Evaluation of agronomic practices to reduce Russian wheat aphid, Diuraphis noxia (Mordvilko) (Homoptera: Aphididae), damage in wheat
by Kurt John Kammerzell

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Entomology
Montana State University

Abstract:
The effects of seeding dates and insecticide application techniques on Russian wheat aphid Diuraphis noxia (Mordvilko) in winter and spring wheat Triticum aestivum was evaluated in 1988-1990. Autumn infestations declined with later seeding at each location. Winter wheat yields in untreated plots were not adversely affected by infestation levels of 18, 27 and 40%. Infestation levels were low at the 1-2 leaf growth stage? this stage is critical for damage to occur in the autumn. Winter wheat seeded in late September or early October showed reduced yields. Insecticide efficacy was enhanced by application technique. Granular insecticides applied in-furrow showed excellent control during the autumn growing period. However, reduced standcounts were observed with in-furrow applied organophosphates. Chlorpyrifos, applied as a spray, controlled an established RWA infestation. In general spring wheat seeded in early to mid April avoided infestations. Spring wheat yields were increased with the earlier seeding dates. Spring applied insecticide treatments did not effectively control infestation levels during the growing season. Granular insecticides applied in-furrow did not prevent late RWA (winged adults) from developing colonies on wheat plants. Chlorpyrifos lowered aphid numbers (90%) after application, however numbers quickly rebounded.

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APPROVAL

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Kurt John Kammerzell

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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TABLE OF CONTENTS

TABLE OF CONTENTS - Continued

TABLE OF CONTENTS - Continued

LIST OF TABLES

LIST OF TABLES - Continued

LIST OF TABLES - Continued

Table Page

LIST OF TABLES - Continued

ABSTRACT

The effects of seeding dates and insecticide application techniques on Russian wheat aphid Diuraphis noxia (Mordvilko) in winter and spring wheat Triticum aestivum was evaluated in 1988-1990. Autumn infestations declined with later seeding at each location. Winter wheat yields in untreated plots were not adversely affected by infestation levels of 18, 27 and 40%. Infestation levels were low at the 1-2 leaf growth stage; this stage is critical for damage to occur in the autumn. Winter wheat seeded in late September or early October showed reduced yields. Insecticide efficacy was enhanced by application technique. Granular insecticides applied in-furrow showed excellent control during the autumn growing period. However, reduced standcounts were observed with in-furrow applied organophosphates. Chlorpyrifos, applied as a spray, controlled an established RWA infestation. In general spring wheat seeded in early to mid April avoided infestations. Spring wheat yields were increased with the earlier seeding dates. Spring applied insecticide treatments did not effectively control infestation levels during the growing season. Granular insecticides applied in-furrow did not prevent late RWA (winged adults) from developing colonies on wheat plants. Chlorpyrifos lowered aphid numbers (90%) after application, however numbers quickly rebounded.

LITERATURE REVIEW

History

The Russian wheat aphid, Diuraphis noxia (Mordvilko), is indigenous to Afghanistan, Iran, and the Mediterranean regions of the Old World, including southern Russia (Blackman et al. 1990). The original distribution of the pest led to the common name Russian wheat aphid (RWA). In 1900 serious attention was paid to Brachycolus noxia, Mordw. (= Diuraphis noxia), which was one of the most dangerous pests of cereal crops (Grossheim N.A. 1914). In southern Russia RWA devastated barley crops and was known to feed on wheat (Mokrzechi 1914). For example, in what is now Eupatoria of the former Soviet Union, B. noxia in 1900 caused barley crops to yield 76% of their normal yield (Mokrzecki 1913).

Russian wheat aphid was first recorded in South Africa during 1978 (Walter 1984). The pest was found to cause severe damage to wheat at Bethlehem in the Orange Free State of the Republic of South Africa. RWA was restricted to the Old World including South Africa until 1980, when it was identified in Central Mexico (Gilchrist et al. 1984), and in central Chile (Zerene et al. 1988). By 1983, RWA had spread north to the State of Coahuila in Mexico. The first documentation of RWA in the United States occurred March 1986, when it was collected near Muleshoe, Texas (Valiulis 1986). Aided by prevailing winds, the RWA migrated throughout the Great Plain States of Texas, New Mexico, Colorado, Oklahoma, Kansas, Nebraska and Wyoming. The RWA continued to spread during 1987 into an additional seven western states: South Dakota, Arizona, Utah, Oregon, Montana, Idaho and Washington (Kindler & Springer 1989). The following year the aphid had spread to three Canadian provinces: British Columbia, Alberta, and Saskatchewan (Butts & Thomas 1989).

