IMPACT OF APHIDS SPECIES AND BARLEY YELLOW DWARF VIRUS ON SOFT RED WINTER WHEAT

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CHAPTER I

Literature Review

Research Justification. Barley yellow dwarf (BYD) is one of the most important viral diseases of wheat (*Triticum aestivum* L. em. Thell) in the world (Gill 1988), however many producers are unaware of the presence and economic impact of this disease. In the 2001-2002 winter wheat growing season, several Missouri producers reported stunting and yellowing of wheat plants. Laboratory results indicated that these symptoms were caused by a complex of BYD viral strains. In these same fields, producers noticed substantial yield reductions at harvest, some over 50%. Currently, there is a lack of field research that quantifies the impact of *Barley yellow dwarf virus* (BYDV) on winter wheat yield in Missouri.

Barley yellow dwarf is one of the most widespread viral diseases of wheat in Missouri (Palm 1993). Currently, the optimal strategy for managing BYD is to control the associated aphid vectors. Recommendations from regions that have developed economic thresholds for aphid control are diverse, ranging from 10 to 980 aphids per meter-row (Herbert et al. 1999, Kieckhefer and Gellner 1992, Buntin 1999, Johnson and Townsend 1999). This disparity in economic thresholds has limited grower use in Missouri. Therefore, research is needed to evaluate the management strategies used to manage BYD incidence in Missouri. The objectives of this research were to quantify the effect of *Barley yellow dwarf virus* on soft red winter wheat grain yield and to develop economic thresholds for aphid management.

INTRODUCTION

Historical Perspective

Wheat was originally a wild grass domesticated in Southwest Asia. Wheat originated in the Fertile Crescent, a region that includes southwestern Iran, the Tigris and Euphrates basins, Syria, central Israel and Jordan (Feldman 2001). Wild emmer (*Triticum dicoccoides*), an early ancestor to present-day wheat, was first cultivated as early as 19,000 years ago in Israel (Kislev et al. 1992). Wheat cultivation enabled humans to produce large quantities of food, resulting in the establishment of cities. Wheat production quickly spread to other areas, now ranking first in the world's grain production, supplying more than 20% of the total calories and protein in the human diet (Nevo et al. 2002).

Cultivated wheats are classified into three main groups: diploids, tetraploids, and hexaploids (Feldman 2001). Wild einkorn is the ancestor of cultivated diploid wheats and wild emmer is the ancestor of tetraploid wheats. However, hexaploid wheat has no wild hexaploid ancestors. Hexaploids formed as a result of hybridization between several tetraploid wheat geneotypes and *Aegilops tauschii*, a diploid wheat (Feldman 2001). Hexaploid wheat is believed to have originated in Iran (Feldman 2001). The species *Triticum aestivum* orginiated from the hexaploid *T. dicoccoides* and is the source of all cultivated bread wheats (Nevo et al. 2002).

Soft red winter wheat belongs to the species *T. aestivum*. The endosperm of soft red winter wheat contains an enzyme that inhibits sprouting in the head, making it suitable for production in humid areas. In the United States, soft red winter wheat is grown in the Midwest, the South, and along the East Coast. Soft red winter wheat is primarily used in

the baking industry to make cakes, pastries and flat breads. Wheat grain that does not meet quality standards is used for animal feed.

Soft red winter wheat is the dominant wheat planted in Missouri. There are roughly 400,000 hectares of soft red winter wheat planted in Missouri (USDA 2004). Wheat production in Missouri peaked in 1981 with about 460,404 metric tons (USDA 2004). The number of harvested soft red winter wheat acres has continued to decline. In 2002, 307,572 hectares of wheat were harvested in Missouri, down 39% from 1996 (USDA 2004). Missouri currently ranks third among the 50 U.S. states in the production of soft red winter wheat.

Barley Yellow Dwarf

Barley yellow dwarf symptoms were first observed in 1951 on barley (*Horedum vulgare* L.) in California (Oswald and Houston 1951). The disease was later characterized in oat (*Avena sativa* L.) and wheat. Since then it has been identified worldwide.

Barley yellow dwarf symptoms are often mis-diagnosed because they resemble plant nutrient deficiencies. The most obvious symptoms are stunting and leaf discoloration. The stunted plants often appear in circular patches or as randomly scattered plants within a field. Leaf discoloration varies from shades of yellow, to red or purple. Visual leaf symptoms begin at the leaf tip and progress toward the middle and base of the leaves. High light intensity and cool temperatures (15 to18° C) have been found to favor expression of BYD symptoms (D'Arcy 1995).

Symptom expression is generally dependent on the time of infection. Seedling infection may be lethal or cause a distinct yellowing of older leaves (Wiese 1977). Plots

with post seedling infections have a yellowed or reddened flag leaf (Wiese 1977). Disease symptoms usually appear in late spring at jointing. Symptoms at jointing are predominately from fall infections. Spring infections have delayed symptoms that are usually less severe.

Carrigan et al. (1981) and Herbert et al. (1999) noted that fall infection reduced yield to a greater extent than spring infection. Cisar et al. (1982) indicated that fall infection reduced yield 63%. Yield loss from spring infection is generally lower due to the shortened period of virus replication in the plant. However, significant yield loss may still occur. Cisar et al. (1982) reported spring infection reduced yield by 41%. Though, fall infections tend to be more severe, Perry et al. (2000) reported that there may be little yield difference between fall and early spring infections. *Barley yellow dwarf virus* also weakens plants, making them more susceptible to winter injury. Stand loss may be attributed to winterkill, but other factors may have weakened the plants, putting them at greater risk for winterkill. Cook and Veseth (1991) reported that stand loss may be a warning that the entire crop is in trouble, the survivors may only appear healthy and the culprit may be BYDV. Additional BYD symptomology may include stiff leaves, underdeveloped root systems, decreased tillering, and inhibited head development and grain fill (Wiese 1977).

Vectors

Various studies have been conducted that verify BYDV is vectored by more than 25 species of aphids (Halbert and Voegtlin 1995). Winter wheat in Missouri is colonized mainly by four species of aphids: bird cherry-oat aphid, *Rhopalosiphum padi* (L.); greenbug, *Schizaphis graminum* (Rondani); the English grain aphid, *Sitobion avenae* (F.);

and the corn leaf aphid, *Rhopalosiphum maidis* (L.). Aphid feeding results in crop injury and yield reduction both directly and indirectly through virus transmission. The amount of injury depends on the size of infestation, infection time during the growing season, and efficiency of virus transmission to the crop. Visible injury from aphid feeding can be obvious or unseen and may be vector specific. *S. graminum* is unique in that it may cause visible injury to plants at relatively low numbers (Wadley 1929). According to Pike and Schaffner (1985), no visible injury was caused by feeding *R. padi*, although yield and quality loss were reported.

Cool (10 to 18° C), moist weather favors aphid multiplication (Wiese 1977). Weather also plays a role in aphid movement. Aphids can travel from field to field or if assisted by wind, they may be carried hundreds of miles. Early spring wind currents are responsible for aphid movement from southern to northern states. Recent mild (warm) winters have increased aphid survival and increased the potential for greater damage in the spring**.** Aphids are able to tolerate cold temperatures for short periods of time by cold hardening. Powell and Bale (2004) reported adult *S. avenae* survival of freezing temperatures increased from 16 to 68% when subjected to a cold acclimation treatment of 0° C for three hours. However, aphid survival is greatly reduced when temperatures remain around 0° C for extended periods of time.

Aphids species found in much of Missouri are holocyclic. They have a sexual generation in autumn that produces overwintering eggs, but reproduce parthogenically the remainder of the year (Stoetzel 1987). Winged adult females and males move into fields in the fall from surrounding pastures and grass waterways, as well as migrate in from long distances. After mating the females give birth to wingless females that

continue to reproduce without mating. Most spring aphid infestions in Missouri result from winged aphids that are blown up from southern states in air currents. In warmer climates many aphids overwinter anholocyclically, as adults that reproduce parthogenically. However, *R. padi* may overwinter in Missouri on *Prunus padus* L. (bird cherry) and several species of Gramineae (Stoetzel 1987).

Aphids reproduce extremely quickly. Immatures can reproduce in as few as seven days after birth, this allows females reproducing parthogenically to produce 60 to 80 offspring during their 20 to 30 day reproductive period (Herbert et. al. 2003). *R. padi* is frequently the most abundant species in the Midwest (Kieckhefer and Gustin 1967). Hesler and Berg (2003) reported *R. padi* accounted for almost 90% of all cereal aphids sampled.

