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Effects of Barberry Eradication on Stem Rust in the United States

The bumper wheat crop of 1915 in the United States and Canada was followed in 1916 by a season that started out cool and moist. The crop was late in the northern Great Plains, wheat growth was lush, and conditions in May and June were ideal for development of stem rust (*Puccinia graminis* Pers.). Barberry bushes, an alternate host of the fungus, were severely rusted early in the season, and by early July stem rust was present on wheat throughout the spring wheat area. Hot humid weather in May through July favored rust development, and a change to hot dry weather in August ripened the crops prematurely with disastrous effects.

In 1916, 14 million acres of wheat were planted in North Dakota, South Dakota, and Minnesota; yields, however, were only 5.5–7.6 bushels per acre, about one-third those of 1915. Farm prices for wheat rose from 91¢ per bushel in 1915 to $1.60 in 1916, and flour prices increased from $6.10 a barrel to $8.60. An estimated 200 million bushels of wheat were lost in the United States and another 100 million bushels in the Canadian prairie provinces. These crop losses sharply curtailed human food resources during World War I. Immediate action was required to assure an adequate food supply for the Allies. After many meetings and conferences of agricultural and military officials, a national program for the control of stem rust evolved. A part of the program was a plan to eradicate the principal alternate host, the common barberry (*Berberis vulgaris* L.).

An Early Arriver and Favorite

Wheat is the major food crop in the world and sustains the majority of the world's population. Wheat fields occupy more of the earth's surface than do fields of any other food crop. Stem rust is one of the most important wheat diseases limiting production in many areas of the world. The disease has been important throughout the ages. The Romans, in order to please the rust god, Robigus, held a festival called Robigalia.

The common barberry (Fig. 1) was brought to North America by early settlers from Europe, where it had been widely grown for medicinal and other purposes. The medicinal uses were important enough that barberries were planted in monastery gardens throughout southern Europe. The long, straight lightwood of the barberry branches made excellent handles for hand tools. Barberries also made an excellent hedge because their dense growth and sharp spines discouraged penetration by livestock and poultry. In America the fruit became a favorite for sauces, jellies, wines, and preserves and the bark was used as a source of yellow dye. Thus, the barberry became established in areas where it was a close neighbor to the small grain cereals, and both were moved by farmers as agriculture spread west in the early 1800s. The common barberry adapted well throughout much of the Midwest and became widespread locally as seeds were spread by birds, animals, and water.

The disadvantage of growing barberries and small grain cereals together was recognized by European farmers long before it was known that barberry was the alternate host for the fungus causing stem rust. In Rouen, France, a law was passed in 1660 to outlaw the growing of barberry bushes, nearly 200 years before the German scientist A. DeBary proved that the rust on barberry in the spring was the same fungus that caused stem rust of small grain cereals in the summer and fall (Fig. 2). The earliest local laws against growing barberry in the Americas were passed in Connecticut in 1726, Massachusetts in 1754, and Rhode Island in 1766, but enforcement of these laws lapsed as wheat declined in importance in New England.

Eradication Program Started

After the disastrous epidemic of 1916, laws against the growing of barberry were passed in the important wheat-producing states of South Dakota and North Dakota (1917); Michigan, Minnesota, Nebraska, and Colorado (1918); and Illinois, Indiana, Iowa, Montana, Ohio, Wisconsin, and Wyoming (1919). A cooperative federal and state program on barberry eradication was started in these states in 1918, with E. C. Stakman as its head. Six states joined the program later: Washington in 1923; Missouri, Pennsylvania, Virginia, and West Virginia in 1935; and Kansas in 1955.

Barberry eradication was visualized as a way to break the rust cycle and prevent local outbreaks of stem rust principally on wheat and oats in order to maximize grain production during the period of World War I. Two examples of such local epidemics reported by Stakman (9) show the gravity of the problem.

A farmer at Crystal Bay, Minnesota, had a 635-bush barberry hedge. He tried to grow oats on the farm for 10 years, but stem rust destroyed almost all of the grain annually. In May of 1918 the barberry hedge was destroyed before the bushes rusted. The field was examined for rust 10 days before harvest and none was found. This farmer's first successful crop in 10 years had excellent quantity and quality.