Morphology

Adult apterae (wingless) RWA are small (<1/10") lime green, with a spindle shaped body (Blackman & Eastop 1984). This aphid can be distinguished from other small grain aphids by a prominent supra-caudal process which gives it a 'forked-tail' appearance. Antenna are short, less than half the length of the body, and prominent cornicles are absent. Alates (winged RWA) have black heads, thorax and pale green abdomen (Ilharco et al. 1982).

Biology

Russian wheat aphids have two distinct life cycles. Adult females bearing live young (viviparae) without a sexual stage are termed anholocyclic. A more complex cycle, termed holocyclic, also exists. In this cycle, sexual reproduction occurs in the autumn producing overwintering eggs (oviparae), during the remainder of the year individuals are live-bearing females (Halbert et al. 1990). In cold climates RWA are holocyclic on barley and wheat, and probably anholocyclic elsewhere (Blackman & Eastop 1984). In Russia, a sexual reproductive egg stage was observed on winter barley (Grossman 1914). According to Mokrzecki and Kurdjumov, (in Grossheim 1914), _B_. _noxia_ passes the winter in the egg stage on winter-sown barley or volunteer barley. Mokrzecki (1914) found that _B_. _noxia_ rarely winters on fall-sown wheat. Several oviparae were found in southwestern Idaho during the autumn of 1989, however, no males were observed in North America to date (Halbert et al. 1990). Consequently, it is unlikely any egg production occurred. The egg stage, a very cold tolerant stage, could facilitate over-wintering in colder climates.

Russian wheat aphid females can produce 40 to 50 nymphs during a lifetime of 40 days (Michaels & Behle 1988). Nymphs are young aphids that resemble the adult except they are smaller. Nymphal development times decrease as daily temperature increases (Aalbersberg et al. 1987). Nymphs become reproductive adults in the 5th instar, approximately 10.1 days at 17.2° C.

Alates are produced under adverse environments and when the quality of food for aphid development deteriorates (Aalbersberg et al. 1984). Mittler & Dadd (1966) and Johnson (1966) showed that diet or host quality affects the production of alates. Increased water stress plus aphid feeding damage lowers host quality. As a result increased production of alate individuals occurs (Baugh et al. 1991). Alates are the primary mode of dispersal. They are weak flyers, but are capable of traveling long distances with prevailing winds. This is a very effective method of migration; since the introduction into the United States, the RWA migrated 2000 miles from Texas to Canada in 3 years. In the United States and Canada RWA overwinters as an adult or late instar nymph near the crown of a suitable host plant e.g., winter wheat or cool season grasses (Johnson 1989). Russian wheat aphids have overwintered in Montana in regions with low precipitation and sandy well drained soils (K. Kammerzell, personal observation). In addition RWA survival appears to be enhanced when winters are mild and dry.

Plant Symptoms & Damage

Russian wheat aphid feeding produces symptoms in plants that include longitudinal streaking, and tightly curled leaves (Johnson 1989). The longitudinal streaking can be white, yellow, or purple, depending upon the host species and the growth stage. Symptoms in wheat include purple and white streaking when cold temperatures prevail. This streaking is most evident in plants producing vegetative growth; streaks turn to yellow and purple as the growing season progresses. White streaking occurs in barley and triticale.

Russian wheat aphids feed on host plants by penetrating plant tissue with a lancet-shaped stylet, removing plant fluids and injecting a toxic saliva. Damage by RWA feeding is caused by a toxin being injected into the plant. The toxin attacks and disrupts plant chloroplasts which are essential for photosynthesis (Fouche et al. 1984). Chloroplast degradation may be a mechanism which allows the RWA to more efficiently harvest nutrients from the host plant. This kind of feeding is similar to other aphids such as the greenbug, Schizaphis graminum (Rondani), which damage the plant during feeding by injecting degrading enzymes (Runlin et al, 1990).