Aphid species are 0.25 to 0.5 cm long making them hard to identify by species. However, several aphid species have distinguishing marks that can easily be seen under magnification. A few species of aphids have distinguishing marks on leg appendages and the main body (Fig. 1.1). In addition, the shape and overall color of the body, as well as the length and coloring of the cornicles and antennae are useful in identification (Fig. 1.1).

Barley yellow dwarf virus is transferred to aphids feeding on plants that contain the virus. The virus is not soil-borne, does not remain in the seed, and is not transmitted to aphid offspring. Aphids transfer the virus by removing phloem sap from infected plants and then feeding on other plants, thus transmitting the virus from host to host.

Virus Strains

There are several strains of BYDV; most are associated with a particular species of aphid (Table 1.1). The virus strains were originally differentiated by aphid vector, but

now they are often differentiated by serotype-specific antibodies, with most of the strains classified under BYDV or *Cereal yellow dwarf virus* (CYDV). *Barley yellow dwarf virus* and CYDV are in the Luteoviridae family; however BYDV is in the genus *Luteovirus* and CYDV is in the genus *Polerovirus* (Miller et al. 2002). The five common strains of BYDV/CYDV are PAV, SGV, RPV, RMV, and MAV. The RPV strain is now classified under CYDV. PAV and MAV remain classified under BYDV. However, SGV and MRV are currently not assigned to a Luteoviridae genus but remain under BYDV. PAV, a strain vectored by *R. padi* and *S. avenae* (Rochow 1979), is the most common and devastating strain in the Midwest.

Aphid species, length of feeding period, and the physiological age of plant tissue influence transmission efficiency of various BYD viral strains (Gray et al. 1991). *Barley yellow dwarf virus* is phloem restricted and is vectored more efficiently by different aphid species (Slykhuis 1967). Gray et al. (1991) reported that *R. padi* required a 1- to 2-hr or 2- to 3-hr acquisition access period (AAP) for 50% of the aphids to transmit PAV or RPV, whereas 50% of *S. avenae* required a 4- to 6-hr or 10- to 12-hr AAP to transmit MAV or PAV. It may take up to 48 hours for BYDV to be acquired from phloem sap, move through the aphid gut, and then be transmitted back into the phloem of another host plant (Zitter 2001).

Host Range and Yield Loss

The host range of BYDV includes more than 150 species of plants in the Poaceae family (Gould and Shaw 1983). The cultivated hosts include wheat, oat, barley, rice (*Oryza sativa* L.), and corn (*Zea mays*). Many annual and perennial lawn and pasture grasses are also hosts, allowing the virus to over-season during the summer. Grafton

(1980) reported that tall fescue served as a host for BYDV in areas with limited small grain production. Missouri has large acreages of grass that may serve as host reservoirs, increasing the likelihood of early season infection. Weerapat et al. (1972) reported that four out of ten random tall fescue (*Festuca arundinacea* Schreb.) samples collected around the borders of small grain plots in Missouri tested positive for the BYDV strain PAV.

Wheat yield loss associated with BYDV may be colossal. Yield losses of 40 and 67% have been reported in winter wheat (Yount et al. 1985, Kieckhefer and Kantack 1988). Pike (1990) reported that yield loss as great as 80% has resulted from BYDV infection. *Barley yellow dwarf virus* may also result in reduced tiller number and low-test weight. Yield loss associated with BYDV infection may be a result of reduced head number (Kieckhefer and Kantack 1988, Herbert et al. 1999), decreased thousand kernel weight (TKW) (Yount et al. 1985, Kiechhefer and Kantack 1988, Kieckhefer and Gellner 1992, Hoffman and Kolb 1998, and Herbert et al. 1999, Riedell et al. 2003), as well as a reduction in the number of kernels per spike (Kieckhefer and Kantack 1988, Kieckhefer and Gellner 1992, Hoffman and Kolb 1998, and Herbert et al. 1999, Riedell et al. 1999). Kieckhefer and Gellner (1992) reported that 10 aphids per plant substantially reduced the number of seeds per tiller. Herbert et al. (1999) reported that significant yield loss occurred even when aphid populations were well below published economic thresholds. This indicates that more research is needed to quantify yield loss associated with low aphid populations. Significant yield loss is also associated with *R. padi*. Chapin et al. (2001) reported BYD incidence and yield loss were correlated ($r = 0.72$) with *R. padi*

peak abundance and were correlated (r = 0.90) with the number of aphid-days accumulated on the crop.

Tolerance and Resistance

Barley yellow dwarf tolerance varies from environment to environment, making it difficult to select appropriate cultivars. Many times a variety that exhibits tolerance in one environment may be less tolerant in another environment. Hoffman and Kolb (1998) reported symptom expression was negatively correlated with yield reduction the first year and symptoms the following year were positively correlated with yield. This research strengthens statements made by Carrigan et al. (1981) and Cheor et al. (1989) that chlorosis is an unreliable symptom for evaluating BYD tolerance in wheat. High yielding varieties may suffer yield loss but still maintain a higher yield than many varieties with tolerance (Hoffman and Kolb 1998).

Genes for BYDV resistance are being tested and slowly incorporated into germplasm lines. Various studies have shown that BYDV is a group of related viruses (Aapola and Rochow 1971, Halstead and Gill 1971, Rochow 1979), therefore making resistant varieties more difficult to obtain. True resistance to BYDV is not found in wheat but in wheatgrasses such as *Thinopyrum intermedium*. Hybrids resulting from crossing *T. aestivum* and *T. intermedium* are being backcrossed to incorporate resistance into wheat (Sharma et al. 1995, Francki et al. 2001). Efforts are yielding promising results. Wiangjun and Anderson (2004) reported a wheat substitution line (P29) allowed viral replication in inoculated areas but no viral strain was detected in new tissue. Other resistance efforts are focused on using a coat protein gene from BYDV and a gene derived from yeast (Gianessi et al. 2002). The yeast-derived gene interferes with an

enzyme needed for viral replication, thereby providing more general virus resistance (Gianessi et al. 2002). Use of the coat protein gene has been shown to significantly reduce the amount of virus present in tissue and indirectly influence *R. padi* through decreased fecundity and shortened reproductive period (Jimenez-Martinez et al. 2004).

A joint effort between the USDA-ARS and Purdue University has resulted in the development and release of resistant soft red winter wheat germplasm (Sharma et al. 2002). The germplasm, P98134 was developed by utilizing resistant genes from related wild wheatgrass. In addition, a wheat substitution line (P29) offering complete resistance to CYDV was also developed (Wiangjun and Anderson 2004). The germplasm is intended to act as a source of resistance for wheat breeders and other scientists. Commonwealth Scientific and Industrial Research Organisation (CSIRO) plant breeders working jointly with Chinese researchers have recently developed a resistant variety that is commercially available through AWB Seeds (AWB 2003). This resistance may play a crucial role in the future. Until then, tolerance and timely insecticide application can play an important role in maintaining yield.

Virus Detection

Enzyme-linked immunosorbant assay (ELISA) is the most widely used technique for the detection of BYDV (Sutula et al. 1986). This method utilizes antiserum specific to virus strains and absorbance readings to determine the presence of a virus strain. However, BYDV occurs in very low concentrations in grasses complicating the detection processs. This results in readings that may vary depending on tissue sample and sap extraction procedures.

Gray et al. (1991) reported that older plant tissue almost always contained less virus; resulting in a significant reduction in the ability of *R. padi* to transmit PAV. Tolerant or sensitive cereal plants infected with BYDV show wide variations in virus content among leaves on the same plant and among leaves in the same position on different plants (Pereira 1989). This suggests uneven virus distribution within leaves and the need to sample many different leaves from various plants. Virus extraction procedures also influence virus detection. Henry and Francki (1992) increased optical density (OD) without increasing background by incubating samples overnight at 25° C in 0.1 M citrate buffer, pH 6.0, or in 0.1 M phosphate buffer, pH 7.0. However, the highest OD was obtained by adding celluclast to the incubation buffer (Henry and Francki 1992). A high OD results in higher absorbance readings, increasing the likelihood of virus detection. ELISA has been the standard method used to detect BYDV, but a new method has recently been developed.