Near Lake Preston, South Dakota, common barberry bushes were growing for a half a mile along the roadside in a grain-growing area. Practically all of the bushes were heavily rusted. The nearest grainfield was a field of barley about 400 ft west of the bushes, and there was a great deal of wild barley (*Hordeum jubatum* L.) near the bushes. On July 20, 1917, the grasses and barley were carefully examined, but the weather had been hot and dry and rust spread was light. It was clear, however, that the rust had spread from the bushes to the wild grasses, barley, and wheat 2½ miles from the bushes. Wet weather occurred between July 20 and 30, and on July 30 rust on wheat was severe up to 2½ miles and had spread to wheat 5 miles from the bushes. The effect of the bushes was so apparent that 27 farmers composed and signed the following statement: "Since the common barberry harbors the black stem rust of the wheat in the early spring and thereby starts an early and serious infection of rust, particularly because of the barberries on two farms south of town which are known as the ——— farms, where for many years early and serious stem-rust infection has been noted and is due to the presence of the barberries, we the undersigned, believe that in order to protect the wheat crop of South Dakota from the rust infection caused by the common barberry, there should be a special barberry law in South Dakota making it a crime to propagate, grow or have growing on any public premises any of the common rust susceptible varieties of barberries."

Fig. 1. Common barberry bush (*Berberis vulgaris* L.).

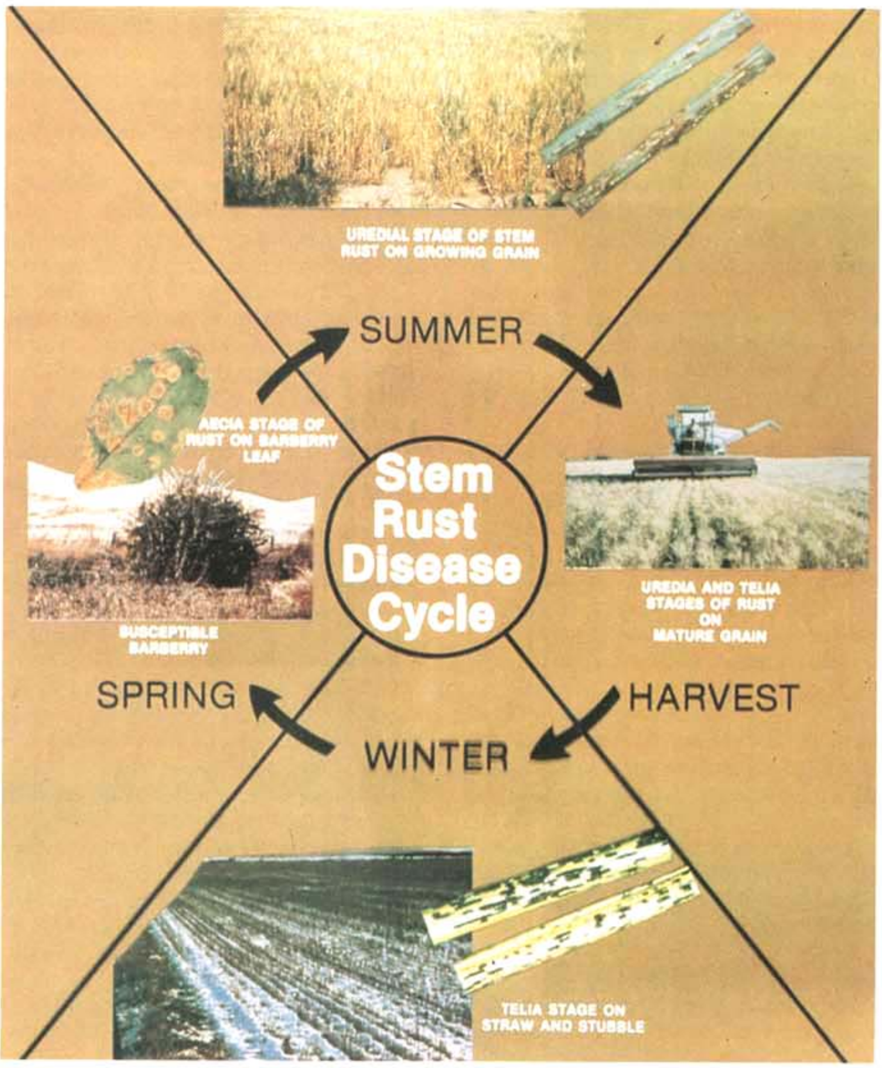

Fig. 2. Disease cycle of the stem rust of small grain cereals caused by *Puccinia graminis* Pers.