Symptoms at Different Plant Growth Stages

Tillering to Jointing (Zadocks 20 to 30)

Tillering winter wheat plants exhibit symptoms similar in appearance to drought stressed plants. Closer inspection will show plants with a pale yellow-green appearance, rolled leaves, and light purple and white longitudinal streaking. Inside the rolled leaf, RWA can number from two or three to several hundred. A severe infestation at an early growth stage decreases winter-hardiness (Butts & Thomas 1989), and if infested early in the spring the host plant can be killed (K. Kammerzell, personal observation). The effect of coldhardiness on winter wheat seedlings was investigated after an infestation by the RWA (Storlie 1991). This research concluded that infested Froid and Brawny winter wheat had higher osmotic potentials and lower fructan contents than non-infested controls. Lower osmotic potentials of crown tissue are associated with increased winter-hardiness (DeNoma et al. 1989). Tognetti et al. (1991) indicated a linear association occurred between winter-hardiness in winter wheat and fructan accumulation.

Jointing to Boot (Zadocks 30 to 40)

Jointing wheat plants continue to appear drought-stressed with the most common symptoms being rolled leaves (Baker 1986). During this period, purple and yellow streaking becomes more prominent. Infested wheat plants are stunted with tillers spreading from the crown. Heavily infested tillers are prostrate to the ground instead of standing erect (Baker 1986).

Boot to Maturity (Zadocks 40 to 99)

Russian wheat aphids migrate to the newest emerging tissue (Kriel et al. 1984). Migration to young tissue suggests that RWA may be selecting more palatable tissue. Over crowded conditions on young leaf tissue will cause RWA to migrate and feed on older previously non-infested leaves. Older leaves have a thicker more hardened cuticle layer and are resistent to roll up like younger leaf tissue. Heavily infested plants will have aphids feeding on leaves even before they emerge from the leaf sheath. Flag leaves become rolled and twisted during emergence. Severe damage to the flag leaf can prevent wheat heads from emerging normally. The resulting damage has the appearance of frost or phenoxy herbicide injury. Awns begin to emerge through the auricles, but the remainder of the head becomes trapped (Brooks et al. 1989). Trapped heads push through the side of the sheath, emerging as a bent loop (fish-hook appearance). Consequently, pollination is less effective, producing blank florets and lower yields (Walters et al. 1984). Aphid populations increase substantially from flag leaf emergence to the milky dough stage (Aalbersberg et al. 1987). Increased water stress, coupled with aphid feeding damage, results in alate production to increase (Baugh et al. 1991). Changes in nutrients supplied by the plant as the plant approaches maturity triggers the aphid to reproduce young with the ability to grow wings (Johnson 1966). As the host plant progresses toward senescence aphid populations decrease due to migration or death (Hewitt et al. 1984).

Host Preference

Kindler and Springer (1989) tested cool and warm season grasses, forbs and legumes. RWA survived on all but 1 of 48 cool season grass species, about 50% of 32 warm season grass species, and none of the 27 legumes or 17 forbs. Jointed goatgrass, Triticum cylindricum Host, was the most suitable host, followed by barley, European dunegrass, Elymus arenarius L., and little barley, Hordeum pusillum Nutt. Russian wheat aphid survived equally well on most cool season grasses when compared to wheat. Although RWA survived on some of the warm season grasses, reproduction was limited when compared to wheat. The importance of the RWA in North America has increased because of its ability to survive on a broad host range of cool and warm season grass species that commonly occur throughout the barley and wheat production areas (Burton 1988). Montana has many of the cool season grasses (Agropyrons, Hordeum, and Elymus) that could act as reservoirs for this important crop pest.

