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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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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Date June 5 1992

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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 cold-hardiness 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 assigned a numeric value for the growth stages using Zadocks scale (Zadocks 1974). Plants or tillers, depending on growth stage, were randomly selected and clipped at ground level. Plants were categorized in the field as RWA infested or uninfested. Infested plants or tillers were dissected in the field, and the number of RWA on each sample were counted and recorded. Uninfested plants were discarded. Although the same sampling technique was used for each study, the sample size varied from 50 per replicate for the 1988 CARC study to 20 per replicate for the 1989 CARC and Molt studies. For statistical analyses 20 samples per replicate were sufficient. Standcounts were taken in the spring by sampling in 10 locations in each replicate, the number of live tillers per foot row was recorded. Plots were kept aphid free by spraying with chlorpyrifos 4E during the spring and summer growing season to determine the effects of an autumn RWA infestation.

Spring seeding experiments were sampled from crop emergence to crop maturity. Sampling techniques were similar to the autumn studies although aphid numbers were not recorded for the 1989 spring studies. Sample size varied for the spring studies. Fifty plants or tillers were sampled per replicate for the 1989 studies and 20 samples were taken for the 1990 studies. Samples taken after July 15, at MSU-CARC and Molt in 1990 for the mid and late seeding, were placed in quart size canning jars and filled with 70% ETOH for later evaluation because RWA numbers were too numerous to be counted in the field.

Equipment and sample size were standardized for yield data and test weights. Plots were harvested with a small plot combine; sample size was 4 X 25 ft. Samples were cleaned & weighed, and test weights determined using a quart container. Sample weights were measured on a Mettler gram scale and converted to bushels per acre.

Data Analysis

Data (aphids per tiller, standcount, test weight and yields) were analyzed by analysis of variance of the means (Lund 1989). Means were compared and separated by LSD at the 5% level of significance ($P < 0.05$).

RESULTS

Winter Wheat

MSU-CARC: Early Seeding (1 Sept. 1988)

Insecticide Treatments. Granular treatments applied in-furrow kept RWA densities below 0.1 per tiller for the autumn sampling period (Table 3). Disulfoton kept all plants RWA free, and phorate treated plots averaged <0.1 RWA per tiller on the last sampling date. By eight weeks after planting the untreated averaged 0.5 RWA per tiller.

Russian wheat aphid densities were significantly lower in the micro-tube injected treatments than the untreated (Table 3). Carbofuran and disulfoton averaged <0.1 and 0.2 RWA per tiller, respectively, at week eight. During the autumn sampling period, carbofuran averaged higher RWA infestation levels and densities than the other insecticide treatments.

MSU-CARC: Mid Seeding (15 Sept. 1988)

Insecticide Treatments. Granular applications of phorate and disulfoton kept plants RWA free during the autumn sampling period (Table 4). RWA were not detected prior to tillering (Zadocks 21). At the tillering stage (Zadocks 21), untreated plots averaged 0.2 RWA per tiller and a 7% infestation level.

When comparing insecticide treatments, RWA densities were found to be highest in carbofuran treated plots. Six weeks after planting (Nov. 2, 1988), carbofuran treated plants were

8% infested averaging 0.1 RWA per tiller. Carbofuran was the only insecticide treatment that did not significantly reduce RWA numbers when compared to the untreated.

MSU-CARC: Late Seeding (30 Sept. 1988)

Insecticide Treatments. All treatments, including the untreated, remained RWA free from crop emergence to soil freeze up (Table 5). On the last sampling date, Nov. 2, 1988, winter wheat had reached the two tiller growth stage (Zadocks 21).

Spring sampling for each seeding date began after spring regrowth on April 6, 1989 and continued until crop maturity. RWA were not detected in the early, mid, or late seeding date during the spring sampling period.

Yield, Test Weights and Standcounts

Grain yields and test weights did not differ statistically for the early-seeding date (Table 6). Grain yields averaged from 21.8 to 22.4 bushels per acre. Standcounts were lowest in the organophosphate treatments (Table 6). Plots treated with granular formulations of phorate and disulfoton averaged 58.3 and 62 tillers per ft row. Untreated plots averaged the highest standcount (70.0 tillers per ft row).

Yields for the mid-seeding date averaged from 22.5 to 25.7 bushels per acre and were not significant according to the LSD (Table 6). Insecticide treatments did not affect test weight which ranged from 57.5 to 58.4 lb per bushel.

Standcounts were significantly reduced by approximately 10 tillers per ft row for the organophosphates; disulfoton and phorate averaged 45 and 48 tillers per ft row, respectively, compared to 56.6 for the untreated.

Yield and test weight analyses detected no significance between treatment averages for the late seeding date (Table 6). Grain yields ranged from 23.2 to 33.6 bushels per acre. Test weights were low ranging from 55.6 to 55.9 lb per bushel. Standcounts ranged from 20.3 (untreated) to 23.0 (disulfoton in-furrow) tillers per ft^2.

Downy Brome Sampling

On July 15, 1989 treatments for each seeding date were sampled for downy brome (Table 7). A population gradient of downy brome was evident from west to east. Treatments located closest to the west edge had higher downy brome counts. Downy brome counts per linear ft ranged from 16.5 to 4.4 for the early seeding date compared to 11.0 to 3.9 for the mid seeding date and 0.5 to 0.1 for the late-seeding date.