Tissue-blot immunoassay (TBIA) is a sensitive, rapid, and cost effective technique that has recently been developed for evaluating BYDV infection (Lin et al. 1990, Hsu and Lawson 1991). Makkouk et al. (1994) and Qin et al. (1997) demonstrated that TBIA is a reliable and highly sensitive method for detecting BYDV that complements the ELISA technique. Results are obtained by looking for blue-purple colored phloem bundles under magnification, indicating virus presence.

Aphid Scouting Methodology

Fields should be scouted regularly because aphids reproduce rapidly and thresholds can be reached quickly. Fall scouting is most critical and should be done every one to two weeks, whereas scouting every three weeks is generally sufficient in the spring. When

scouting fields it is essential that field edges and terraces are avoided. Aphid densities will be higher around field edges as they move in from grass borders. This results in erroneous estimates of aphid densities. A good representation of aphid density is achieved by sampling several areas of the field (at least five subsamples) in a random pattern.

There are several different aphid sampling techniques. The most common method is to count the numbers of aphids per plant or aphids per meter-row. All areas of wheat plants need to be examined carefully as aphids may be present throughout the plant. Plant sampling may require large amounts of time if aphid densities are high. Therefore, vacuum sampling has been used.

Vacuum or suction sampling has been used since the late 1950's. Two of the commonly used suction samplers are the Dietrick vacuum sampler or D-Vac (Dietrick et al. 1959) and the Thornhill vacuum sampler (Thornhill 1978). Dietrick et al. (1960) reported that vacuum sampling can be more efficient than a sweep net when sampling arthropods from vegetation. However, the D-Vac and Thornhill sampler tend to be heavy and awkward. This has resulted in the use of modified leaf blower/vacs. Field workers ideally require affordable, lightweight and efficient machines that can sample large areas of vegetation (Holtkamp and Thompson 1985, Hand 1986). Leaf blowers are cheaper and are available at local hardware stores. Several authors have used modified leaf blower/vacs to sample insects (De Barro 1991, Macleod et al. 1993, Stewart and Wright 1995, Hossain et al. 1999). The machines are easy to modify; the supplied vacuum tube is attached to the leaf blower, and a fine voile bag is placed in the muzzle of the vacuum tube. A sleeve or rubberband is used to hold the voile bag in place. A wire mesh screen

may be placed inside the tube to prevent the bag from being sucked into the fan, should it become dislodged from the end of the vacuum tube. Once an area is sampled, the voile bag can be removed, tied shut for later inspection or turned inside out in a plastic bag to remove the insects collected.

The efficiency of suction sampling using a modified leaf blower/vac has been studied by several authors (Hand 1986, De Barro 1991, Macleod et al. 1993, Hossain et al. 1999). De Barro (1991) reported sampling efficiencies of bird cherry-oat aphid (*Rhopalosiphum padi* (L.)) ranged from 77 ± 9% to 93 ± 2% in pastures of 31 to 278 mm in height. Similar sampling efficiencies of 73, 74, and 60% were reported in 483 mm tall lucerne (*Medicago sativa* L.) for the transverse ladybird beetle (*Coccinella transversalis* Fabricius), pollen beetle (*Dicranolaius bellulus* (Guerin-Meneville)), and the spined predatory shield bug (*Oechalia schellembergii* (Guerin-Meneville)), respectively (Hossain et al. 1999). In addition, Hossain et al. (1999) reported higher sampling efficiencies ranging from 88 to 98% in 82 mm tall lucerne for the same species. These sampling efficiencies are considerably higher than D-Vac recovery efficiencies of less than 50% reported for *R. padi* on seedling wheat (Hand 1986). Using a modified leaf blower/vac Macleod et al. (1993) captured significantly more aphids per unit area ($t = 4.12$; $P < 0.01$, $df = 20$); mean aphid densities per 0.1 m^2 were 2.5 ± 1.68 using the blower/vac compared to aphid densities of 0.2 ± 0.06 using a conventional Thornhill type suction sampler. There are concerns with sampling damp vegetation and the effect of various insect densities on sampling efficiencies. De Barro (1991) reported that wet vegetation did not affect performance of the sampler and that the sampler was just as efficient at high aphid densities as it was at low aphid densities in roadside grasses and

pastures. In contrast, Dewar et al. (1982) reported that D-Vac efficiency decreased as aphid density increased on mature wheat.

Vacuum efficiency is related to muzzle air velocity. A muzzle air velocity of at least 26.8 meters per second is crucial in achieving high efficiency (Southwood 1978). The muzzle air velocity of blower/vacs studied was 33 meters per second (Hossain et al. 1999), 45.6 meters per second (Stewart and Wright 1995), and 62.6 meters per second (DeBarro 1991). Reported air velocities achieved using the D-Vac were 5.0 meters per second (Richmond and Graham 1969), 5.7 meters per second (McLeod et al. 1993), and 10.6 meters per second (Stewart and Wright 1995). However, later modifications such as a smaller diameter high suction hose and lighter engine (Summers et al. 1984) have increased D-Vac muzzle velocities, some now achieving velocities up to 40.3 meters per second (De Barro 1991). Still, the D-Vac remains considerably heavier, bulkier, and more expensive than modified leaf blowers.

Thresholds & Control Methods

Pest management is the appropriate selection and use of pest-control actions that ensure favorable economic, ecological, and sociological consequences (Rabb 1972). By using thresholds and an integrated management approach for pest management, effective control can be achieved with reduced pesticides.

Thresholds among aphid species and states vary considerably. Many thresholds being used are nominal and vary depending on the growth stage of the crop and the species of aphid present. Buntin (1999) reported thresholds of 3 aphids per 30 cm of row in the first 30 days after planting and 5 aphids per 30 cm of row at 30 to 60 days after planting. Other thresholds range from 5 to 30 aphids per stem before treatment is recommended.

Most guides do not recommend treatment from dough to maturity because late infestation has not been proven to cause significant yield loss.

There are several aphid management options available to producers. One option is to delay wheat planting until aphid activity has decreased in the fall. The Hessian fly free date is a good planting guide that reduces potential aphid problems. Maintaining healthy, vigorous plants helps reduce BYD. Plants with nutritional stress are more susceptible and yield less if BYDV is present. Another cultural method is to control volunteer wheat. Controlling volunteer wheat destroys over-seasoning sites of the virus and aphids. This may work in major wheat producing regions; however, Missouri has large acreages of grass that serve as hosts for BYDV (Weerapat et al 1972).

Suppression of aphid populations may be achieved with beneficial insects. Lady beetles, the most commonly known beneficals belong to the Coleoptera: Coccinellidae. The convergent lady beetle, *Hippodamia convergens* (Guerin) is a well known beneficial in American agroecosystems (Hagen 1962, Edelson and Estes 1987, Elliot and Kieckheffer 1990). Other prominent species of lady beetles found in Missouri include: the seven-spotted lady beetle, *Coccinella septempunctata* (L.) and the twelve-spotted lady beetle, *Coleomegilla maculate*. Both adult and larva lady beetles feed on aphids. There are also green lacewing larva, *Chrysoperla sp*., and damsel bugs, *Nabis sp*. In addition there are several flower fly larva (syrphids), and parasitic wasps: *Aphelinus mali* (Haldeman), and *Lysiphlebus testaceipes* (Cresson) that help control aphids. Beneficials are able to reduce aphid numbers but may not prevent aphid populations from increasing rapidly. Dreistadt and Flint (1996) reported that 25 to 84% aphid control was achieved when 34 to 42 adult convergent lady beetles, *H. convergens* were released per plot.

Aphids are persistent and can tolerate cold temperatures; whereas, beneficials are generally more susceptible to cold temperatures and insecticides. Hurej and Dutcher (1994) reported 100% mortality to convergent lady beetle from feeding on yellow pecan aphids (*Monelliopsis pecanis* Bissel) treated with esfenvalerate, carbaryl, and phosmet. Questions arise as to whether fall pyrethroid applications reduce beneficial numbers the following spring. Brown et al. (1988) showed that any effects of fall application of lambda-cyhalothrin on cereals could not be detected the following spring. Although, cultural methods may reduce aphid numbers, more effective control can be achieved with insecticides.

