THE IMPORTANCE OF FUNGICIDES IN U.S. CROP PRODUCTION

Leonard Gianessi and Nathan Reigner, CropLife Foundation, Washington, DC, U.S.A describe how the use of fungicides has benefited US agriculture

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Introduction

Plant pathogenic fungi are ubiquitous in the environment. 20,000 different species of fungi require a plant host for continuation of their life cycle (Ragsdale *et al.*, 1991). Countless numbers of spores are released by these organisms with the purpose of withdrawing nutrients from an infected plant. Fungicides are routinely used on the vast majority of the U.S.'s acres of fruit and vegetables to protect these crops from fungal invasions. Fungicides are essential if the U.S. is to continue large scale production of fruit and vegetables. The importance of fungicides to U.S. crop production can be understood through a historical perspective as well as examinations of recent experimental data, practices of organic growers and performance of alternatives. Recent aggregate studies document the importance of in field applied fungicides to many U.S. crops by simulating the effects of their non-use.

Historical Perspective

Crop losses to plant pathogens were commonplace in the U.S. in the 1800s and early 1900s: in the 1840s, 20-90% of the potatoes in northeastern states rotted due to late blight (*Phytophthora infestans*); in the 1850s it was reported that 50-75% of the peaches in Georgia were typically destroyed by brown rot (*Monilinia fructicola*); in the 1890s most asparagus fields in Atlantic states were entirely destroyed by rust (*Puccinia asparagi*) (Smith, 1905) (White, 1852).

Spraying fungicides to kill plant pathogens began in earnest in the 1800s in France. The first fungicide, sulfur, was found to completely inhibit powdery mildew (*Uncinula necator*) which had lowered French wine production by 75% in the 1850s. The downy mildew fungus (*Plasmopara viticola*) lowered French wine grape production by 50% in years prior to the regular use of Bordeaux mixture, a combination of lime with copper sulfate (Schumann, 1991).

Testing of Bordeaux mixture and sulfur in the U.S. demonstrated their effectiveness which led to widespread adoption resulting in significant declines in crop losses to diseases. Twenty years of tests with Bordeaux mixture at the University of Vermont (1890-1910) resulted in an average potato yield increase of 64% as a result of late blight control; Bordeaux mixture reduced cranberry rots by 50%; sulfur applications to Georgia peaches reduced brown rot losses to 13% (Jones *et al.*, 1912).

Widespread production of fruit and vegetable crops became dependent on regular use of fungicides. In the early 1900s powdery mildew was considered capable of destroying the entire grape crop in California if sulfur sprays were not made. By the 1920s spraying of lime sulfur for scab (*Venturia inaequalis*) became a universal practice in U.S. apple orchards and it was impossible to grow apples for the fresh market without fungicide sprays (Bioletti, 1907).

Most U.S. acres of fruit and vegetable crops were routinely treated with a fungicide (sulfur, lime sulfur, copper, Bordeaux mixture) for control of one or more plant diseases beginning in the early 1900s. The use of copper and sulfur as fungicides totalled 300 million pounds per year in the 1940s (Groggins, 1945). [Figure 1]

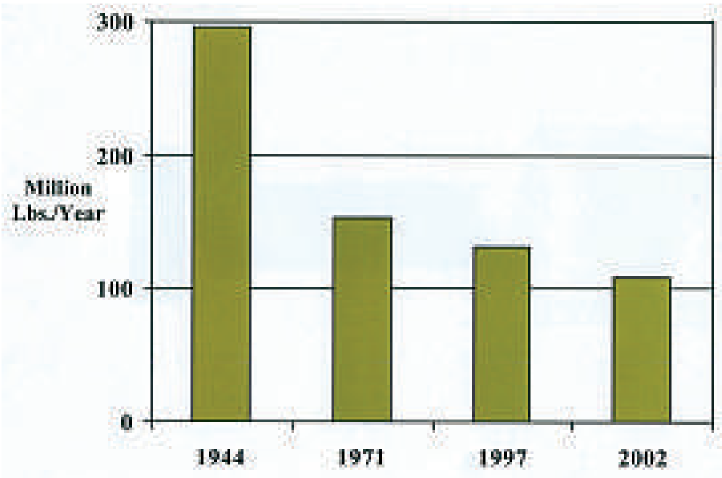

Figure 1: **U.S. Crop Production Fungicide Use**

Research with synthetic chemical fungicides began in the 1940s and demonstrated that crop yields were higher as a result of improved disease control efficacy and/or reduced damage to the crop. Although precise use estimates are not available, it is believed that growers of apples, potatoes and most other crops rapidly switched from older fungicides to new synthetic fungicides in the 1950s. For example, it was reported that the synthetic fungicides were used on 75% of U.S. potato acreage in 1953 (Brandes, 1953).