The effect of a single rusted barberry bush on wheat yields was shown by Beeson (1) (Fig. 3).

The barberry eradication program varied in scope over the years principally because of the level of state and federal support. Initial eradication efforts were made by gaining the cooperation of farmers and youth groups in reporting and removing bushes. During this period, bounties and medals were awarded by some states for reporting the location of a barberry bush. In 1922, agribusinesses concerned with the marketing and processing of small grain cereals formed the Rust Prevention Association to publicize the need to eradicate barberries and to rally public support for the program. In 1936, the Minnesota eradication program at its peak employed over 650 persons.

Eradication was supplemented in 1919 by the issuance of Federal Quarantine No. 38 to prevent interstate movement and reestablishment of susceptible barberries. A program was established to test species and cultivars of *Berberis*, *Mahonia*, and *Mahoberberis* for reaction to *P. graminis*. Those found to be susceptible were not permitted in the commercial trade and were destroyed if found in the eradication area. They were often detected on inspection of plants in the commercial trade. Untested stocks were destroyed or held without further propagation until the response to stem rust was determined so that appropriate action could be taken.

During 1975 through 1980 the federal eradication program was gradually terminated. The states now are independently responsible for eradication. The federal program continues to test new cultivars and species for resistance to rust and to inspect bushes in commercial trade.

Success of Eradication

Barberries were reported eradicated in large numbers (Table 1), and thousands of unreported bushes were removed by the owners. Generally the first bushes removed were those responsible for rust spreads to small grain cereals, the large planted ones, and many thousands in commercial nurseries. The effect of removing 100 large bushes from fence rows in cereal fields in 1918 was much greater than that of removing 1,000 bushes from wooded areas or 1,000 seedlings and smaller bushes adjacent to cereal fields in the later years of the barberry eradication program. Thus, the early stages of the program had a rapid effect on the diseases caused by *P. graminis*.

Common barberry was widespread in the 13 original barberry eradication states (Fig. 4). Early eradication efforts were concentrated in areas adjacent to small grain cereal fields where barberries were associated with the grain. The vast numbers of barberries eradicated after 1926 were from nearby areas where the barberry was common but not in immediate contact with cereal-producing fields. In the later years of the program, many of the bushes removed were seedlings or small bushes that probably never were exposed to rust.

The initial success of the barberry eradication program dictated that it be continued after the war ended. Success was measured generally by reductions of local severe epidemics as shown by the decreasing annual losses caused by stem rust. It was evident by 1927 (4,10) that losses caused by the cereal stem rusts had decreased, and losses have continued to decrease through the 1970s (8). Changes in frequency of epidemics are probably the most useful estimate of changes in disease levels, because increases in crop production also reflect greater yield potential of cultivars grown, cultivation practices, and acreages planted over the past 63 years. The average number of wheat and oat stem rust epidemics in the original 13 states has decreased over six decades since the beginning of the barberry eradication program (Table 2). Although use of resistant cultivars has contributed to the decreasing frequency of wheat stem rust epidemics, nearly all commercial oat cultivars have been susceptible to the prevalent races (6). Thus, the barberry eradication program was effective in reducing the frequency of epidemics.

Four Effects of Barberry Removal

In 1918, barberries appeared to be the only source of inoculum of wheat stem rust in the spring grain-growing area (9). After eradication of the barberry was under way, however, uredospores were found to be transported into the spring grain area from the southern states. Still, barberry eradication affected the frequency and severity of stem rust epidemics by: 1) delaying disease onset by about 10 days, 2) reducing the initial inoculum level, 3) decreasing the number of pathogenic races, and 4) stabilizing pathogenic races.

Delayed disease onset. This effect was shown by the simultaneous rust surveys (2) that were conducted for many years. These surveys were initiated in 1923 as an aid to finding sites with undetected barberries and were made annually over established routes at a time before incipient local epidemics had spread widely. The first survey (2) was during late July but in later years surveys were done on July 8. By this date fields in the vicinity of barberry bushes were lightly to moderately rusted in southern Minnesota, while fields remote to barberry had only traces of rust infection. In recent years, such "hot spots" have not been found. My experience is that infection levels on susceptible cultivars range from none to a maximum of one pustule per 10 ft of row on July 8. The time required for the currently observed levels of infection to increase to the light to moderate disease severities formerly observed in fields near barberries would be at least 14 days. Thus, initial infection currently must occur at some later time than when barberry was active in stem rust epidemiology. Records of disease onset kept for many years at the Cereal Rust Laboratory show that early disease onset is correlated with an increase in disease losses (3,8).