Table 3. Average number of RWA per tiller and percent infestation for winter wheat seeded Sept. 1, 1988, Central Agricultural Research Center, Moccasin, MT.

	Average no. RWA/tiller (% infestation)									
	Sampling dates									
Treatments	10-5	10-19	11-2	4-6	5-17	5-31	6-18	6-27	7-15	8-1
<u>In-furrow</u>										
Disulfoton 15G	0a (0)	0a (0)	0a (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Phorate 20G	0a (0)	<0.1a (1)	<0.1a (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
<u>Micro-tube injected</u>										
Carbofuran 4F	<0.1a (3)	0.3a (11)	0.2a (4)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Disulfoton 8	0a (0)	<0.1a (2)	<0.1a (3)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
<u>Untreated</u>	0.2a (8)	0.5a (17)	0.5b (18)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Overall mean	0.05	0.1	0.1	0	0	0	0	0	0	0
Plant Growth Stage (Zadocks)	20	24	25	25	33	45	59	65	73	87

Means within a column with the same letter are not significantly different ($P \leq 0.05$; LSD).

Table 4. Average number of RWA per tiller and percent infestation for winter wheat seeded Sept. 15, 1988, Central Agricultural Research Center, Moccasin, MT.

	Average no. RWA/tiller (% infestation)									
	Sampling dates									
Treatments	10-5	10-19	11-2	4-6	5-17	5-31	6-18	6-27	7-15	8-1
<u>In-furrow</u>										
Disulfoton 15G	0a (0)	0a (0)	0a (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Phorate 20G	0a (0)	0a (0)	0a (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
<u>Micro-tube injected</u>										
Carbofuran 4F	0a (0)	0a (0)	0.1ab (8)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Disulfoton 8	0a (0)	0a (0)	<0.1a (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
<u>Untreated</u>	0a (0)	<0.1a (2)	0.2b (7)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Overall Mean	0	<0.01	0.07	0	0	0	0	0	0	0
Plant Growth Stage (Zadocks)	10	21	22	22	30	35	45	53	70	85

Means within a column with the same letter are not significantly different ($P \leq 0.05$; LSD).

Table 5. Average number of RWA per tiller and percent infestation for winter wheat seeded Sept. 30, 1988, Central Research Center, Moccasin, MT.

Treatments	Average no. RWA/tiller (% infestation)								
	Sampling dates								
	10-19	11-2	4-6	5-15	5-31	6-18	6-27	7-15	8-1
In-furrow									
Disulfoton 15G	0a (0)	0a (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Phorate 20G	0a (0)	0a (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Micro-tube injected									
Carbofuran 4F	0a (0)	0a (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Disulfoton 8	0a (0)	0a (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Untreated	0a (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Overall Mean	0	0	0	0	0	0	0	0	0
Plant Growth Stage (Zadocks)	11	21	21	27	40	39	45	59	73

Means within a column with the same letter are not significantly different ($P \leq 0.05$; LSD).

Table 6. Yield, test weight and standcount for 1988 winter wheat seeding date studies, Central Agricultural Research Center, Moccasin, MT.

	Early seeding			Mid seeding			Late seeding		
Treatments	Yield bu/ac	Test wt	Tiller $/ft^2$	Yield bu/ac	Test wt	Tiller $/ft^2$	Yield bu/ac	Test wt	Tiller $/ft^2$
In-furrow									
Disulfoton 15G	22.4a	57.7a	58.3 c	23.0a	58.2a	45.0 b	31.4a	55.6a	23.0a
Phorate 20G	21.8a	57.5a	62.0 b	23.5a	58.4a	48.0 b	32.1a	55.6a	22.6a
Micro-tube									
Carbofuran 4F	23.7a	57.5a	69.3a	24.7a	58.3a	55.6a	23.2a	55.7a	22.3a
Disulfoton 8	23.1a	57.6a	60.0 bc	25.7a	57.5a	45.3 b	26.8a	55.5a	21.6a
Untreated	22.1a	57.6a	70.1a	22.5a	58.4a	56.6a	33.6a	55.9a	20.3a
Overall Mean	22.2	57.6	63.9	23.9	58.1	50.1	29.4	55.7	22.0

Means within a column with the same letter are not significantly different ($P \leq 0.05$; LSD).

Table 7. Downy brome population counts for the 1988 winter wheat seeding date studies, Central Agricultural Research Center, Moccasin, MT.

	Downy brome tillers/ft^2		
Treatments	Early seeding date	Mid seeding date	Late seeding date
<u>In-furrow</u>			
Disulfoton 15G	16.5 b	8.5ab	0.5a
Phorate 20G	8.2ab	11.0 b	0.3a
<u>Micro-tube</u>			
Carbofuran 4F	4.4a	4.0a	0.0a
Disulfoton 8	8.6ab	3.9a	0.3a
<u>Untreated</u>	9.9ab	8.2ab	0.1a
Overall Mean	9.5	7.1	0.23

Means within a column with the same letter are not significantly different ($P \leq 0.05$; LSD).