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Researchers determined that apple trees sprayed with ferbam yielded 41% more than trees sprayed with the standard lime sulfur treatment. Much of the yield increase was attributed to reduced damage to trees from ferbam in comparison to the lime sulfur sprays. When growers switched to synthetic fungicides in the late 1940s and early 1950s, U.S. apple yields increased dramatically due to reduced phytotoxicity. [Figure 2] Experiments with zineb and nabam resulted in potato yields that were 23-35% higher than with Bordeaux mixture. When U.S. growers switched to the synthetic fungicides in the late 1940s and early 1950s, potato yields increased dramatically. [Figure 3] For some diseases the synthetic chemicals offered the first effective controls. For apples, there were no effective spray materials for black rot (*Botryosphaeria obtusa*) prior to the introduction of ferbam and 25-50% fruit losses were commonplace in the Southeast. Ferbam reduced the incidence of black rot to 1% (Palmiter, 1949) (Muncie, 1947) (Brown *et al.*, 1986).

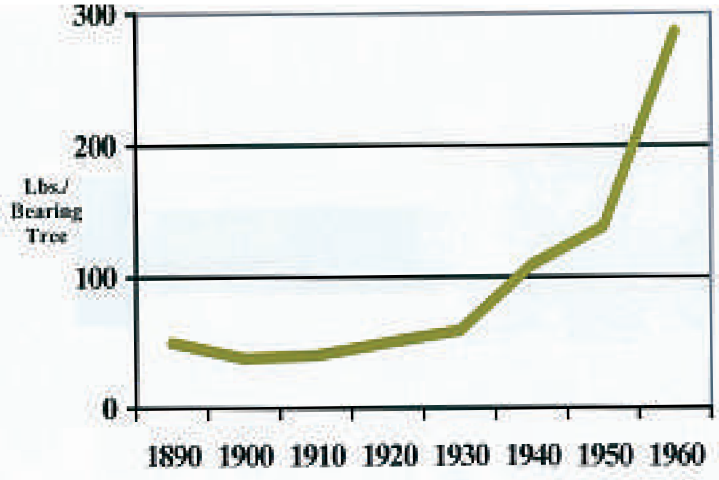

Figure 2: **U.S. Apple Yields**

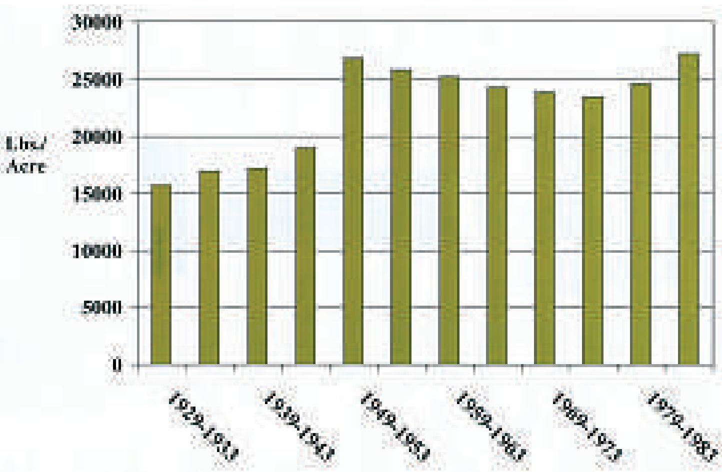

Figure 3: **Maine Potato Yields**

In a 1950 report to Congress the American Phytopathological Society reported that many fruit and vegetable crops could not be produced in reliable volume without chemical protection from diseases (APS, 1950).