Foliar applied insecticides can be used to control aphids. Several synthetic pyrethroids, organophosphates, and carbamates have been developed for aphid control (Horrellou and Evans 1980, Kendall et al. 1983). To avoid phytotoxicity, these insecticides are usually applied at Zadoks' growth stage 14 or 15 (Zadoks et al. 1974). The foliar sprays may reduce disease symptoms, but if infection occurs prior to application, yield may be reduced. BYDV transmission may occur when aphid populations are high prior to the window of treatment or when aphids from a nearby field migrate in and infect plants after an insecticide has been used.

McKirdy and Jones (1996) reported two foliar applications of alpha-cypermathrin or beta-cyfluthrin, applied at rates as low as 12.5 g a.i. per ha before flag leaf emergence decreased the spread of BYDV by up to 75%. The study indicated the same rates increased yield up to 41%. One of the most commonly used synthetic pyrethroids is lambda-cyhalothrin. Herbert et al. (1999) reported that lambda-cyhalothrin helped reduce BYD symptoms. An advantage associated with lambda-cyhalothrin is "residual activity"

that generally lasts for 3 to 4 weeks. Effective control can be achieved if lambda-cyhalothrin has been applied prior to infection; however, better early season control may be achieved by using an insecticide such as imidacloprid.

Imidacloprid is applied as a seed treatment offering 4 to 6 weeks of aphid control. Imidacloprid is a systemic insecticide that interferes with the transmission of nerve impulses, leading to permanent excitation and death (Bai et al. 1991). Research indicated that imidacloprid increased wheat test weight and grain yield 15 to 21% and did not affect stand establishment (Gourmet et al. 1996, Krenzer et al. 1995). Imidacloprid treated seed followed by two foliar applications of alpha-cypermethrin decreased BYD incidence by up to 88% and increased grain yield by up to 76% (McKirdy and Jones 1996).

Brown et al. (1988) showed that autumn application of lambda-cyhalothrin persisted for around three months and the effects could not be detected the following spring. Field trials indicate that the application of cypermethrin (Shires 1985) and deltamethrin (Vickerman et al. 1987) in cereals had limited effects on the abundance of adult parasitic Hymenoptera. Insecticides may or may not have a significant impact on predatory and parasitic insects. This is dependent on the type of insecticide used and the insects that are present. This leads people to question whether the insecticides are directly reducing beneficial numbers or indirectly through the vast reduction in their food source.

Summary and Objectives

Barley yellow dwarf is a viral disease of wheat that has increased in recent years due to warm winters and early planting of wheat in the fall. *Barley yellow dwarf virus* may result in yield reduction over 50%. In addition, Missouri has large acres of grass that

serve as host for *Barley yellow dwarf virus*. Consequently BYDV will remain a problem in Missouri wheat production systems. Tolerance and resistance have been insufficient at reducing the impact of BYDV, therefore the focus is on controlling the aphid vectors. Outdated aphid thresholds for Missouri were established before modern, high yielding wheat varieties. Therefore, the objectives of this research were to quantify the effect of *barley yellow dwarf virus* on soft red winter wheat grain yield and to determine economic thresholds for aphid management.

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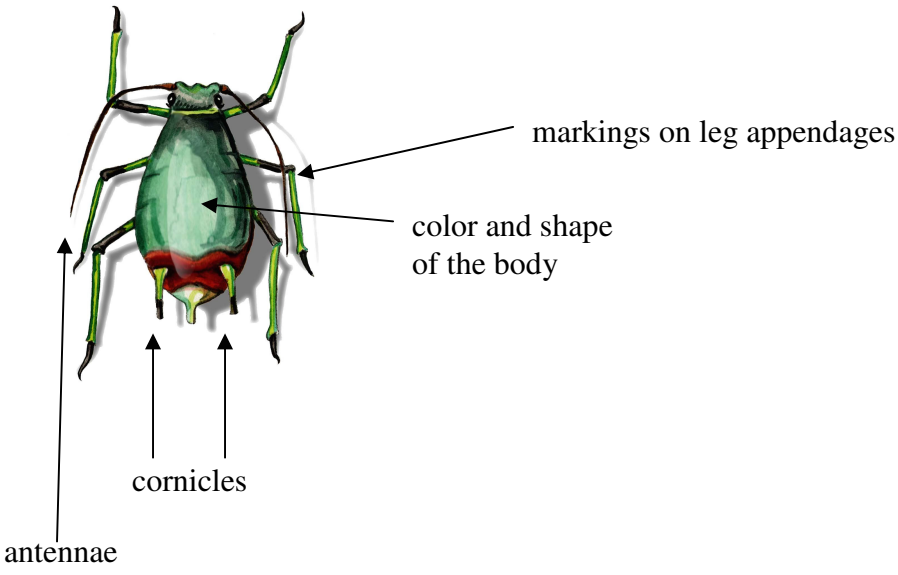
Table 1.1. BYDV strains transmitted regularly by aphid species and Luteoviridae genus.

Virus	Efficient vector	Luteoviridae genus
RPV	*Rhopalosiphum padi* (BCOA)	Polerovirus (CYDV)
RMV	*Rhopalosiphum maidis* (CLA)	Not assigned
MAV	*Sitobion avenae* (EGA)	Luteovirus (BYDV)
SGV	*Schizaphis graminum* (GB)	Not assigned
PAV	*R. padi* and *S. avenae*	Luteovirus (BYDV)

Adapted from Compendium of Wheat Diseases and Miller et al. (2002).

Figure 1.1. Aphid body parts that aid in species identification.



CHAPTER II

Impact of Aphids and Barley Yellow Dwarf Virus on Soft Red Winter Wheat (*Triticum aestivum* L.)

CHRISTOPHER ZWIENER AND SHAWN P. CONLEY

Abstract. Yield loss in soft red winter wheat caused by aphid transmission of barley yellow dwarf virus was measured over a two-year period in central Missouri. *Rhopalosiphum padi* (L.) was the most common and economically important species, accounting for > 90% of the total aphids. *Schizaphis graminum* (Rondani), *Rhopalosiphum maidis* (Fitch), and *Sitobion avenae* (F.) comprised the remainder of the aphids surveyed. Aphid numbers peaked at jointing in 2003 with 771 *R. padi* per meter-row. In the 2003-2004 growing season aphid numbers averaged 7 aphids per meter-row in the fall and peaked at 18 aphids per meter-row at jointing. Wheat grain yield was reduced 17 and 13% in 2003 and 2004 respectively. Thousand kernel weights were reduced 10 and 5% in the untreated plots when compared to the treated control in 2003, 2004 respectively. PAV was the predominate strain, accounting for 81 and 84% of the symptomatic plots that tested positive for barley yellow dwarf virus in 2003 and 2004. Our results indicate that economic thresholds for *R. padi* are 16 aphids per meter-row in the fall and 164 aphids per meter-row at jointing.

INTRODUCTION

Barley yellow dwarf (BYD) is one of the most important viral diseases of wheat (*Triticum aestivum* L.) in the world (Gill 1988). Various studies verify *barley yellow dwarf virus* (BYDV) is vectored by 25 species of aphids (Halbert and Voegtlin 1995). The four main vectors of BYDV in North America are the bird cherry-oat aphid,

Rhopalosiphum padi (L.); greenbug, *Schizaphis graminum* (Rondani); English grain aphid, *Sitobion avenae* (F.); and the corn leaf aphid, *Rhopalosiphum maidis* (Fitch) (Rochow 1961). Yield loss associated with aphids may result from mechanical interference (feeding), as well as virus transmission.

Yield reductions ranging from 20 to 40% have resulted from aphid infestation (Kieckhefer & Kantack 1988, Kieckhefer and Gellner 1992, Riedell et al. 1999, Chapin et al. 2001); whereas yield loss of 34 to 67% have resulted from virus transmission (Yount et al. 1985, Pike 1990, Herbert et al. 1999, Jensen and D'Arcy 1995, Riedell et al. 1999, Riedell et al. 2003). Yield loss associated with aphid infestation and BYDV infection may be a result of reduced head number (Kieckhefer and Kantack 1988, Herbert et al. 1999), decreased thousand kernel weight (TKW) (Yount et al. 1985, Kiechhefer and Kantack 1988, Kieckhefer and Gellner 1992, Hoffman and Kolb 1998, Herbert et al. 1999, Riedell et al. 2003), as well as a reduction in the number of kernels per head (Kieckhefer and Kantack 1988, Kieckhefer and Gellner 1992, Hoffman and Kolb 1998, Herbert et al. 1999, Riedell et al. 1999).