Economic Thresholds

In South Africa, the lack of knowledge on the pest status of RWA led to haphazard insecticide applications. A preliminary treatment threshold of 20% plant infestation was advocated as the norm for spraying in order to minimize the injudicious use of insecticides (Walters 1984). Field trials in 1980 and 1981 by Du Toit & Walters (1984) were initiated to determine economic thresholds on winter wheat at different growth stages. Du Toit et al. (1984) found that a high infestation for a relatively short time, during tillering (Zadocks 22-25), did not cause a significant reduction in yield. This suggests wheat can recover from a high infestation provided the duration of infestation is relatively short, and the wheat is kept aphid free after the infestation period. The 1981 trial by Du Toit and Walters (1984) was designed to allow different infestation periods, long enough to reach a damaging threshold. Plots were infested at the 2-3 leaf stage (Zadock 12-13). Elimination of the infestation from flag leaf emergence to maturity prevented significant yield losses, while removal of RWA from kernel formation to crop maturity did not prevent significant yield losses (Du Toit et al. 1984). The period from flag leaf emergence to crop maturity appeared to be the critical stage where the potential yield was most affected. In trials where an insecticide application was applied only once, the first node growth stage (Zadocks 31) was the latest stage where a single application could prevent a significant yield reduction (Du Toit et al. 1981). In winter wheat, an RWA infestation before the first node growth stage (Zadocks 31) did not affect yield. It appears that an insecticide application before this growth stage only enhances the necessity of additional treatments (Du Toit 1986). Data gathered from these trials prompted the researchers to recommend treatments when 10% of the plants were infested at the first node growth stage (Zadocks 31).

Economic treatment thresholds developed in South Africa were used in the United States the first two years after its arrival. Researchers in Texas began developing treatment thresholds applicable for growing conditions in Texas. Archer and Bynum (1988) found that significant yield losses did occur prior to the first node growth stage (Zadocks 31). Studies showed that for every percent infested tiller there was a 0.5% reduction in yield. Archer and Bynum (1988) used economic injury levels, crop worth, and the cost of control to determine economic treatment thresholds. For example, the economic treatment threshold on wheat that returns $150 per acre with a $10 per acre control cost would justify a treatment at 13% infested plants. Research on irrigated durum (Triticum durum) in Arizona resulted in a 0.4% loss in yield for every 1% infested tillers (Dick 1988). Research conducted with artificially infested caged winter wheat plants concluded RWA can cause significant yield loss during the autumn (Girma and Wilde 1989). Based on this work, they established a threshold level on winter wheat in the autumn of 6% infested stems at the tillering stage. The threshold for a spring RWA infestation was 4% infested stems during the jointing stage (Zadocks 30-39). Although growing conditions change from the southern to the northern states, many of the states have currently adopted similar treatment thresholds developed in Texas.

Control Practices

Insecticides

Due to the minor status of the RWA within its original area of distribution, control practices were not available on the RWA when it first appeared in South Africa. Contact insecticides registered for other aphids were ineffective against this newly introduced pest (Walters 1984). By 1980 better chemical control was obtained when tank mixing parathion and systemic insecticides such as, demeton-s-methyl, monocrotophos, dimethoate and heptenophos; also singular applications of chlorpyrifos were effective (Walters et al. 1984).

Chemical control recommendations using foliar-applied insecticides have been extensively tested. Criteria set for acceptable control levels for foliar-applied insecticides are 90% control three weeks post-treatment (Peairs 1988). In Colorado, chlorpyrifos 4E at 0.5 AI/Acre had 90% or better control 10 out of 15 times tested, compared to 6 out of 20 for disulfoton at 0.75 AI/Acre (Peairs 1988). In addition Peairs found esfenvalerate 0.025 AI/Acre to be 90% effective 4 out of 10 times tested and dimethoate at 0.375 AI/Acre was 90% effective 4 out of 15 times tested. Foliar sprays tested in Nebraska for RWA control on winter wheat revealed that out of five insecticides chlorpyrifos 4E at 0.5 AI/Acre was the only treatment to have 90% or better control at 21 days post-treatment (Hein 1990). In New Mexico, Baker (1988) found that foliar-applied chlorpyrifos, disulfoton and esfenvalerate at 0.38, 0.5 and 0.025 AI/Acre had 90% or better control three weeks post-application on dryland wheat. Treatments of dimethoate, phosphamidon (0.375 and 0.5 AI/Acre, respectively) and esfenvalerate (<0.025 AI/Acre) were below 90% control in the same trial. In Montana disulfoton (1.0 AI/Acre), parathion (0.5 AI/Acre), esfenvalerate (0.0375 Ai/Acre), and dimethoate (0.375 Ai/Acre) were applied to drought stressed winter wheat that was 100% infested at the tillering stage. Disulfoton was the only treatment to reduce percent infestation 73% after one week and 23% at week two (Johnson et al. 1988). This suggests that insecticide effectiveness is lower when plants are heavily infested and drought stressed.