<u>MSU-CARC: Early Seeding (6 Sept. 1989)</u>

<u>Insecticide Treatments</u>. Russian wheat aphid densities were lowest (0.1 RWA per tiller) in plots treated with disulfoton applied in-furrow (Table 8). Phorate applied in-furrow averaged 1.0 RWA per tiller. The untreated plots had 23% of the plants infested with an average of 1.3 RWA per tiller at the early tillering stage (Oct. 19). By soil freeze up (Oct. 30), percent infestation in the untreated had increased to 40%, but RWA densities were unchanged.

Post-emergence treatments were applied on Oct. 10 at the 3-4 leaf stage (Table 8). Chlorpyrifos reduced the number of RWA per tiller from 0.9 to <0.1 by nine days post-treatment.

Granular treatments did not reduce RWA numbers. Prior to treatment, disulfoton and phorate plots averaged 1.0 and 0.9 RWA per tiller, respectively. At 20 days post-treatment plants in both granular treatments averaged 1.0 RWA per tiller compared to 1.3 for the untreated.

Following spring regrowth, plots for each seeding date were periodically sampled for RWA or other insect pests (Table 8). On June 6, 1990, RWA were present on less than 1% of the tillers sampled. At this time plots in each seeding date were sprayed with chlorpyrifos, RWA were not present in subsequent samples.

MSU-CARC: Mid Seeding (20 Sept. 1989)

Insecticide Treatments. Untreated plots averaged 0.1 RWA per tiller on Oct. 30 compared to 1.3 for the same date in the early-seeding (Tables 8 and 9). Plots treated with disulfoton applied in-furrow had lower RWA densities per tiller than plots treated with in-furrow applied phorate.

Russian wheat aphid infestation levels never approached the 20% infestation level, consequently the post-emergence treatments were not applied. Plants in the untreated were 7% infested averaging 0.1 RWA per tiller on the last autumn sampling date (Oct. 30).

MSU-CARC: Late Seeding (10 Oct. 1989)

Insecticide Treatments. Winter wheat was sown on Oct. 10, 1989 and sampled on Oct. 30. RWA infested 3% of the plants averaging <0.1 RWA per tiller in the untreated;

granular treatments applied in-furrow were uninfested. Due to low infestations the post-emergence treatments were not applied.

Yield, Test Weights and Standcounts

Analyses of grain yields for the early seeding date showed no significant yield differences between treated and untreated (Table 11). Plots with disulfoton in-furrow had the lowest grain yields (41.6 bu/ac) and plots treated with chlorpyrifos had the highest (47.1). In-furrow applications of disulfoton had the lowest percent RWA infestation. Grain test weights averaged between 58.2 to 58.7 lb per bushel (Table 11). The overall effect from RWA or insecticide treatments on grain test weight was not significant. Standcounts ranged from 71.9 to 88.8 tiller per ft row for disulfoton applied in-furrow and chlorpyrifos, respectively. Untreated plots averaged 79.8 tillers per ft row.

Grain yields for the mid seeding date ranged from 41.0 to 44.0 bushels per acre. Yield differences between treatments were not significant (Table 11). Test weights varied from 57.1 for phorate applied in-furrow to 58.8 for the untreated. Although the data are non-significant, standcounts were lowest in plots treated with in-furrow applied granules. Plots receiving in-furrow applications of disulfoton and phorate averaged 30.1 and 30.3 tiller per ft row compared to 45.2 for the untreated.

Grain yields for the late seeding date ranged from 28.3 to 31.3 bu/acre, respectively (Table 11). Plots with granular disulfoton and phorate applied in-furrow averaged the lowest (58.0 lb/bu) and the highest (59.1 lb/bu) test weights. Standcounts averaged from 9.7 and 9.9 tillers per ft row for disulfoton and phorate. Untreated plots in the late seeding averaged 28.3 bushels per acre compared to 43.9 and 44.2 for the mid and early seedings.

Table 8. Average number of RWA per tiller and percent infestation for winter wheat seeded Sept. 6, 1989, Central Agricultural Research Center, Moccasin, MT.

Treatments	Average no. RWA/tiller (% infestation)										
	Sampling dates										
	9-20	10-10	10-19	10-30	4-6	4-23	5-2	5-15	6-6	*6-20	7-11
<u>In-furrow</u>											
Disulfoton 15G	0a (0)	0.2a (5)	0.1a (2)	0.1a (3)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	-	0 (0)
Phorate 20G	<0.1 (2)	0.9a (18)	0.9ab (12)	1.0b (18)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	-	0 (0)
<u>Post-emergence</u>											
Disulfoton 15G	0a (0)	1.0a (18)	0.9bc (25)	1.0b (25)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	-	0 (0)
Phorate 20G	<0.1a (2)	0.9a (30)	1.1bc (28)	1.0b (27)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	-	0 (0)
Chlorpyrifos 4E	0a (0)	0.9a (18)	<0.1a (2)	0.1a (5)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	-	0 (0)
<u>Untreated</u>	0a (0)	1.3a (23)	1.1bc (28)	1.3b (40)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	-	0 (0)
Overall Mean	0.01	0.97	0.58	0.73	0	0	0	0	0	0	0
Plant Growth Stage (Zadocks)	12	16	23	25	26	29	30	33	40	55	77

Means within a column with the same letter are not significantly different ($P \leq 0.05$; LSD).
* Aphids were detected after spring regrowth. Plots were sprayed.