Fall BYDV infection is considered to be more detrimental than spring infection (Halbert and Pike 1985, Clement et al. 1986, Halbert et al. 1992). Carrigan et al. (1981) and Herbert et al. (1999) reported that fall infection reduced yield to a greater extent than spring infection. Cisar et al. (1982) indicated that fall infection reduced yield 63%, whereas spring infection reduced yield 41%. Though, fall infections tend to be more severe, Perry (2000) reported that there may be little yield difference between fall and early spring infections.

BYD tolerant varieties are available, but chemical methods have proven most effective in managing BYD. Several synthetic pyrethroids, organophosphates, and carbamates have been developed for aphid control (Kendall et al. 1983, Mann et al. 1991). Research on insecticide treatment is promising. McKirdy and Jones (1996) reported two foliar applications of pyrethroids decreased the incidence of BYD by 75% and increased wheat yield by 41%. In addition, imidacloprid plus two foliar sprays of a synthetic pyrethroid decreased BYD incidence by up to 88% and increased grain yield by up to 76% (McKirdy and Jones 1996).

Many wheat producers in the United States do little to control BYD. Warm winters have increased the incidence of BYD, triggering producer interest in controlling the aphid vectors. A species shift in cereal aphids in Missouri has caused previous thresholds to become outdated, further research is needed to determine current cereal aphid thresholds. Therefore, the objectives of this research were to quantify the effect of BYD on soft red winter wheat yield and to determine economic thresholds for aphid management.

MATERIALS AND METHODS

The impact of BYD on soft red winter wheat yield was quantified in central Missouri in the 2002-2003 and 2003-2004 winter wheat growing seasons. The experimental design was a randomized complete block factorial design with four replications. All possible combinations of variety, seed treatment, and foliar insecticide treatment timings were evaluated. The four wheat varieties utilized were ‘Truman’, ‘Ernie’, ‘Roane’, and ‘Pioneer 25R37’. The seed treatment was the presence or absence of imidacloprid (0.38 g [AI]/ha, Gaucho 480 FS™, Bayer, Kansas City, MO). The foliar insecticide treatment included: no application, fall only, fall followed by spring, or a treated control (every 28

days) of lambda-cyhalothrin (30.7 g [AI]/ha, Warrior™, Syngenta Crop Protection Inc, Greensboro, NC). Foliar treatments were applied with a CO_2 backpack sprayer using TeeJet 8002 nozzles delivering 187 liters/ha. Prior to planting, 50.4 kg/ha of nitrogen (NH_4NO_3) was applied and another 89.6 kg/ha was applied at greenup. Wheat was seeded on 24 September 2002 and 6 October 2003 in rows spaced 18 cm apart at 4,200,000 seeds per ha with a planting drill equipped with disk openers and closing wheels. Plot size was 9.5 m^2. A pre-package mix of thifensulfuron-methyl and tribenuron-methyl was applied March 2003 at 26.3 g [AI]/ha to control a complex of winter annual broadleaf weeds. The same herbicide was applied at 31.5 g [AI]/ha in late October 2003 to control *Lamium amplexicaule* L.

Barley yellow dwarf virus infection was dependent on natural aphid infestation. In 2002, wheat was planted two weeks ahead of the Hessian free fly date of 6 October to encourage aphid activity. However, in 2003 environmental conditions delayed planting until 6 October. Aphid and beneficial species were identified and counted every three weeks from crop emergence to physiological maturity. Aphids were counted on ten randomly selected plants per plot. Aphid densities were calculated as aphid-days per meter-row as defined by Ruppel (1983).

Leaf samples were collected from each plot at Zadoks' growth stage 55 (Zadoks' et al. 1974) and an enzyme-linked immunosorbent assay (ELISA) was conducted using virus antibodies attained from Agdia (Agdia Inc., Elkhart, IN). Random leaves exhibiting BYD symptomolgy were selected; 10 flag leaves and 10 leaves directly below the flag leaf were collected from each plot. Percent BYDV infection was measured as the percent of the plots that tested positive for BYD viral strains. Barley yellow dwarf viral strains

screened for included: PAV, RPV, and SGV. Leaf samples were also screened for the presence of *wheat streak mosaic virus*, *soilborne wheat mosaic virus*, and *wheat spindle streak mosaic virus*. Plots were determined to be positive for viral strains when ELISA absorbance readings were twice the absorbance reading of the negative control.

Head number per meter-row was recorded and 20 heads per plot were collected prior to harvest. Wheat heads were threshed by hand and seeds were counted to determine average number of kernels per head. Wheat was harvested on 25 June 2003 and 21 June 2004 using a Wintersteiger plot combine. A Dickey-John Grain Analysis Computer was used to determine test weight (TW) and moisture content. Yield was adjusted to 13% moisture and thousand kernel weight (TKW) was recorded.

Economic decision levels were calculated as defined by Stern et al. (1959). Economic thresholds were calculated as a percentage of the economic injury level (EIL). First the gain threshold (GT) or beginning point of economic damage was calculated by equation 1:

$$Gain\ threshold\ (GT) = Management\ costs\ (\$/hectare) \div Market\ value\ (\$/kg) \qquad [1]$$

where management costs of $31.50 per hectare and market value of $0.14 per kg were used. Management cost was the fee to apply lambda-cyhalothrin at 30.7 g [AI]/ha. Next economic injury level was calculated using equation 2:

$$EIL = GT \div (b \times k) \qquad [2]$$

where *b* is the amount of yield loss per insect and *k* is the reduction in injury or percent control. Yield loss per insect was obtained by regressing aphid number against grain yield. The resulting slope described yield loss per insect. Lambda-cyhalothrin and imidacloprid have proven effective at controlling aphids; therefore, 95% control was utilized. Finally, economic thresholds were calculated as 70% of the economic injury

level.

Analysis of variance (ANOVA) was used to analyze all data and means were separated with Fisher's protected LSD at $P < 0.05$ (PROC GLM, SAS Institute 1999). Insecticide treatment effects and all interactions were considered significant when $P < 0.05$. Bartlett's test for homogeneity of variance was conducted prior to testing for year interactions. Pearson correlation coefficients were calculated for aphid-days and yield loss.

RESULTS AND DISCUSSION

Variety by treatment interaction was not significant; therefore, data are presented for treatments only. Variety by treatment by year interaction was not significant ($P \geq 0.12$) for yield; however, Bartlett's test was significant therefore yield is presented separately for each year (Table 2.1, 2.2). There was also a significant variety by treatment by year interaction for TKW and TW ($P \leq 0.0001$); therefore, results are presented separately for each year (Table 2.1, 2.2).

R. padi were present in the plant whorl, upper and underside of leaves, shoot, and the base of the stem both years. In addition, *R. padi* were present at the plant crown when temperatures approached freezing. Alates were common in early fall and spring as fields were colonized before wingless adults became prominent. Few cereal aphids were present the fall of 2002; 61 aphid-days accumulated in the untreated treatment before freezing temperatures reduced numbers to zero (Table 2.3). Low aphid numbers in the fall of 2002 may have been due to the wet, cold weather conditions. Aphid-days were considerably higher in the spring of 2003. Numbers peaked in the untreated plots on 22 April 2003 with 771 *R. padi* per meter-row before declining as the wheat matured. In the

fall of 2003, 281 aphid-days were accumulated before winter weather reduced numbers to zero (Table 2.3). Aphids were slow to colonize wheat plots in the spring of 2004. Peak numbers in the untreated plots occurred in late April as numbers reached 18 *R. padi* per meter-row on 30 April 2004. *R. padi* was the predominant aphid species, accounting for 99 and 90% of the total aphids found in 2003 and 2004, respectively. Hesler and Berg (2003) reported similar findings, stating that *R. padi* comprised nearly 90% of all the cereal aphids sampled. Aphid-days accumulated for *S. graminum*, *R. maidis*, and *S. avenae* were low (data not presented). Beneficial numbers were less than 1 per meter-row (data not shown).

