any fungicide or soybean cultivar with the exception of prothioconazole + trifloxystrobin applied to HBK 5025 which resulted in a 14% yield increase over the unsprayed HBK 5025 treatment (Table 2).

3.2. Net Returns Based on Fungicide Sprays. The use of a fungicide resulted in a net increase in returns in only two instances (Table 3). In 2010, when prothioconazole + trifloxystrobin was applied to NKS 51-T8 or DP 5335 there was a net increase in returns over the untreated check by $315/ha and $188/ha, respectively. However, there were several instances where the use of a fungicide reduced net returns when compared with the untreated check (Table 3). In 2010, prothioconazole + trifloxystrobin applied to HBK 5025 reduced net returns when compared with the untreated check. In 2011, all fungicide treatments with the exception of prothioconazole + trifloxystrobin applied to HBK 5025 reduced net returns compared with the untreated check.

4. Discussion

The use of fungicides on soybean along the upper Texas Gulf Coast under little or no disease pressure resulted in few increases in yield and subsequent increases in net returns. In several instances the use of fungicides resulted in a decrease in net returns, especially in a year with below normal rainfall. There is sufficient controversy on the use of general fungicide sprays in row crops to improve yield [6, 26–28]. Holmes [28] stated that under low levels of brown spot (*Septoria glycines*) and *Cercospora* leaf blight, the use of a fungicide at R1 resulted in the soybean plants in both the treated and untreated plots losing their leaves and maturing at the same time. Meanwhile, soybeans sprayed at R3 maintained their leaves for approximately one week longer than the unsprayed check. Plots sprayed at R3 yielded 637 kg/ha more than the untreated check while those sprayed at R1 did not yield greater than the untreated check.

Harrington [6] stated that the use of fungicides on soybean was more likely to create a positive yield response when foliar diseases were present. Another study in Ontario at two different locations with 20 different soybean cultivars reported at one location that the use of pyraclostrobin increased yield by 230 kg/ha when averaged over all cultivars but no soybean cultivar yield response was noted, while at the second location, no yield difference or variety effect was detected between the treated or untreated plots [29].

It was also reported that, in the province of Ontario, the application of a fungicide sometimes showed an increase in soybean yields with an average increase of approximately 325 kg/ha [29]. It was also stated that only about 30% of the decisions to apply a fungicide resulted in a yield response that was economically beneficial to the producer. In our studies, the use of a fungicide only resulted in a net increase in dollars per hectare 13% of the time.

Studies in other crops have reported that foliar fungicide use has not always been beneficial. Wrather et al. [30] reported that foliar applications of azoxystrobin may be

Table 2: Soybean cultivar yield response to fungicides under no disease pressure.

Fungicide[a]	HBK 5025		NKS51-T8		DP 5335		PIONEER 95Y01	
	2010	2011	2010	2011	2010	2011	2010	2011
	Kg/ha							
Untreated	5214	1222	3332	1138	3219	1298	4072	1208
Prothioconazole + trifloxystrobin	5029	1389	4083	1196	3754	1208	4082	1105
Pyraclostrobin	5481	1105	3723	1196	3456	1350	4165	1067
LSD (0.05)	543	155						

[a]Fungicide rate: prothioconazole at 0.04 kg/ha + trifloxystrobin at 0.15 kg/ha; pyraclostrobin at 0.11 kg/ha.

Table 3: Net return per hectare based on the use of fungicides under no disease pressure[a,b].

Fungicide	HBK 5025		NKS51-T8		DP 5335		PIONEER 95Y01	
	2010	2011	2010	2011	2010	2011	2010	2011
	$/ha							
Untreated	3076	721	1966	671	1899	766	2402	713
Prothioconazole + trifloxystrobin	2839	692	2281	578	2087	585	2280	524
Pyraclostrobin	3119	541	2082	591	1924	682	2342	515
LSD (0.05)	150	59						

[a]Fungicide rate: prothioconazole at 0.04 kg/ha + trifloxystrobin at 0.15 kg/ha; pyraclostrobin at 0.11 kg/ha.

[b]Soybean price: $0.59/kg; fungicide application costs: $12/ha/application (2 applications) for a total cost of $24/ha; fungicide costs for 2 applications, prothioconazole + trifloxystrobin: $104/ha; pyraclostrobin: $90/ha. Therefore, prothioconazole + trifloxystrobin costs were $128/ha while pyraclostrobin costs were $115/ha.

useful for the management of some foliar diseases, but azoxystrobin may increase the percent of *Phomopsis* spp. seed infection. It was felt that azoxystrobin may interfere with the plant's natural defense mechanism to *Phomopsis* spp., or it may protect the plant from other diseases, thus extending the life of the plant so that *Phomopsis* spp. has more time to move from the pod into the seed. Spokas and Jacobson [31] reported no long-term negative impacts on the soil system or strawberry (*Fragaria* x *ananassa*) production as a consequence of strobilurin application. In one of two years they reported a yield boost on strawberries as a result of fungicide usage. Paul et al. [27] stated that unless a corn (*Zea mays* L.) crop is at risk of developing fungal disease, farmers would be smart to skip fungicide treatments that promise increased yields. They reported that fungicides used in fields where conditions were optimal for fungal diseases improved yields and paid for themselves.

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