Table 9. Average number of RWA per tiller and percent infestation for winter wheat seeded Sept. 20, 1989, Central Agricultural Research Center, Moccasin, MT.

	Average no. RWA/tiller (% infestation)									
	Sampling dates									
Treatments	10-10	10-19	10-30	4-6	4-23	5-2	5-15	6-6	*6-20	7-11
<u>In-furrow</u>										
Disulfoton 15G	0a (0)	<0.1a (3)	<0.1a (2)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	-	0 (0)
Phorate 20G	<0.1a (2)	0.2ab (5)	0.5b (8)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	-	0 (0)
<u>Post-emergence</u>										
Disulfoton 15G	0.2a (5)	0.1ab (5)	0.1a (5)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	-	0 (0)
Phorate 20G	0a (0)	0.3b (10)	0.3ab (12)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	-	0 (0)
Chlorpyrifos 4E	0.1a (2)	0.2ab (8)	0.2ab (8)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	-	0 (0)
<u>Untreated</u>	0.2a (7)	0.2ab (5)	0.1a (7)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	-	0 (0)
Overall Mean	0.9	0.17	0.22	0	0	0	0	0	0	0
Plant Growth Stage (Zadocks)	10	13	21	22	25	27	29	31	50	70

Means within a column with the same letter are not significantly different ($P \leq 0.05$; LSD).
* Aphids were detected after spring regrowth. Plots were sprayed.

Table 10. Average number of RWA per tiller and percent infestation for winter wheat seeded Oct. 10, 1989, Central Agricultural Research Center, Moccasin, MT.

	Average no. RWA/tiller (% infestation)							
	Sampling dates							
Treatments	10-30	4-6	4-23	5-2	5-15	6-6	*6-20	7-11
<u>In-furrow</u>								
Disulfoton 15G	0a (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	-	0 (0)
Phorate 20G	0a (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	-	0 (0)
<u>Post-emergence</u>								
Disulfoton 15G	0.1a (3)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	-	0 (0)
Phorate 20G	0a (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	-	0 (0)
Chlorpyrifos 4E	0a (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	-	0 (0)
<u>Untreated</u>	<0.1a (3)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	-	0 (0)
Overall Mean	0.01	0	0	0	0	0	0	0
Plant Growth Stage (Zadocks)	11	12	16	20	22	25	29	60

Means within a column with the same letter are not significantly different ($P \leq 0.05$; LSD).
* Aphids were detected after spring regrowth. Plots were sprayed.

Table 11. Yield, test weight and standcount for 1989 winter wheat seeding date studies, Central Agricultural Research Center, Moccasin, MT.

	Early seeding			Mid seeding			Late seeding		
Treatments	Yield bu/ac	Test wt.	Tiller /ft^2	Yield bu/ac	Test wt.	Tiller /ft^2	Yield bu/ac	Test wt.	tiller /ft^2
In-furrow									
Disulfoton 15G	41.6 b	58.4a	77.1a	41.5a	57.2a	30.1 b	28.3a	58.0 b	9.7a
Phorate 20G	44.6ab	58.2a	71.9a	41.0a	57.1a	30.3 b	31.3a	59.1a	9.9a
Post-treatment									
Disulfoton 15G	43.9ab	58.7a	71.9a	41.5a	58.3a	43.2ab	28.2a	59.0a	11.6a
Phorate 20G	44.5ab	58.6a	82.7a	43.0a	58.2a	37.7ab	29.2a	58.2 b	12.9a
Chlorpyrifos 4E	47.1a	58.7a	88.8a	42.8a	58.0a	37.7ab	29.7a	58.6ab	12.3a
Untreated	44.2ab	58.3a	79.8a	43.9a	58.8a	45.2a	28.3a	58.5ab	10.6a
Overall Mean	44.3	58.5	79.3	42.3	57.9	37.4	29.4	58.6	11.2

Means within a column with the same letter are not significantly different ($P \leq 0.05$; LSD).

Molt, MT: Early Seeding (1 Sept. 1989)

Insecticide Treatments. In-furrow treatments of disulfoton kept the plants aphid free throughout the autumn sampling period (Table 12). Phorate controlled RWA through the four tiller stage. By eight weeks after planting 2% of the phorate treated plots were infested.

Post-emergence treatments were applied at the three tiller growth stage on Oct. 10 (Table 12). At 16 days post-treatment disulfoton and phorate treated plots averaged 1.2 and 0.6 RWA per tiller, respectively. Russian wheat aphid densities were not significantly lower in post-emergence granular plots compared to the untreated. Chlorpyrifos reduced aphid levels from 1.4 RWA per tiller to zero by 16 days post-treatment.

The level of infestation in the untreated plots increased from 5% to 27% during the autumn sampling period. The average number of RWA per tiller ranged from 0.2 to 1.6 (Table 12).