The treated control was effective at minimizing the number of aphid-days (Table 2.3). In both years many more aphid-days were accumulated in the spring than in the fall. For this reason spring application of insecticide was necessary to control aphids. The fall plus spring insecticide treatments reduced aphid numbers equal to the treated control (Table 2.3). The seed treatment imidacloprid was no more effective than the fall plus spring lambda-cyhalothrin at reducing aphid numbers (Table 2.3). In 2003 imidacloprid reduced aphid numbers, however there was no difference in yield (Table 2.1, 2.2).

PAV was the predominate strain each year, accounting for > 80% of the plots that exhibited visual symptoms testing positive for BYDV. PAV, a strain vectored by *R. padi* and *S. avenae* is common and highly virulent (Yount 1985). Chapin et al. (2001) reported 96% of symptomatic stems tested positive for PAV. RPV, vectored by *R. padi* and *S. avenae* (Wiese 1977), accounted for 21% of the symptomatic leaves that tested positive for BYDV. Few plots tested positive for *soilborne wheat mosaic virus*, *wheat*

spindle streak mosaic virus, and *wheat streak mosaic virus*: < 2, < 10, and < 36% respectively (data not shown).

The imidacloprid reduced TW by an average of 2% (Table 2.2). The reason is unclear. In 2003, the fall plus spring lambda-cyhalothrin with or without imidacloprid was just as effective as the treated control at maintaining TKW (Table 2.2). The only significant difference in TKW in 2004 was between the treated control and the remaining treatments (Table 2.2). Heads per meter-row and kernels per head were affected by variety; however, there was no significant difference between insecticide treatments (Table 2.1, 2.2).

In 2003 the use of fall insecticide did not increase yield (Table 2.2). The fall foliar with seed treatment or spring insecticide did not increase yield (Table 2.2). In 2004 all treatments increased yield over the untreated (Table 2.2). McKirdy and Jones (1996) reported imidacloprid treated seed followed by two foliar applications of alpha-cypermethrin increased grain yield 76%. In 2004, the spring insecticide treatment with imidacloprid resulted in a yield increase over the imidacloprid plus fall foliar insecticide (Table 2.2).

Fall infections tend to be more severe (Carrigan et al. 1981, Herbert et al. 1999); however authors have reported a reduction in yield caused by aphids in the spring (George and Gair 1979, Holt et al. 1984). In our study in 2003 we had many more aphids in the spring than fall and yield was reduced 17% (Table 2.2). *R. padi* was the predominate aphid species found both years, this corresponds to statements made by Kickhefer and Gustin (1967) that *R. padi* is frequently the most abundant species.

Although aphid densities remained low for much of 2004, yield was reduced 13%, due to aphid infestation in the fall.

Grain yield and TKW were reduced in both years. Previous studies indicate that BYD can result in a reduction in thousand kernel weight (Yount et al. 1985, Kieckhefer and Kantack 1988, Hoffman and Kolb 1998, Herbert et al. 1999 Riedell et al. 1999). Thousand kernel weights were reduced 10 and 5% in the untreated plots when compared to the treated control in 2003, 2004 respectively (Table 2.2). Test weight was reduced 2.4 % in 2004 (Table 2.2).

Our results indicated that economic thresholds in Missouri were approximately 16 *R. padi* per meter-row in the fall and 164 *R. padi* per meter-row at jointing. *R. padi* comprised greater than 90% of the total aphids sampled, therefore thresholds were calculated for *R. padi* only. Aphid numbers in the 2002-2003 winter wheat growing season remained low until jointing in April, however a significant yield reduction resulted; therefore, spring thresholds were calculated using aphid numbers from the spring of 2003. Fall thresholds were calculated using aphid numbers from the fall of 2003. Aphid numbers in the fall of 2003 were considerably higher than the fall of 2002. In addition aphid numbers only reached 15 aphids per meter-row at jointing in 2004.

Effective control of BYDV will allow producers to maximize their return. This can be achieved through scouting and timely application of insecticides to control aphids that vector the virus. Aphids began colonizing wheat fields one to two weeks after emergence. Aphid populations remained low in 2003 before escalating in late April. High aphid numbers present at jointing was determined to be responsible for the yield loss suffered in 2003. Aphid populations the following fall were higher than the previous

year; however, increased numbers of beneficial insects were also present. The beneficial insects may have suppressed the aphid population, reducing the impact of BYDV. Although beneficial insects may reduce aphid numbers, many times they fail to control aphid populations in a timely manner. This may be due to aphids' extremely fast reproductive cycle and cold tolerance.

Beneficial insects are incapable of tolerating cold temperatures. Aphids are able to tolerant temperatures around freezing for short periods of time by cold hardening. Powell and Bale (2004) reported adult *S. avenae* survival increased from 16 to 68% when subjected to a cold treatment of 0° C for 3 hours. In our study R. padi were found just below the soil surface in early December. Hesler and Berg (2003) reported similar findings stating that *R. padi* in the Midwest were found occasionally below the soil surface and in a few instances in soil cracks around individual plants. The soil may act like a blanket, insulating the aphids, allowing them to tolerate temperatures below freezing for shortened periods.

Planting date may increase the likelihood of BYD incidence. Wheat planted early in the fall is more likely to be colonized by aphids. Chapin et al. (2001) reported increased densities of *R. padi* and increased yield loss in wheat that was planted in early-November when compared to early-December planted wheat. Wheat was planted in late-September and early-October for 2003 and 2004, respectively. This allowed wheat to emerge and acquire substantial growth in order to attract aphids before winter. Many times fields planted early become targets for aphids as they prefer lush, green vegetation. Similar aphid preferences were observed throughout the year as higher densities of aphids were found in thick, lush plots. Wheat planting may be delayed to reduce aphid activity;

however, delaying planting too late will not allow for adequate tiller development before winter dormancy and may reduce potential yield.

Insecticide applications have proven successful at reducing BYD incidence. This research supports findings that lambda-cyhalothrin helps reduce BYD symptoms (Herbert et al. 1999). In our study, the application of lambda-cyhalothrin in the fall and spring with or without imidacloprid was just as effective as the treated control at maintaining grain yield in 2003 (Table 2.2). The following year, imidacloprid plus fall and spring lambda-cyhalothrin was just as effective as the treated control at maintaining yield (Table 2.2). This indicates that two or three insecticide applications may significantly reduce the impact of BYD on winter wheat yield. Fall foliar lambda-cyhalothrin resulted in a net return (Table 2.4). In 2004, the use of imidacloprid as an insecticide did not offset the cost of treatment (Table 2.4). The fall lambda-cyhalothrin and fall plus spring lambda-cyhalothrin resulted in a net return in 2003 and 2004 (Table 2.4).

The effects of BYDV can be minimized with timely insecticide applications. This paper supports findings that insecticide applications can decrease the incidence of BYD and minimize yield loss. Reducing the impact of BYDV should allow producers to maximize profits and may lead to an increase in winter wheat acres. The economic benefit of insecticide application is dependent on the cost of insecticide application and the market value of the crop. From this study we conclude that late aphid infestation and low aphid populations in the fall can result in significant yield loss.

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Table 2.1. Wheat yield components for various varieties at Columbia, MO in 2003 and 2004.

	Grain yield (kg per ha)		Test weight (lb per bu)		Thousand kernel weight (g per 1000 kernels)		Heads per meter-row		Kernels per head	
Variety[a]	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004
Truman	7914.2 a	6393.1 a	60.4 b	58.5 b	34.6 c	31.4 c	118.8 c	98.1 c	45.2 a	39.9 a
Ernie	7046.7 b	6173.9 b	59.7 b	58.5 b	40.2 b	39.0 a	145.9 b	123.8 b	26.2 c	23.9 c
Roane	7401.1 b	6168.8 b	62.1 a	60.3 a	30.8 d	29.3 d	158.9 a	141.8 a	36.6 b	29.8 b
P25R37	7905.5 a	6048.6 b	61.9 a	57.1 c	43.5 a	35.8 b	127.6 c	106.7 c	36.9 b	29.4 b
LSD: 0.05	377.0	215.1	0.9	0.5	0.8	0.6	10.4	9.2	2.8	2.1

[a]No significant variety by treatment by year interaction ($P \geq .12$), however Bartlett's test for homogeneity of variance was significant ($P \leq .0001$) therefore data is presented separately for each year.
Treatment means analyzed using Fisher's protected LSD ($P < 0.05$).