Foliar insecticide trials were conducted to determine insecticidal activity on RWA when spring daily temperatures averaged 60° F. or lower, and in the summer when daily temperatures averaged greater than 60° F. (Johnson et al. 1989). The following insecticides and treatment rates (lb AI/Acre) were evaluated in this study: esfenvalerate (0.025), dimethoate (0.375), chlorpyrifos (0.5), endosulfan (0.75), ethyl parathion (0.75) and disulfoton (0.75). In the spring, reduction of RWA was low seven days post-treatment; the highest percent control was (83%) ethyl parathion. Chlorpyrifos and esfenvalerate recorded 90% or better control at 21 days post-treatment. Best control for the insecticide treatments applied during the summer occurred seven days post-treatment: aphid numbers increased substantially for the treatments on 14 and 21 days post-treatment. Disulfoton, ethyl parathion, and chlorpyrifos were the most effective at reducing aphid numbers 7 days post-treatment, chlorpyrifos was above 90% control and disulfoton and ethyl parathion were above 80% control.

Seed treatments are an economic and practical method for controlling many crop pests. Seed treatments were tested by Butts and Walters (1984) for RWA control and for seed and seedling phytoxicity. A wide range of organophosphate and carbamate insecticides were tested. Of 11 insecticides used to treat wheat seeds, six prevented normal germination: ethiofencarb, heptenophos, demeton-s-methyl, EC & WP formulations of dimethoate, and triazophos. Those not phytoxic to seed germination were carbofuran, CGA 73102 (a carbamate), oxamyl, and omethoate. CGA 73102 was the only insecticide of the four tested which showed no significant reduction in plant emergence when compared with the control. The insecticides that were not phytotoxic were tested on RWA. At three weeks CGA 73102 kept 70% of the plants aphid free and at four weeks 62% of the plants were aphid free. Four weeks after planting the only seed treatment to have better than 50% control was the CGA 73102 compound. Although it is generally accepted that at least 90% control is required in order to be economic, the results seem to indicate that an increase in the concentration of CGA 73102 might fulfill this requirement (Butts & Walters 1984). Tests were conducted in 1988-1990 to evaluate an experimental seed treatment, NTN 33983 (active ingredient imidacloprid), at the rates of 70 to 500 g/100 kg of seed for controlling the RWA in wheat and barley (Brenchley 1990). Imidacloprid at 250g/100 kg of seed in wheat and barley recorded at least 90% control, seven weeks after planting at all test locations. Disulfoton 15G at 0.025 g/meter in furrow application was compared to imidacloprid at the same locations. Seven weeks after planting, disulfoton treated plots had <70% RWA control compared to better than 90% control for the imidacloprid at 250g/100kg (Anderson 1990). Meyer et al. (1990) compared at planting insecticide treatments. At 10 weeks post-planting imidacloprid at 150g/kg of seed had 95.1% control compared to 89.8% control for in furrow application of disulfoton 15G at 51 g/0.3 km.

Systemic granular insecticides applied in-furrow is a common practice used by growers to control chewing and sucking insects in winter wheat. The following research data suggests in-furrow applications of systemic insecticide may be a viable management practice. Research in South Africa found that winter wheat treated with in-furrow applications of disulfoton or phorate was aphid free up to twelve weeks after planting with the untreated being 4% infested at this time (Du Toit 1984). In Montana, in-furrow treatments of disulfoton and phorate (0.75 and 0.66 AI/Acre) kept winter wheat plants aphid free five weeks after application. At week eight disulfoton, phorate and the untreated plots were 0, 2, and 18% infested, respectively (Kammerzell and Johnson 1990). In Washington, Pike and Allison (1990) found that in-furrow applications of disulfoton 15G at 1.7 oz./1000ft. row in winter wheat had 94% control 39 days post-treatment.