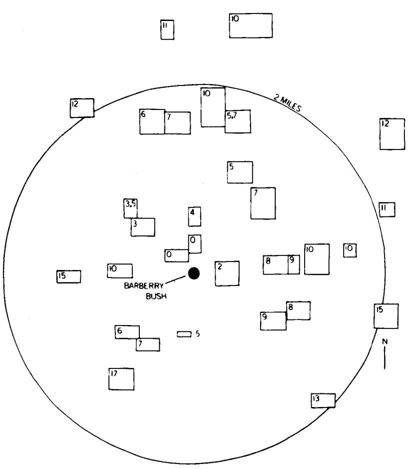

Fig. 3. Wheat yield in bushels per acre in the immediate vicinity of a barberry bush near Alert in Decatur County, Indiana. Yields outside the rusted area were 15–25 bushels per acre (1).

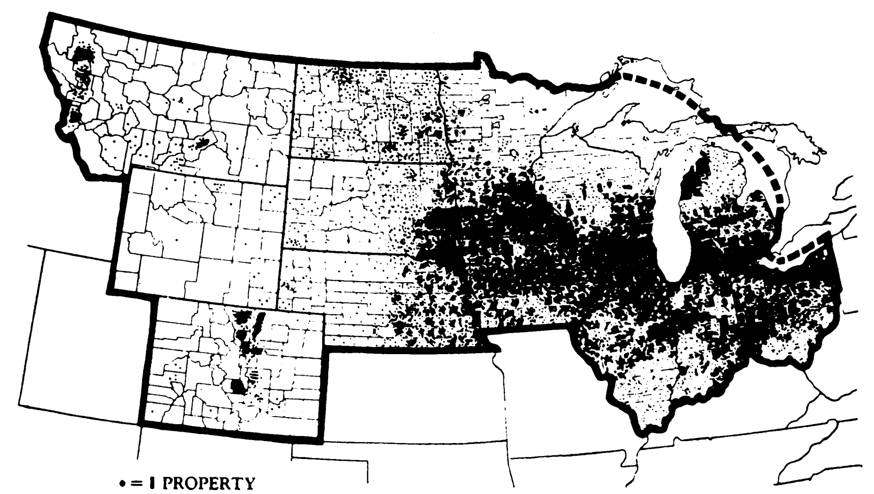

Fig. 4. Distribution of rural properties on which common barberries were found from 1918 through 1926 in the 13 north central states comprising the original barberry eradication area (5).

Table 1. Cumulative number of barberry bushes destroyed at the end of 5-year periods in the original 13 barberry eradication states

Year	Bushes destroyed (cumulative no.)
1918	1,692,971
1922	5,411,935
1927	16,066,444
1932	18,665,403
1937	25,713,333
1942	36,995,627
1947	41,042,511
1952	74,691,695
1957	96,180,475
1962	98,690,462
1967	99,445,774

Table 2. Average number of years per decade in which stem rust epidemics occurred in the original 13 barberry eradication states[a]

Wheat stem rust		Oat stem rust	
Decade	Average number of epidemics[b]	Decade	Average number of epidemics[b]
1918–1927	5.1	1919–1928	3.5
1928–1937	3.0	1929–1938	1.3
1938–1947	2.7	1939–1948	1.9
1948–1957	2.8	1949–1958	3.3
1958–1967	2.1	1959–1968	0.1
1968–1977	0.1	1969–1978	0.4

[a] Data from Roelfs (6).
[b] Yield losses greater than 1% in any year.

Table 3. Average date of the first reported observation of wheat stem rust in selected areas in the north central region of the United States

Decade	East central South Dakota	Southeast Minnesota	Southeast North Dakota
1919–1927	June 16	June 14	June 19
1928–1937	June 15	June 16	June 22
1938–1947	June 22	June 23	June 28
1948–1957	June 17	June 20	June 22
1958–1967	June 19	June 18	July 5
1968–1977	June 29	June 24	July 13

Table 4. Average number of wheat stem rust races found per year in each decade since 1918 in the United States

Decade	Number of races[a]
1918–1927	17.5
1928–1937	10.7
1938–1947	6.5
1948–1957	7.7
1958–1967	7.5
1968–1977	5.2

[a] Races that comprised more than 0.6% of all isolates.