One result of the adoption of synthetic chemical fungicides has been a significant decrease in the total volume of fungicides used in U.S. agriculture. Synthetic chemical fungicides were used at significantly lower rates per acre than copper and sulfur (3-6 pounds/acre versus 10-60). As newer fungicides with even lower use rates (0.1 pound/acre) were introduced, the aggregate volume of fungicides declined further and currently totals 108 million pounds per year. (In comparison to 300 million pounds per year in the 1940s. [Figure 1]) (Andrilenas, 1974) (Gianessi and Marcelli, 2000)

Table 1 shows the current extent of fungicide use by crop in the U.S. More than 80% of the acres of most fruit and vegetable crops are treated with fungicides every year.

Table 1: Benefit of Fungicide Use in U.S. Crop Production

Crop	% Acres Treated	% Yield Attributable to Fungicides[1]	Production Increase Million Lbs.	Production Increase $ Thousand
Almonds	82	70	626	682,486
Apples	93	86	6,803	1,223,007
Artichokes	81	35	27	18,928
Asparagus	43	22	18	14,973
Bananas	75	30	4	1,887
Barley	9	16	158	8,854
Blueberries	75	63	116	103,777
Cabbage	61	34	596	68,956
Cantaloupes	60	23	320	58,574
Carrots	95	26	810	126,221
Celery	92	39	727	91,991
Cherries	92	76	526	228,027
Citrus	88	49	14,105	926,968
Collards	78	65	85	15,992
Cotton	12	14	134	59,361
Cranberries	87	68	338	110,323
Cucumbers	77	70	1,093	184,605
Garlic	61	50	144	42,090
Grapes	100	95	13,873	2,674,028
Green Beans	70	27	331	75,757
Hazelnuts	60	75	18	8,775
Hops	100	69	40	78,255
Hot Peppers	44	50	42	11,546
Kiwi	33	25	4	1,493
Lettuce	85	47	3,829	878,052
Mint	16	23	<1	3,816
Nectarines	89	45	239	45,864
Onions	84	24	1,308	171,778
Papaya	100	100	46	11,900
Parsley	66	33	5	1,480
Peaches	91	54	1,207	283,650
Peanuts	92	71	2,180	389,143
Pears	89	99	1,526	224,704
Pecans	69	44	53	45,755
Pistachios	39	50	59	65,584
Plums and Prunes	66	45	221	62,015
Potatoes	94	44	18,262	1,158,947
Raspberries	97	60	67	49,986
Rice	54	23	2,595	111,825
Soybeans	1	19	919	26,309
Spinach	71	38	190	44,565
Strawberries	97	59	1,123	705,500
Sugarbeets	78	28	11,902	232,925
Sweet Corn	34	44	1,347	112,584
Sweet Peppers	80	78	1,006	329,811
Tomatoes	77	19	3,905	749,410
Walnuts	47	50	152	71,440
Watermelons	81	62	1,961	147,166
Wheat	9	19	1,720	106,804
Wild Rice	20	28	1	1,848
Total			**96,761**	**12,849,735**

[1]National average % yield increase from fungicide use on treated acreage.

Alternative Control Methods

One strategy for disease management in the years before fungicides was simply to abandon acres in infested states and move production to areas of the country where a pathogen was not present. In certain crops, this strategy worked well for many years; however, due to long range transport of fungi, the uninfected areas have become infected, resulting in the use of fungicides to preserve continued production in the previously uninfected areas. In the 1920s, eastern filbert blight (*Anisogramma anomala*) destroyed all the filbert trees in eastern states. Filbert production thrived in the northwest, which was free of the fungus. Eastern filbert blight was detected for the first time in Oregon in 1971. Without fungicide use, it is estimated that 75% of Oregon's filbert (hazelnut) trees would be killed within 25 years. In the 1800s the center of hop production was New York, where uncontrolled mildews (*Sphaerotheca macularis* & *Pseudoperonospora humuli*) led farmers to discontinue production. The center of hop production moved to the northwest where the powdery mildew fungus did not occur. The powdery mildew fungus was detected for the first time in the Northwest in 1997 and currently 100% of hop acres in the region are sprayed with fungicides.