Cultural Practices

Cultural practices implemented over the years have been very important for pest control in many crops. Modified planting dates have been adopted to control weeds, insects and diseases. Development of resistant cultivars has made it possible to grow crops in areas that were once devastated by insects and diseases. Clean farming and destruction of hosts and overwinter sites has reduced the reliance on pesticides to control weeds, insects, and diseases. The Hessian fly, *Mayetiola destructor* Say, historically has been a severe pest of wheat. This insect has been managed in traditional wheat growing areas by delayed planting (Webster 1899, McColloch 1923, Gallun 1965). In cotton, growers have adopted modified planting dates that allows for maximum suicidal emergence of overwintering pink bollworm moths *Heliothis zea* Boddie, moths emerge and die before cotton fruit is available for oviposition (Adkisson and Gaines 1960). In spring wheat, delayed planting decreases wheat stem sawfly, *Cephus cinctus* Norton, infestations and increases yield, although too much delay decreases yield as well as sawfly infestation (Weiss et al. 1987). Banded sunflower moth, Cochylis hospes (Walsingham), larvae feed on cultivated sunflowers in Manitoba, Canada (Westdal 1949), the Red River Valley of North Dakota and Minnesota (Schulz 1978). Studies in 1981 and 1982 in southeastern North Dakota and northwestern Minnesota concluded delayed planting can reduce banded sunflower moth damage without appreciably reducing achene weight and oil content (Oseto et al. 1989). Planting time has been manipulated to significantly reduce damage caused by the sunflower moth, Homoeosoma electellum (Hulst), (Carlson et al. 1972, Rogers and Jones 1979, Oseto et al. 1982) and the red sunflower seed weevil, Simicronyx fulvus (LeConte), (Oseto et al. 1987). In Montana the wheat curl mite Eriophyes tulipae Keifer, transmits wheat streak mosaic virus to early planted winter wheat. Growers are able to control the spread of wheat streak mosaic virus by eliminating host volunteer in and around fields prior to planting coupled with delayed planting (Wiese 1977). In western Colorado winter wheat emergence date is closely correlated with autumn RWA infestations, early planted fields tend to have higher RWA infestations than later planted fields (Hammon et al. 1990) In Montana RWA infestation levels are reduced with delayed seeding of winter wheat (Kammerzell and Johnson 1990).

The use of resistant cultivars is one of the most effective means of preventing damage from the Hessian fly (Gallun 1965). In spring wheat, population levels of the wheat stem sawfly are reduced by use of solid-stemmed resistant spring wheat cultivars (Holmes and Peterson, 1957). Greenbug infestations are effectively controlled with resistant cultivars of wheat (Webster et al. 1986).

Objectives

Since the arrival of the RWA in Montana, growers have relied on control practices and economic thresholds developed in areas climatically different from Montana. Studies were initiated to answer some basic but very important questions about managing this newly introduced cereal pest. The following research objectives were studied to determine: 1) if modified seeding dates are a feasible agronomic practice to reduce RWA feeding damage in autumn and spring seeded wheat, 2) if the current recommended autumn treatment threshold of 20% is an appropriate treatment threshold for controlling RWA in winter wheat, 3) the performance of systemic granular insecticides applied in-furrow on autumn and spring seeded wheat, and 4) to evaluate foliar and granular insecticide treatments applied post-emergence to plots that have reached or exceeded the recommended treatment threshold.

MATERIALS AND METHODS

Study Sites

Selection of autumn study sites for each year was based on high RWA numbers during July and August and good winter wheat survivability. The 1988 site was located at the Montana State University Central Agricultural Research Center (MSU-CARC) Moccasin, MT. The 1989 sites included the MSU-CARC and on land of a private cooperator located seven miles west of Molt, MT. Sites selected were different in several respects. The Moccasin site has a clay loam soil receiving 14-16 inches of annual precipitation and yields for winter wheat average 40-50 bushels per acre. The Molt site has a sandy loam soil receiving 10-12 inches of precipitation per year with average winter wheat yields of 20-25 bushels per acre.