Table 5. The most commonly identified race of wheat stem rust in the United States during 1918 through 1979

	Occurrence	
Race	Number of years	Years
3	1	1919
29	1	1921
21	1	1922[a]
32	1	1923
11	2	1920, 1924
49	2	1929, 1933
38	2	1938, 1948
17	2	1922,[a] 1941
36	3	1928, 1930, 1931
18	4	1918, 1925–1927
56	23	1934–1940, 1942–1947, 1949, 1950, 1956,[b] 1958–1964
15	22	1951–1957,[b] 1965–1979

[a] Races 17 and 21 equally common.
[b] Races 15 and 56 equally common.

Dates of reported initial observations for wheat stem rust away from barberry for the north central states (Table 3) show a trend toward later detection. In the decade of 1968 through 1977, the initial date of observation was later and the level of initial infection was lighter than in the past. This must reflect a general reduction in the primary inoculum level, due in part to barberry eradication, disease-resistant cultivars, and agricultural practices. In 1924, the earliest year for which data are available, known barberry bushes in the vicinity of small grain fields had already been removed.

Reduced virulent inoculum in the spring. At present, successful infection of the spring small grain cereal crops requires: 1) spore production in the overwintering area, 2) favorable conditions for spore liberation and movement into the upper air masses, 3) favorable conditions for transport of viable spores, 4) rain to deposit spores on a susceptible host cultivar, and 5) favorable environmental conditions. In general, inoculum from the barberry required only favorable environmental conditions locally, and the same conditions favored aeciospore release and infection. Thus, many fewer aeciospores were required to initiate infection on small grains because losses in uredospore numbers and viability are great during long-distance transport.

According to Stakman et al (10) an average size common barberry bush in southern Minnesota had about 35,000 leaves, of which about 28,000 would be infected with stem rust. A single infected leaf on the average produced 2.3–8 million aeciospores. Thus, the average bush could be the source of 64 billion aeciospores, and often several such crops of spores were produced. If weather conditions were favorable, each spore potentially could infect a small grain cereal plant and produce a uredium within a week to 10 days. Each uredium produces about 200,000 or more uredospores, each of which could produce another uredium in another week to 10 days.

Of course, all spores do not cause infection, but it is evident that rust could multiply and spread from barberries with almost miraculous rapidity. Only a few bushes in a grain-growing county could produce an unbelievably large number of spores in that county. For example, 82 bushes were found in Norman County, Minnesota, in 1925. These bushes were the potential source of about 5 trillion aeciospores, each of which might cause rust on a grain plant. As there are 2–3 million tillers per acre in a grain field, enough spores could be produced from these 82 bushes to cause rust on every tiller of grain on more than 1.5 million acres. These figures are really not unrealistic because as many as 15,000 common barberry bushes were found in one Minnesota county.

Currently, the inoculum level of uredospores arriving from further south is such that the resulting infection level is about one infection per 40 ft of row (approximately 1,500 infections per acre). Using figures of Stakman et al (9), this would produce (1,500 × 200,000) 300 million spores per acre, or about 0.5% of what a single barberry bush could produce. Such calculations show how eradication of barberries destroyed a major source of primary inoculum.

Decreased number of pathogenic races. The third effect of barberry removal has been the reduction in the number of races present (Table 4) in the pathogen population (7,11). Racial diversity results from the sexual stage of the organism that occurs on the barberry. The number of races in the 1970s was less than one-third that in the 1920s. This is an underestimate for two reasons. First, many fewer isolates were studied during 1918–1927 (1,541) than during 1968–1977 (18,403), and generally the number of races found increases with the number of isolates studied in a sexually reproducing population. Second, most of the barberries in close association with small grain cereals were removed early during 1918–1927, ie, 28 races were found in 1918 and only 20 in 1919. In a recent study (7) of an asexually reproducing population of wheat stem rust, an average of one race was found per 148 isolates, whereas uredial collections from a sexually reproducing population of wheat stem rust yielded one race per 4.3 isolates.

Stabilized pathogenic races. The fourth effect of barberry removal was to increase the probability that the most commonly identified race one year would be the most common race the next year (Table 5). During the decade of 1918–1927 seven races predominated in one or more years, while during 1968–1977 a single race predominated each year. This decrease in numbers of races identified and the increased stability of races have made the development of resistant cultivars possible. Imagine the plight of a plant breeder who must evaluate his progenies against 28 different races in a year, expecting that six will not reappear and three new ones will appear the next year. This occurred in 1918 and 1919.