The removal of nearby alternate hosts of pathogens has been utilized as a means of reducing pathogen pressure on susceptible crops. For example, in the early 1900s eight states passed laws empowering the removal of cedar trees as a way of preventing infections of apple orchards by cedar apple rust spores (*Gymnosporangium juniperi-virginianae*). However, the measure proved impractical due to the large number of cedar trees and their aesthetic value (Palmiter, 1954). In 1918 the federal government began a campaign to eradicate the barberry plant from the northern Great Plains since the wheat rust fungus, *Puccinia graminis*, could only survive there by overwintering on a barberry plant. Over a half billion barberry plants were eliminated. Barberry eradication did not eliminate the threat of rust infections since rust spores blow northward from Mexico and Texas. The effect of barberry eradication was to delay potential rust epidemics by several weeks.

One disease control method that has been continuously explored as a means of managing plant diseases in the U.S. is the breeding of resistant cultivars. For several field crops, the breeding of resistant cultivars has proven to be an effective strategy and fungicides are not required: corn, sorghum, sugarcane. However, plant pathogen populations adapt to resistant cultivars and races of pathogens that overcome the resistance become dominant. As a result, in order to sustain host plant resistance, crop breeding needs to be continuous, with new resistant varieties in development at all times.

For some crops, despite decades of breeding thousands of new varieties, disease suppression with host plant resistance has proven completely unstable because the pathogen mutates so rapidly. As a result, fungicides are required to prevent losses. No potato variety has been produced combining resistance genes to all late blight races with the many genetic traits needed to produce a commercial variety. Although the search for peanut cultivars resistant to white mold (*Sclerotium rolfsii*) originated in 1917, a high degree of resistance has not been found. There are numerous examples of the breakdown in host plant resistance which resulted in a need for fungicides. Prior to 1960, downy mildew was a significant disease on lettuce in California. It was brought under control with resistance genes from wild lettuce. New races of the fungus appeared in 1976 and overcame the resistance. In 1989, another set of resistant plants were introduced, but by 1992 control slipped again and fungicides have been used since to control the disease. In many cases resistant cultivars have been released but are not widely planted because of poor horticultural characteristics. For example, more than twenty apple cultivars bred with resistance to scab have been released, but none are widely planted since they produce fruit of small size, have a tendency to ripen unevenly, and have brownish interiors.

Often "resistant" cultivars are not totally resistant to the pathogen. For example, resistant peanut varieties provide 20-40% control of leaf spot, rust and stem rot (*Cercospora spp.*, *Puccinia arachidis*, & *Sclerotium rolfsii*). By contrast, fungicides provide more than 90% control.

Organic Practices

Organic fruit and vegetable growers find it necessary to spray fungicides to control diseases. Organic growers are permitted the use of approved disease control materials including sulfur, copper, and lime sulfur. A recent production budget guide for organic apple growers in the northeast estimated that ten gallons of lime sulfur and twelve pounds of wettable sulfur are used per organic apple acre. Organic grape and strawberry growers in California are reported to apply 66 and 45 pounds of sulfur per acre respectively to control powdery mildew. In order to control late blight, it has been reported that organic potato growers make nine to fifteen copper applications per season (Rutgers, 2004; Bolda *et al.*, 2003; Weber *et al.*, 2005).

Experimental Results

Fungicides are regularly tested for control efficacy and impacts on crop yield. These tests demonstrate the importance of fungicide use. For over forty years, the annual incidence of scab in apple trees untreated for scab has been 98-100% in experiments at Michigan State University (Jones, 1995). Some recent test results include: garlic yields doubled with control of rust (*Puccinia allii*); watermelon yields increased 61% with gummy stem blight (*Didymella bryoniae*) control; fungicides reduced the incidence of citrus scab (*Elsinoë fawcettii*) from 44% to 0.4%; fungicides reduced purple spot (*Pleospora herbarum*) losses in asparagus by 99%; fungicides reduced the defoliation of cherry trees due to leaf spot (*Blumeriella jaapii*) from 80% to 0.3%; control of blast with fungicides increased rice yields by 45%. Fungicide treatments for phytophthora (*Phytophthora capsici*) control increased yield of sweet peppers by 25,000 pounds per acre.