Three sites selected for the spring studies were located at the MSU-CARC, seven miles west of Molt Mt., and at the Montana State University Southern Agricultural Research Station (MSU-SARC) Huntley, MT. Average spring wheat yields are 35 and 20 bushels per acre for MSU-CARC and Molt, respectively. The MSU-SARC, has a silty clay soil, 12-14 inches of annual precipitation, and an average spring wheat yield of 30 bushels per acre.

Table 1. Location, seeding dates, and treatments for Russian wheat aphid autumn winter wheat study.

Location	Location	Location
MSU-CARC	MSU-CARC	Molt MT
Year: 1988	Year: 1989	Year: 1989
Seeding Dates	**Seeding Dates**	**Seeding Dates**
Early (Sept. 1)	Early (Sept. 6)	Early (Sept. 1)
Mid (Sept. 15)	Mid (Sept. 20)	Mid (Sept. 15)
Late (Sept. 30)	Late (Oct. 10)	Late (Sept. 30)
Treatments[1]	**Treatments**[1]	**Treatments**[1]
In-furrow	In-furrow	In-furrow
Disulfoton 15G (1.0)	Disulfoton 15G (1.0)	Disulfoton 15G (1.0)
Phorate 20G (0.66)	Phorate 20G (0.66)	Phorate 20G (0.66)
Micro-tube injection	Post-emergence	Post-emergence
Disulfoton 8 (1.0)	Disulfoton 15G (1.0)	Disulfoton 15G (1.0)
Carbofuran 4F (0.5)	Phorate 20G (0.66)	Phorate 20G (0.66)
	Chlorpyrifos 4E (0.5)	Chlorpyrifos 4E (0.5)
Untreated	Untreated	Untreated

[1] Rate = lb AI/acre.

Table 2. Location, seeding dates, and treatments for Russian wheat aphid spring wheat study.

Location	Location	Location	Location
MSU-CARC Year: 1989	MSU-SARC Year: 1989	Molt MT Year: 1990	MSU-CARC Year: 1990
Seeding Dates	**Seeding Dates**	**Seeding Dates**	**Seeding Date**
Early (None) Mid (May 18) Late (May 31)	Early (None) Mid (May 19) Late (June 6)	Early (April 6) Mid (April 19) Late (May 5)	Early (April 23) Mid (May 5) Late (May 28)
Treatments[1]	**Treatments[1]**	**Treatments[1]**	**Treatments[1]**
In-furrow Disulfoton 15G (1.0) Phorate 20G (0.66)	In-furrow Disulfoton 15G (1.0) Phorate 20G (0.66)	In-furrow Disulfoton 15G (1.0) Phorate 20G (0.66)	In-furrow Disulfoton 15G (1.0) Phorate 20G (0.66)
Post-emergence Disulfoton 15G (1.0) Phorate 20G (0.66)	Post-emergence Disulfoton 15G (1.0) Phorate 20G (0.66)	Post-emergence Disulfoton 15G (1.0) Phorate 20G (0.66) Chlorpyrifos 4E (0.5)	Post-emergence Disulfoton 15G (1.0) Phorate 20G (0.66) Chlorpyrifos 4E (0.5)
Untreated	Untreated	Untreated	Untreated

[1] Rate = lb AI/acre.

Treatments

The location, seeding dates and treatments for each study are summarized in Tables 1 and 2. Three seeding dates were selected for each study. Insecticide treatment selection was based on research from previously tested insecticides that effectively controlled aphids and were grower acceptable. The insecticides tested were the organophosphates disulfoton (Miles: Agricultural Chemicals Division, Box 4913, Kansas City, MO 64120), phorate (American Cyanamid: Agricultural Division, Crop Protection Chemicals Department, Wayne, NJ 07470), chlorpyrifos (DowElanco: U.S. Crop Production, Quad IV, 9002 Purdue Rd., Indianapolis, IN 46268-1189) and the carbamate carbofuran (FMC: Agricultural Chemical Group, 1735 Market Street, Philadelphia, PA 19103).