There is one additional effect of barberry removal that currently has little immediate importance but should be noted nevertheless. Because *P. graminis* has been separated from its alternate host in the Great Plains of the United States and Canada, the asexually reproducing population has lost some of its ability to form telia and the telia have lost some of their ability to germinate and infect barberry. At the Cereal Rust Laboratory, cultures of recent sexual origin are readily recognized by the production of telia on seedling plants and large telia on adult plants. Teliospores from many of these isolates readily germinate and infect barberry, whereas isolates from the Great Plains asexually reproducing population do not. Because the teliospores would tend to have the genes for virulence and environmental adaptation favored in the area, recombinant lines with the necessary genes to be a successful local pathogen would be among the sexual progeny.

Risk of Rust Recurrence

Currently, there are no known areas in the wheat- and oat-producing areas of the Great Plains of the United States where rust spreads from barberry to commercial fields. Barberry could again become a problem, however, if reintroduced into the area. Scattered barberry plants still remain in 12 of the 13 original eradication states. Most are either seedlings or remote from small grain-growing areas. These bushes are not involved in rust spread because: 1) teliospores on straw are not close to the bushes, 2) basidiospores are relatively sensitive to environmental conditions and travel only short distances, 3) basidiospores are less likely to land on a seedling or a bush in heavy woods than on a large bush in an open area, 4) pycniospores are less likely to be transferred between pycnia, which is necessary for fertilization, as the distance between pycnia increases, and 5) aeciospore numbers must increase as the distance to the cereal crop increases to produce similar numbers of uredia.

There is a risk of barberry becoming reestablished in fence rows and field edges. Barberries were originally spread naturally by seeds that can remain dormant for up to 10 years and can pass through the digestive tract of birds. Bird transport of seed has been reduced by removal of the large fruiting bushes, and fence-row inhabiting birds rarely feed on berries on bushes growing deep in wooded areas. But if barberries spread back into the edges of the woods, both birds and water may become important means of reintroducing the bushes into the fields. An example of the spread of barberry bushes from a known source is shown in Figure 5.

Hybridization between susceptible and resistant barberries also can occur. In 1948, during a routine inspection of a nursery near Shenandoah, Iowa, 98 barberry bushes of questionable identity were observed. Because of their unusual characteristics, an investigation followed that revealed the bushes had been purchased from another nursery as 'Sherman's New Red Leaf Barberry.' The originating nursery had found an off-type red leaf barberry in a plot of Japanese barberries. The nursery made cuttings and propagated 95 bushes. When found in 1948 these bushes were 6–7 ft tall and rusted with *P. graminis*. The nursery had established 300 2-year-old and 2,050 1-year-old bushes from these bushes, and,

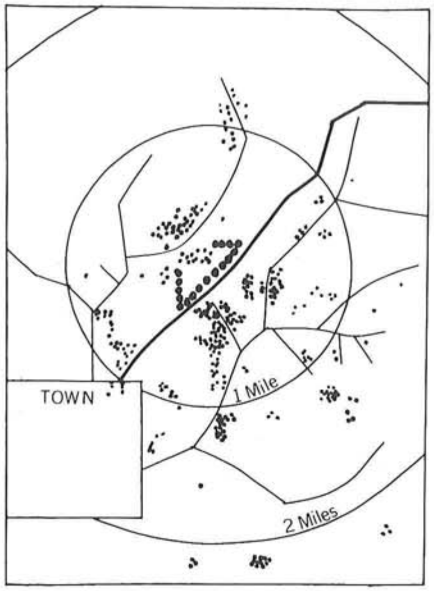

Fig. 5. Location of a common barberry hedge (large dots) and the bushes (small dots) that developed from seed spread from the hedge in Fayette County, Iowa (10).

additionally, 5,820 bushes had been sold to 64 firms in 19 states, which in turn had sold some to the public. The bushes were found principally in Nebraska, Illinois, New York, and Iowa. Fortunately, all were found and destroyed. This shows how fast the barberry could be reintroduced without an adequate program for determining resistance of barberry cultivars to rust and without a phenotypical evaluation of barberries that move in intranational and international commerce.

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