Molt, MT: Mid Seeding (15 Sept. 1989)

Insecticide Treatments. Russian wheat aphid infestation levels in the untreated plots were <10% during the autumn sampling period (Table 13). Granular treatments applied in-furrow remained aphid free from crop emergence to soil freeze up. Post-emergence treatment thresholds were not reached, consequently these treatments were not applied. Untreated plots on the last sampling date had 4 out of 60 tillers infested (7%).

Molt, MT: Late Seeding (30 Sept. 1989)

Insecticide Treatments. Winter wheat was sown on Sept. 30, 1989, emerging 20 days later. At soil freeze up, the last sampling date, plants had reached the 2 leaf stage (Table 15). Granular insecticides applied in-furrow kept the plants aphid free from plant emergence to soil freeze up (approximately 10 days after plant emergence).

The untreated plots averaged 0.5 aphid per plant and was 10% infested on Oct. 26, 1989. Post-emergence treatments were not applied.

Sampling of seeding date studies at Molt were initiated in early April and continued until crop maturity (Table 15). On the first sampling date, April 6, 1990, RWA were found to have overwintered on <1% of the tillers sampled. RWA were detected again in low numbers on June 20. Upon detection of RWA, all plots were immediately sprayed with chlorpyrifos.

Yield, Test Weights and Standcounts

Grain yield for the early seeding ranged from 22.5 to 26.5 bu/acre (Table 15). Disulfoton applied in-furrow was the only one significantly higher than the untreated. RWA control for treatments applied in-furrow was similar. Test weights ranged from 59.0 to 59.3 lb/bu and were unaffected by the insecticides. Granular applications applied in-furrow had the lowest standcounts. Winter wheat plants in disulfoton treated plots averaged 30.6 tillers per ft row, significantly lower than 40.9 observed in the untreated plots. Significant differences were not detected for the other treatments.

Yields for the mid seeding ranged from 16.7 to 19.8 bushel per acre (Table 15). Test weight averaged from 59.0 to 59.5 lb per bushel. Standcounts were similar ranging from 28.8 to 39.5. tillers per ft row.

Yield differences ranged from 12.6 to 15.2 bushels per acre for the late seeding date (Table 15). The untreated had significantly higher test weights than most of the insecticide treatments. Test weights ranged between 59.6 to 60.6 lb per bu. Standcounts taken in the spring were not significantly different. Tillers per ft row ranged from 15.2 for plots treated with phorate applied in-furrow to 17.6 for untreated plots.

Table 12. Average number of RWA per tiller and percent infestation for winter wheat seeded Sept. 1, 1989, Molt, MT.

	Average no. RWA/tiller (% infestation)													
	Sampling dates													
Treatments	9-14	9-21	9-28	10-10	10-20	10-26	*4-6	4-17	5-2	5-16	5-30	*6-20	6-27	7-19
<u>In-furrow</u>														
Disulfoton 15G	0a (0)	0a (0)	0a (0)	0a (0)	0 (0)	0a (0)	-	0 (0)	0 (0)	0 (0)	0 (0)	-	0 (0)	0 (0)
Phorate 20G	0a (0)	0a (0)	0a (0)	0a (0)	0 (0)	<0.1a (2)	-	0 (0)	0 (0)	0 (0)	0 (0)	-	0 (0)	0 (0)
<u>Post-emergence</u>														
Disulfoton 15G	0a (0)	0.3a (10)	1.0b (17)	1.5ab (17)	0.5ab (18)	1.2b (23)	-	0 (0)	0 (0)	0 (0)	0 (0)	-	0 (0)	0 (0)
Phorate 20G	<0.1a (3)	0.2a (5)	0.3a (17)	0.8ab (17)	0.1a (4)	0.6ab (17)	-	0 (0)	0 (0)	0 (0)	0 (0)	-	0 (0)	0 (0)
Chlorpyrifos 4E	<0.1a (1)	<0.1a (3)	0.4a (10)	1.4ab (18)	0a (0)	0a (0)	-	0 (0)	0 (0)	0 (0)	0 (0)	-	0 (0)	0 (0)
<u>Untreated</u>	0a (0)	0.2a (5)	0.3a (10)	1.7b (18)	1.6b (25)	1.6b (27)	-	0 (0)	0 (0)	0 (0)	0 (0)	-	0 (0)	0 (0)
Overall Mean	<0.01	0.13	0.33	0.91	0.37	0.56	0	0	0	0	0	0	0	0
Plant growth stage (Zadocks)	12	13	20	23	24	25	25	28	30	32	37	59	65	85

Means within a column with the same letter are not significantly different ($P \leq 0.05$; LSD).
* Aphids were detected after spring regrowth. Plots were sprayed.

Table 13. Average number of RWA per tiller and percent infestation for winter wheat seeded Sept. 15, 1989, Molt, MT.