Granular formulations of disulfoton and phorate were applied in-furrow using two different applicators. A granular applicator (Gandy Co., 528 Gandrud Rd., Owatonna, MN 55060) attached to a hoe-drill was used at the 1988 MSU-CARC and 1989 Molt sites. Seed, fertilizer and granular insecticides were applied in-furrow through the hoe opener. A cone-type research drill was used at the MSU-CARC in autumn of 1989 to seed and apply the granular insecticides. The cone-type distributor did not effectively apply all of the insecticide granules. Micro-tube injection of liquid disulfoton and carbofuran, was tested at MSU-CARC in 1988. Pressurized liquid insecticide powered with CO_2 is distributed through a manifold into plastic micro-tubes. The micro-tubes were placed inside the hoe shank and were attached to the shovel opener. Liquid insecticide was injected in-furrow with the seed. This system frequently malfunctioned; the micro-tubes continually plugged up. Consequently this unit was not used after 1988.

Post-emergence applications of granular disulfoton and phorate replaced the micro-tube injection treatments in 1989 and 1990. These treatments were applied over the furrow with a granule applicator (Gandy) attached to a walking cart. The walking cart was constructed with bicycle wheels attached to a light metal frame. Granules were applied directly over the furrow with 1/2 inch clear plastic tubes attached to the Gandy box applicator. Chlorpyrifos was applied as a foliar treatment with a CO_2 backpack sprayer using 11015 flat fan nozzle tips (Spraying System Co., North Avenue, Wheaton, IL 60188) at 30 psi and 12.5 gallons of water per acre.

Experimental Design

Seeding date studies were set up on summer-fallow ground. Three parallel blocks, separated by a 35 ft. buffer, were staked out before treatment application with each block representing one of three seeding dates. Treatments for each seeding date were arranged in a completely randomized block with three replicates.

Seeding Equipment and Treatment Techniques

Autumn Seeding Date Studies

MSU-CARC 1988. A modified 14 inch row spacing Noble hoe drill, with attached fertilizer, Gandy granular application equipment, and micro-tube injection system, was used to seed, fertilize and apply insecticides. Plot size was 16 x 100 ft. Winter wheat, *Triticum aestivum* L. var. Tiber, was treated with thiram and carboxin (Gustafson), and sown at 50 lb per acre. Prior to seeding, each treatment block was worked with a chisel plow cultivator using sweeps to control weeds and establish a uniform seed bed. Fifty lb/acre of diammonium phosphate (18-46-0) fertilizer was applied.

MSU-CARC 1989. A cone-type research drill (manufactured at MSU-CARC) with 12 inch row spacing was used to seed and apply granular insecticides. Each plot measured 8 x 30 ft. Winter wheat, *Triticum aestivum* L. var. Tiber, treated with thiram and carboxin, was sown at 50 lb per acre. Granular insecticide treatments were applied in-furrow through the cone distributer. Prior to seeding, each treatment block was worked with a chisel plow using sweeps to control weeds and to establish a uniform seed bed. Urea fertilizer was broadcast on 3-1-90 at a rate of 100 lb per acre to each seeding date.

Molt 1989. A 14 inch row spacing John Deere LZ 1400 hoe drill with attached fertilizer and Gandy application boxes was used to fertilize and apply the insecticide treatments at planting. Plot size was 8 x 50 ft. Winter wheat, Triticum aestivum L. var. Judith, treated with thiram and carboxin, was sown at 50 lb per acre. Each treatment block was cultivated with a chisel plow using sweeps to control weeds and establishing a uniform seed bed. Forty-eight lb/acre of 18-46-0 fertilizer were applied with the seed as a starter fertilizer.

Spring Seeding Date Studies

A 14 inch row spacing John Deere LZ 1400 hoe-drill with fertilizer attachments and Gandy application boxes were used to seed, fertilize and apply granular insecticides at planting. Spring wheat for each spring seeding date study, Triticum aestivium L. var. Newanna, treated with thiram and carboxin, was sown at 60 lb/acre. Each plot, measuring 8 X 50 ft, was worked before seeding with a chisel plow. Forty-eight lb per acre of 18-46-0 fertilizer was applied with the seed as a starter fertilizer.

Sampling Techniques

Sampling the autumn studies began at crop emergence and continued until soil freeze up. Drill rows were designated for sampling or yield rows. When sampling, plants were