Table 2.2. Wheat yield components for various insecticide treatments at Columbia, MO in 2003 and 2004

	Grain yield (kg per ha)		Test weight (lb per bu)		Thousand kernel weight (g per 1000 kernels)		Heads per meter-row		Kernels per head	
Treatment [a]	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004
untreated	6683.7 c	5703.2 e	60.8 ab	57.7 c	35.1 c	33.2 c	133.0 a	116.4 a	35.4 a	29.3 a
control[b]	8042.9 a	6549.8 a	61.6 a	59.1 a	38.9 a	34.8 a	139.5 a	115.6 a	35.6 a	31.0 a
flc[c]	7167.1 bc	6017.1 cd	60.6 ab	58.4 abc	36.3 b	33.6 bc	137.5 a	121.5 a	38.0 a	30.5 a
fslc[d]	7856.2 a	6263.6 bc	61.2 a	58.8 ab	38.0 a	33.4 c	137.3 a	114.3 a	36.3 a	31.4 a
i[e]	6989.2 c	5946.3 de	59.9 b	58.1 bc	36.1 b	33.5 c	136.8 a	119.0 a	37.0 a	31.7 a
iflc[f]	7668.7 ab	6081.8 cd	61.0 ab	58.8 ab	36.9 b	33.8 bc	134.0 a	118.1 a	37.9 a	30.6 a
ifslc[g]	8094.6 a	6457.1 ab	61.7 a	59.0 a	38.0 a	33.9 bc	144.8 a	120.3 a	34.2 a	30.3 a
LSD: 0.05	533.1	304.1	1.3	0.7	1.1	0.9	14.7	13.1	3.9	3.0

[a]No significant variety by treatment by year interaction ($P \geq .12$), however Bartlett's test for homogeneity of variance was significant ($P \leq .0001$) therefore data is presented separately for each year.
Treatment means analyzed using Fisher's protected LSD ($P < 0.05$).
[b]control consisted of an application of lambda-cyhalothrin (every 28 days) at 30.7 g [AI]/ha.
[c]flc= fall lambda-cyhalothrin
[d]fslc= fall plus spring lambda-cyhalothrin
[e]i= imidacloprid seed treatment
[f]iflc= imidacloprid plus fall lambda-cyhalothrin
[g]ifslc= imidacloprid plus fall and spring lambda-cyhalothrin

Table 2.3. *R.* padi aphid-day accumulation for various insecticide treatments at Columbia, MO in 2003 and 2004.

	Aphid-days (per meter-row)[b]			
Treatment	Fall 2002	Spring 2003	Fall 2003	Spring 2004
Untreated	61.0 a	19677.0 a	281.1 a	564.4 b
Treated control[a]	0.0 b	115.0 c	36.2 d	89.5 c
Fall lambda-cyhalothrin	43.5 ab	11330.0 b	142.0 b	751.3 a
Fall + spring lambda-cyhalothrin	43.5 ab	237.0 c	179.9 b	83.3 c
Imidacloprid	0.0 b	10668.0 b	121.2 bc	574.3 b
Imidacloprid + fall lambda-cyhalothrin	0.0 b	4065.0 c	67.2 cd	435.0 b
Imidacloprid + fall and spring lambda-cyhalothrin	0.0 b	119.0 c	46.4 d	52.0 c
LSD: 0.05	44.6	4955.1	59.3	172.9

Aphid-days calculated as defined by Ruppel (1983).
[a]Treated control consisted of an application of lambda-cyhalothrin (every 28 days) at 30.7 g [AI]/ha.
[b]Bird cherry-oat aphid numbers only
Treatment means analyzed separately for each year using Fisher's protected LSD ($P < 0.05$).

Table 2.4. Net return from various insecticide treatments at Columbia, MO in 2003 and 2004.

		Net return ($ per hectare)	
Insecticide treatment	Treatment cost (per hectare)	2003	2004
fall lambda-cyhalothrin[a]	$31.51	$27.16	$6.59
fall & spring lambda-cyhalothrin	$63.01	$79.31	$5.01
imidacloprid[b]	$60.32	($23.24)	($30.81)
imidacloprid plus fall lambda-cyhalothrin	$91.82	$27.74	($45.87)
imidacloprid plus fall & spring lambda-cyhalothrin	$123.33	$47.93	($31.82)

[a]lambda-cyhalothrin rate of 9.5 oz per hectare

[b]imidacloprid rate of 2.5 oz per cwt.

Cost of imidacloprid calculated using seeding rate of 123.3 kg of seed per hectare and price of $300 per liter of Gaucho 480™

Net return calculated using $0.12 per kg of wheat

CHAPTER III

Efficiency of Vacuum Sampling Aphids in Soft Red Winter Wheat (*Triticum aestivum* L.)

CHRISTOPHER ZWIENER AND SHAWN P. CONLEY

Abstract. A modified leaf blower was used to vacuum sample cereal aphids in soft red winter wheat in central Missouri in the 2002-2003 and 2003-2004 winter wheat growing seasons. Aphid species were identified and counted on twenty random plants per plot and vacuum sampling was conducted on 60 meter-row of wheat. Capture efficiency of the vacuum was determined by comparing plant sampling to vacuum sampling. *Rhopalosiphum padi* (L.) alates accounted for 8.0 and 96.6% of the aphid species captured with the vacuum in 2003 and 2004, respectively. Sampling efficiencies were < 8% in the 2003 winter wheat growing season. Sampling efficiencies peaked at 19% at Zadoks' growth stage 12 in the 2004 winter wheat growing season. Our results demonstrate the ineffectiveness of vacuum sampling to obtain accurate estimates of cereal aphid densities.

INTRODUCTION

Vacuum (suction) samplers allow large areas to be sampled in a short amount of time. The Dietrick vacuum sampler or D-Vac (Dietrick et al. 1959) and the Thornhill vacuum sampler (Thornhill 1978) are some of the most commonly used vacuum samplers. These devices tend to be heavy and have resulted in the use of modified leaf blower/vacs. Field workers prefer lightweight and efficient machines that can sample large areas of vegetation (Holtkamp and Thompson 1985, Hand 1986). Leaf blowers are cheaper and are available at local hardware stores. With slight modification, these machines can be

used to sample insects from large areas (De Barro 1991, Macleod et al. 1993, Stewart and Wright 1995, Hossain et al. 1999).

The efficiency of vacuum sampling using a modified leaf blower/vac has been studied by several authors (Hand 1986, De Barro 1991, Macleod et al. 1993, Hossain et al. 1999). Sampling efficiencies of 73, 74, and 60% were reported in 483 mm tall lucerne for *Coccinella transversalis* Fabricius, transverse ladybird beetle, *Dicranolaius bellulus* (Guerin-Meneville), pollen beetle, and *Oechalia schellembergii* (Guerin-Meneville), the spined predatory shield bug, respectively (Hossain et al. 1999). In addition, Hossain et al. (1999) reported higher sampling efficiencies ranging from 88 to 98% in 82 mm tall Lucerne for the same species. De Barro (1991) reported sampling efficiencies of *Rhopalosiphum padi* (L.), bird cherry-oat aphid ranged from 77 ± 9% to 93 ± 2% in 31-278 mm tall pastures. These sampling efficiencies are considerably higher than D-Vac recovery efficiencies of less than 50% reported for *R. padi* on seedling wheat (Hand 1986).

Using a modified leaf blower/vac, Macleod et al. (1993) captured significantly more aphids per unit area; mean aphid densities per 0.1 m^2 were 2.5 ± 1.68 using a modified blower/vac compared to aphid densities of 0.2 ± 0.06 using a conventional Thornhill type suction sampler. There are concerns with sampling damp vegetation and the effect of insect density on sampling efficiencies. De Barro (1991) reported that wet vegetation did not affect performance of the sampler and that the sampler was just as efficient at high aphid densities as it was at low aphid densities in roadside grasses. In contrast, Dewar et al. (1982) reported that D-Vac efficiency decreased as aphid density increased on mature wheat.

Few studies have used modified leaf blower/vacs to sample aphids in wheat. Further research is needed to determine the efficiency of vacuum sampling before it is utilized as a sampling tool in wheat production systems. Therefore, the objective of this research were to compare the efficiency of vacuum sampling versus plant sampling in wheat production systems.