	Average no. RWA/tiller (% infestation)								
	Sampling dates								
Treatments	9-28	10-11	10-20	10-26	4-6	5-15	6-6	6-20	7-11
<u>In-furrow</u>									
Disulfoton 15G	0a (0)	0a (0)	0a (0)	0a (0)	0 (0)	0 (0)	0 (0)	-	0 (0)
Phorate 20G	0a (0)	0a (0)	0a (0)	0a (0)	0 (0)	0 (0)	0 (0)	-	0 (0)
<u>Post-emergence</u>									
Disulfoton 15G	0a (0)	<0.1a (3)	0.1ab (5)	0.4a (8)	0 (0)	0 (0)	0 (0)	-	0 (0)
Phorate 20G	0a (0)	0a (0)	0.2b (7)	0.5a (10)	0 (0)	0 (0)	0 (0)	-	0 (0)
Chlorpyrifos 4E	0a (0)	0a (0)	<0.1ab (3)	0.4a (10)	0 (0)	0 (0)	0 (0)	-	0 (0)
<u>Untreated</u>	0a (0)	0.1a (2)	0.2b (7)	0.5a (7)	0 (0)	0 (0)	0 (0)	-	0 (0)
Overall Mean	0	0.02	0.08	0.30	0	0	0	0	0
Plant growth stage (Zadocks)	12	13	14	21	30	33	40	55	77

Means within a column with the same letter are not significantly different ($P \leq 0.05$; LSD).
* Aphids were detected after spring regrowth. Plots were sprayed.

Table 14. Average number of RWA per tiller and percent infestation for winter wheat seeded Sept. 30, 1989, Molt, MT.

	Average no. RWA/tiller (% infestation)						
	Sampling dates						
Treatments	10-20	10-26	4-6	5-15	6-6	*6-20	7-11
<u>In-furrow</u>							
Disulfoton 15G	0a (0)	0a (0)	0 (0)	0 (0)	0 (0)	-	0 (0)
Phorate 20G	0a (0)	0a (0)	0 (0)	0 (0)	0 (0)	-	0 (0)
<u>Post-emergence</u>							
Disulfoton 15G	0.1a (3)	0.5a (10)	0 (0)	0 (0)	0 (0)	-	0 (0)
Phorate 20G	0.2a (3)	0.2a (3)	0 (0)	0 (0)	0 (0)	-	0 (0)
Chlorpyrifos 4E	0a (0)	0.4a (7)	0 (0)	0 (0)	0 (0)	-	0 (0)
<u>Untreated</u>	<0.1a (2)	0.5a (15)	0 (0)	0 (0)	0 (0)	-	0 (0)
Overall Mean	0.05	0.25	0	0	0	0	0
Plant growth stage Zadocks	11	13	14	33	40	55	77

Means within a column with the same letter are not significantly different ($P \leq 0.05$; LSD).
* Aphids were detected after spring regrowth. Plots were sprayed.

Table 15. Yield, test weight and standcount for 1989 winter wheat seeding date studies, Molt, MT.

	Early seeding			Mid seeding			Late seeding		
Treatments	Yield bu/ac	Test wt	Tiller /ft^2	Yield bu/ac	Test wt	Tiller /ft^2	Yield bu/ac	Test wt	Tiller /ft^2
In-furrow									
Disulfoton 15G	26.5a	59.3a	30.6 b	19.8a	59.2a	33.8a	15.2a	60.3 b	16.5a
Phorate 20G	23.2ab	59.0 b	35.9ab	16.7a	59.2a	29.7a	12.9a	59.6 c	15.2a
Post-emergence									
Disulfoton 15G	23.1ab	59.0 b	38.1a	17.9a	59.5a	39.5a	15.9a	60.3 b	16.5a
Phorate 20G	23.0ab	59.0 b	41.8a	16.7a	59.3a	35.8a	16.4a	60.4ab	14.5a
Chlorpyrifos 4E	23.2ab	59.0 b	42.9a	17.0a	59.4a	28.8a	14.5a	60.2 b	20.8a
Untreated	22.5b	59.0 b	40.9a	17.9a	59.3a	35.2a	12.6a	60.6a	17.6a
Overall Mean	23.6	59.1	38.4	18.3	59.3	33.8	14.5	60.2	16.8

Means within a column with the same letter are not significantly different ($P \leq 0.05$; LSD).

Spring Wheat

MSU-CARC: Early Seeding (1989)

Due to wet soil conditions and frequent precipitation the early-seeding date was not planted.

MSU-CARC: Mid Seeding (18 May 1989)

Insecticide Treatments. Plots remained RWA free until the last sample date August 1, 1989 (Table 16). On this date, phorate had a 1% infestation. Post-emergence treatments were not applied.

MSU-CARC: Late Seeding (31 May 1989)

Insecticide Treatments. Russian wheat aphid infestation levels remained low (<1%) for the late-seeding date (Table 17). Plots remained uninfested up to head emergence (Zadocks 59). Post-emergence treatments were not applied due to low RWA levels.

Yield and Test Weights

Spring wheat yields for the mid seeding date ranged from 26.8 to 30.0 bushels per acre (Table 18) and were unaffected by insecticide treatments. Test weights averaged above the standard test weight (58.0 lb. per bushel) for No. 1 hard red spring wheat. Average test weights ranged from 59.2 to 60.3 lb. per bushel.

Grain yields for the late seeding averaged from 30.0 to 34.8 bushels per acre. Significant differences ($P = 0.39$) were not detected (Table 18). Untreated plots averaged 2.6

bushels per acre higher in the late seeding compared to the mid seeding. Test weights were approximately one lb per bushel lower then standards set for No.1 hard red spring wheat. Test weights averaged from 56.9 to 57.2 lb. per bushel.