Aggregate Studies

In recent years several national studies have concluded that the failure to use fungicides would lead to significantly lower yields due to the absence of effective disease control alternatives. USDA reports on strawberries, carrots, and fresh tomatoes concluded that national production of the three crops would decline by 58%, 24%, and 60% respectively without fungicides (Davis *et al.*, 1998; Sorenson *et al.*, 1997; Davis *et al.*, 1999). In other reports, USDA estimated state specific losses without fungicide use: Michigan potato yield -50%; Georgia sweet corn yield –40%; Florida pepper yield -100%; Massachusetts tomato yield –75%; Washington asparagus yield –60%; California spinach yield –40%.(Davis, 1991; Johnston, 1991). The American Farm Bureau estimated that without fungicides the following losses would occur: Florida citrus –50%; Maine potatoes –100%; California grapes –97%; Michigan apples –100%; California lettuce –47%; Texas onion –60% (Knutson *et al.*, 1993).

All of these studies relied on university plant pathologists to specify the likely changes in yield if growers did not use fungicides. These expert opinions are based on research trials conducted by the pathologists and on observations of yield losses that occurred in farmers fields when diseases were left uncontrolled. These predicted yield changes are consistent with the historical record.

A recent study from the CropLife Foundation (CLF) organized the predicted yield loss estimates from the individual USDA and Farm Bureau studies into a comprehensive aggregate study estimating the likely impacts on crop yield if fungicides were not used (Gianessi and Reigner, 2005). The national aggregate production loss estimates by crop are shown in Table 1 and national aggregate fungicide benefits by state are shown in Figure 4.

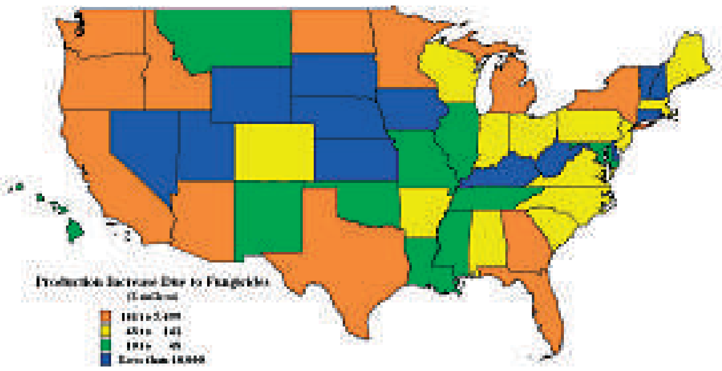

Figure 4: **Fungicide Benefits by State**

Grape growers gain the most as a result of fungicide application: $2.67 billion per year which represents 95% of U.S. grape production value. Apple growers rank second with a gain from fungicides of $1.22 billion, representing 83% of U.S. production. The value of eight other crops is increased by more than $300 million annually as a result of fungicide treatments: potatoes, citrus, lettuce, tomatoes, strawberries, almonds, peanuts, and peppers.

Growers in California benefit the most from fungicide use ($5.5 billion) followed by Florida ($1.9 billion), and Washington ($1.4 billion). [Figure 4] Overall gain in the U.S. as a result of fungicide treatment is $12.8 billion in income with a production increase of 97 billion pounds per year in food and fiber. [Table 1]

Conclusions

Plant parasitic fungi are an implacable foe of US crop production. In the spring and summer countless numbers of spores are released by fungal organisms. If the spores land on susceptible plant tissue that is not protected by a fungicide, a germ tube grows, penetrating the plant and resulting in an infection by the fungal organism and the withdrawal of plant nutrients leading to rot and plant death. Untreated fruit and vegetable fields can be totally destroyed by fungal pathogens while fungicide-treated acres are well-protected. [Figure 5]

Healthy, Fungicide Protected Potatoes   Untreated, Diseased Potatoes

Photo: DuPont Crop Protection

Figure 5. **Potato Late Blight Disease**

In the U.S. before the introduction of fungicides, there were no defenses for plant diseases which typically rotted much of the nation's fruit and vegetable crops. Widespread use of fungicides began in the U.S. in the early 1900s with the spraying of sulfur and copper. Most fruit and vegetable crops have been sprayed with fungicides in the U.S. for one hundred years.

The benefit of fungicide use in U.S. agriculture is a significant increase in the production of fruit and vegetables, which are important for healthy diet. Each year the U.S. harvests 97 billion pounds of food and fiber due to fungicide disease control, boosting farm income by nearly $13 billion. Organic growers use fungicides too, which further indicates their indispensability.

Since fungicides are so important in domestic food production, it is worth asking whether there should be policies adopted to assure that U.S. growers have the fungicides that they need for the foreseeable future.

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