MATERIALS AND METHODS

The experiment was conducted on three producer fields in central Missouri in the 2002-2003 and 2003-2004 winter wheat growing season. The experimental design was a strip plot arrangement with two treatments and three replications. Treatments at two locations consisted of an imidacloprid seed treatement (0.38 g [AI]/ha, Gaucho 480 FS™, Bayer, Kansas City, MO) and fall foliar lambda-cyhalothrin (30.7 g [AI]/ha, Warrior™, Syngenta Crop Protection Inc, Greensboro, NC). Treatments at the third location included: fall lambda cyhalothrin, and a fall plus spring lambda cyhalothrin (30.7 g [AI]/ha). Plot size varied from 0.2 to 0.4 hectares. Three fields were vacuum sampled five times per growing season. A Poulan Pro model BVM200 gas blower/vac was converted to a vacuum using the supplied kit. Collection bags were constructed from fine voile cloth. The voile cloth allowed ample air movement but trapped aphids and other beneficial fauna. A mesh wire grill was attached inside the vacuum tube to prevent the collection bag from being sucked into the fan if it became dislodged. A three wheel cart was constructed to carry the vacuum. The cart allowed the vacuum to be slowly pushed over one row of wheat while maintaining sampling height.

Flags were placed 15 meters apart in each plot to designate vacuum sampling areas. Four rows of wheat were sampled sequentially for a total of 60 meters of wheat vacuum

sampled per plot. A voile bag was placed inside the vacuum tube and the end of the vacuum tube was adjusted to brush the tops of wheat plants. The vac was operated at full throttle and pushed over one row of wheat at a speed of 40.0 meters per min. Sampling bags were removed with the engine running to prevent possible loss of insects before the bags were sealed for later inspection. Vacuum sampling occurred every three weeks until jointing with alternate sides of the marker flag being sampled. This minimized the chance of previous sampling affecting recovery efficiencies. Vacuum sampling ceased after jointing to prevent damage to wheat.

Plant sampling was also conducted in each plot. Aphids and beneficials species were identified and counted on twenty randomly selected plants from each plot. Plants per meter-row were recorded and used to calculate aphids per meter row. Vacuum efficiencies were then calculated by comparing aphid numbers obtained from vacuum sampling to aphid numbers obtained from plant sampling.

RESULTS AND DISCUSSION

In our experiment, peak vacuum sampling efficiency obtained at various locations was 7.5 and 19.3% for 2003 and 2004, respectively. Vacuum sampling efficiency averaged over all locations was highest in the spring of 2003 and fall of 2004 with 4 and 6% respectively (Table 3.1). The density of aphids captured with the vacuum was low in both years, averaging < 0.1 aphid per meter-row. In the fall of 2002, < 1 aphid per meter-row was obtained from plant sampling with no aphids captured using vacuum sampling. In mid-April 2003, aphid numbers obtained from plant sampling peaked at 2 aphids per meter-row. In the fall of 2003 aphid numbers obtained from plant sampling averaged 1 aphid per meter-row at 2 locations. The following spring no aphids were obtained from

plant or vacuum sampling. In addition, wheat plants reached Zadoks' growth stage 31 (Zadoks et al. 1974) earlier in the spring of 2004, reducing the number of vacuum sampling dates. *R. padi* alates were common in 2004, accounting for 96.6% of the aphids captured with the vac. Very few (< 1 per meter-row) *Schizaphis graminum* (Rondani) and *Rhopalosiphum maidis* (Fitch) were observed on plants or captured with the vacuum (data not shown).

Our vacuum sampling efficiencies were substantially lower than vacuum sampling efficiencies for *R. padi* ranging from 77 to 93% reported by De Barro (1991). In addition, Hand (1986) reported D-Vac sampling efficiencies of less than 50% for *R. padi* on seedling wheat.

The difference in sampling efficiencies may be due to low aphid densities and the sampling procedures we utilized. Several authors held vacuum samplers directly over the soil surface for fixed periods of time (Hand 1986, Macleod et al. 1993, Stewart et al. 1995). In our study, we slowly pushed the cart with vacuum over rows of wheat. The vacuum may not have been able to dislodge and capture the aphids in the short amount of time it was over each plant. In addition, aphids may be present throughout wheat plants, hiding in the whorl or near the base of the stem. This may allow the aphids to shelter themselves from the suction of the vacuum. Vacuum efficiencies may be lower if aphids are feeding, making them harder to dislodge. The height of vegetation that is being sampled may also affect vacuum efficiencies. De Barro (1991) reported sampling efficiencies around 80%; however, the height of vegetation in the study was extremely short, allowing more suction to reach the lower canopy. The use of a brush or other device may be needed to dislodge aphids before being vacuum sampled. This may

increase sampling efficiencies; however, care would need to be taken to insure the aphids are not crushed because they are soft bodied insects. In addition, the fields were no-till and substantial amounts of corn and soybean residue were present. The vacuum generated enough suction that crop residue would be picked up periodically and lower the suction of the vacuum. These factors combined may have decreased our vacuum sampling efficiencies.

Vacuum sampling has been shown to be effective at sampling arthropods (Macleod et al. 1993, Hossain et al. 1999). Our results contradict these findings. Vacuum sampling may be effective for sampling Coleoptera and predatory insects that are more easily dislodged from plants. However, additional time is required to examine the samples collected and determine aphid density based on sampling efficiency. Additional equipment needs to be purchased, maintained, and transported from one location to another. Plant sampling may be quicker because aphid counts can be made in the field and densities determined minutes later. In addition, a good hand lens is the only equipment needed to scout for aphids.

Plant sampling remains an accurate way to obtain estimates of aphid density. Vacuum sampling may be effective, however, efficiencies vary based on machine specifications and crop growth stage. Our results conclude that consultants and producers can obtain estimates of aphid densities by examining plants in the field more quickly and less expensively than by using a vacuum sampler.

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Table 3.1. Vacuum sampling efficiencies obtained using a modified leaf blower/vac in 2003, 2004.

	2003			2004		
	Vacuum	Plant	% Eff[a]	Vacuum	Plant	% Eff
	-aphid density m^{-1} row-			-aphid density m^{-1} row-		
Fall	0	0.3	0	0.2	3.8	5.5
Spring	0.1	2.8	4.0	0	0	0

[a]"% Eff" vacuum sampling efficiency.

APPENDIX

Table 1. Effect of fall and spring insecticide treatments on grain yield and yield components at offsite central Missouri location #1 in 2003 and 2004.

	Grain yield (kg per ha)		TW		TKW		Heads per meter- row		Kernels per head	
Treatment	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004
Untreated	6774.2	4181.3	59.0	56.9	36.0	35.4	138.5	112.5	36.1	23.6
Fall lambda-cyhalothrin	6962.8	4162.0	57.7	56.5	36.2	34.4	142.0	121.0	34.9	25.6
Fall + spring lambda-cyhalothrin	7038.1	4592.7	56.6	56.9	36.7	36.0	153.5	108.5	32.9	23.0
LSD	451.2	262.0	9.8	0.9	0.5	2.5	36.7	13.5	5.4	5.5

Table 2. Effect of fall insecticide treatments on grain yield and yield components at offsite central Missouri location #2 in 2003 and 2004.

	Grain yield (kg per ha)		TW		TKW		Heads per Meter-row		Kernels per head	
Treatment	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004
Untreated	7834.1	4764.8	58.5	58.3	39.5	37.8	143.0	105.5	41.4	24.7
Imidacloprid	7923.8	4739.0	56.6	58.1	39.6	37.1	140.0	106.5	37.7	25.2
Fall lambda-cyhalothrin	7934.2	4651.3	57.8	57.9	39.1	36.5	127.3	108.3	35.4	24.1
LSD	315.1	207.3	4.5	1.1	1.1	2.0	27.8	18.7	7.0	3.1

Table 3. Effect of fall insecticide treatments on grain yield and yield components at offsite central Missouri location #3 in 2003 and 2004.

	Grain yield (kg per ha)		TW		TKW		Heads per Meter-row		Kernels per head	
Treatment	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004
Untreated	4757.0	3003.1	59.1	51.8	31.8	28.2	113.3	89.0	37.7	37.8
Imidacloprid	4805.6	2907.1	58.7	50.9	31.7	26.8	107.8	86.0	37.0	40.4
Fall lambda-cyhalothrin	4752.0	2999.0	60.0	51.6	31.6	27.2	113.3	87.5	37.0	36.1
LSD	319.2	328.0	1.8	0.7	1.7	2.2	25.8	9.2	3.9	5.1