Table 16. Average number of RWA per tiller and percent infestation for spring wheat seeded May 18, 1989, Central Agricultural Research Center, Moccasin, MT.

	Average no. RWA/tiller (% infestation)						
	Sampling dates						
Treatments	5-31	6-18	6-27	7-7	7-13	7-26	8-1
In-furrow							
Disulfoton 15G	0	0	0	0	0	0	0a
Phorate 20G	0	0	0	0	0	0	1a
Post-emergence							
Disulfoton 15G	0	0	0	0	0	0	0a
Phorate 20G	0	0	0	0	0	0	0a
Untreated	0	0	0	0	0	0	0a
Overall Mean	0	0	0	0	0	0	0.02
Plant growth stage (Zadocks)	12	25	32	50	60	73	85

Means within a column with the same letter are not significantly different (P = 0.05; LSD).

Table 17. Average number of RWA per tiller and percent infestation for spring wheat seeded May 31, 1989, Central Agricultural Research Center, Moccasin, MT.

	Average no. RWA/tiller (% infestation)						
	Sampling dates						
Treatments	6-18	6-27	7-7	7-13	7-26	8-1	8-17
<u>In-furrow</u>							
Disulfoton 15G	0	0	0	0	0a	<1a	0
Phorate 20G	0	0	0	0	0a	0a	0
<u>Post-emergence</u>							
Disulfoton 15G	0	0	0	0	<1a	0a	0
Phorate 20G	0	0	0	0	0a	0a	0
<u>Untreated</u>	0	0	0	0	0a	0a	0
Overall Mean	0	0	0	0	0	0.25	0.25
Plant growth stage (Zadocks)	25	32	50	60	59	65	85

Means within a column with the same letter are not significantly different ($P \leq 0.05$; LSD).

Table 18. Yield and test weight for 1989 spring wheat seeding date studies, Central Agricultural Research Center, Moccasin, MT.

	Mid seeding		Late seeding	
Treatments	Yield bu/ac	Test wt	Yield bu/ac	Test wt
<u>In-furrow</u>				
Disulfoton 15G	26.8a	60.3a	32.9a	56.9a
Phorate 20G	29.7a	59.2a	30.0a	56.9a
<u>Post-emergence</u>				
Disulfoton 15G	30.0a	59.4a	34.8a	57.0a
Phorate 20G	28.5a	59.8a	33.3a	56.9a
<u>Untreated</u>	28.9a	59.5a	31.5a	57.2a
Overall Mean	28.8	59.6	32.5	57.0

Means within a column with the same letter are not significantly different ($P \leq 0.05$; LSD).

MSU-SARC: Early Seeding (1989)

The early seeding date was not planted due to frequent precipitation and wet soil conditions.

MSU-SARC: Mid Seeding (31 May 1989)

Insecticide Treatments. Precipitation delayed the mid seeding until May 31. The mid-seeding date was RWA free until plants reached the swollen boot stage (Table 19). At this growth stage on July 7, disulfoton and phorate applied in-furrow and untreated plots were 5, 8 and 9% infested, respectively. Russian wheat aphid infestation levels lowered as plant maturity approached. At the hard dough stage RWA were no longer present. Infestation levels never reached the post-emergence treatment threshold.

MSU-SARC: Late Seeding (6 June 1989)

Insecticide Treatments. Granular insecticide treatments applied in-furrow had lower infestation levels than the untreated throughout the sampling period (Table 20). Disulfoton and phorate four weeks after planting were 6 and 8% infested. At the same date the untreated plot was 9% infested. On the last sampling date disulfoton, the only treatment with significantly less RWA than the untreated, had 36% of the tillers infested compared to 55% for the untreated. Post-emergence treatments were applied at the flag leaf stage on July 20. Granular insecticides did not lower RWA infestation levels, in fact infestation levels continued to increase.

Yield and Test Weights

Yields and test weights were low for the mid-seeding date (Table 26). Grain yields ranged from 15.5 to 16.9 bushels per acre (Table 21). Significant differences were not detected when comparing treatment averages. Test weights were below the standard test weight needed to make No.1 hard red spring wheat. Grain yields for the late seeding date were low averaging 7.5 to 9.9 bushels per acre (Table 21). Test weights averaged from 53.3 to 54.4 lb per bushel.

Table 19. Average number of RWA per tiller and percent infestation for spring wheat seeded May 19, 1989, Southern Agricultural Research Center, Huntley, MT.

	Average no. RWA/tiller (% infestation)							
	Sampling dates							
Treatments	5-31	6-6	6-20	7-7	7-12	7-20	7-26	8-17
<u>In-furrow</u>								
Disulfoton 15G	0	0	0	5a	5a	2a	3a	0
Phorate 20G	0	0	0	8a	5a	5a	3a	0
<u>Post-emergence</u>								
Disulfoton 15G	0	0	0	7a	7a	7a	4a	0
Phorate 20G	0	0	0	4a	1a	2a	3a	0
<u>Untreated</u>	0	0	0	9a	3a	5a	3a	0
Overall Mean	0	0	0	6.6	4.2	4.2	3.2	0
Plant growth stage (Zadocks)	12	22	28	45	60	70	75	87

Means within a column with the same letter are not significantly different ($P \leq 0.05$; LSD).

Table 20. Average number of RWA per tiller and percent infestation for spring wheat seeded June 6, 1989, Southern Agricultural Research Center, Huntley, MT.

	Average no. RWA/tiller (% infestation)					
	Sampling dates					
Treatments	6-20	7-7	7-12	7-20	7-26	8-17
<u>In-furrow</u>						
Disulfoton 15G	0	6a	7ab	14a	21a	36a
Phorate 20G	0	8a	5a	13a	25ab	47ab
<u>Post-emergence</u>						
Disulfoton 15G	0	13a	14 b	19a	33 bc	63 bc
Phorate 20G	0	10a	13 b	13a	42 c	67 c
<u>Untreated</u>	0	9a	10ab	15a	40 c	55 bc
Overall Mean	0	9.2	4.6	14.8	32.2	53.8
Plant growth stage (Zadocks)	13	21	22	40	50	85

Means within a column with the same letter are not significantly different ($P \leq 0.05$; LSD).

Table 21. Yield and test weight for 1989 spring wheat seeding date studies, Southern Agricultural Research Center, Huntley, MT.

Treatments	Mid seeding		Late seeding	
	Yield bu/ac	Test wt	Yield bu/ac	Test wt
<u>In-furrow</u>				
Disulfoton 15G	16.2a	53.5a	8.4a	54.4a
Phorate 20G	15.5a	52.5a	8.9a	53.6a
<u>Post-emergence</u>				
Disulfoton 15G	15.2a	52.5a	7.5a	53.9a
Phorate 20G	16.9a	53.5a	7.7a	53.9a
<u>Untreated</u>	15.8a	52.9a	8.6a	53.3a
Overall Mean	15.9	52.9	8.2	53.9

Means within a column with the same letter are not significantly different ($P \leq 0.05$; LSD).

MSU-CARC: Early Seeding (23 April 1990)

Insecticide Treatments. Plants in the early seeding were aphid free until the swollen boot stage (Table 22). At this growth stage the oat bird cherry aphid, *Rhopalosiphum maidis*, had infested 2% of the tillers in plots that received phorate in-furrow and in plots scheduled for post-emergence applications of phorate. Russian wheat aphids were not present until head emergence was complete on July 12 (Table 22). At this time untreated plots averaged 0.2 RWA per tiller. On the last sampling date when plants reached the hard dough stage (Zadocks 87), aphids were no longer present.

Infestation levels never approached the treatment threshold of 20%, consequently the post-emergence treatments were not applied.

MSU-CARC: Mid Seeding (8 May 1990)

Insecticide Treatments. Plots remained aphid free for seven weeks after planting (Table 23). At eight weeks, RWA densities for each treatment were $\leq$0.3 RWA per tiller. On July 25, when plants reached the kernel formation stage, an average of 8.9 RWA per tiller was recorded for the untreated. On the same date phorate and disulfoton applied in-furrow had 5.5 and 6.8 RWA per tiller, respectively. Untreated plots averaged 42.3 RWA per tiller on the last sampling date compared to 19.6 and 20.6 for phorate and disulfoton treatments.

Post-emergence treatments were applied at the flowering stage on July 12, (Table 23). Thirteen days post-treatment, chlorpyrifos averaged 1.9 RWA per tiller and the untreated averaged 8.9 RWA per tiller. At the hard dough stage on the last sampling date, chlorpyrifos had increased to 22.0 RWA per tiller compared to 42.3 in the untreated. Post-emergence granular treatments did not significantly reduce RWA densities compared to the untreated.

MSU-CARC: Late Seeding (28 May 1990)

Insecticide Treatments. Late seeded plots were uninfested up to five weeks (Zadocks 31) after planting (Table 24). After July 3, each successive sampling date saw a substantial increase in RWA densities. On July 12, 25, and August 7, RWA densities per tiller in the untreated plots averaged 1.8, 17.5 and 55.7, respectively. In-furrow treatments did not significantly reduce RWA numbers compared to the untreated. On the last sampling date, August 7, RWA densities in plots treated with disulfoton and phorate applied in-furrow averaged 37.2 and 43.3 RWA per tiller, respectively.

Post-emergence treatments were applied at the booting stage on July 12 (Table 24). Chlorpyrifos was the only treatment to significantly reduce RWA numbers when compared to the untreated. Chlorpyrifos treated plots, at 13 days post-treatment, averaged 5.7 RWA per tiller compared to 17.5 for the untreated plots. RWA densities continued to rise after granular treatments were applied.

Yield, Test Weights and Standcounts

Grain yields (bu/acre) for the early seeding date averaged in the low to mid 20's (Table 25). The untreated plot yielded 4.5 bushels per acre higher than plots treated with phorate applied in-furrow. All other treatments were not significantly different. Test weight averages ranged from 56.4 to 56.8 lb per bushel.

Mid seeded spring wheat yielded from 22.6 to 29.0 bushels per acre (Table 25). Disulfoton applied in-furrow averaged 22.6 bushels per acre compared to 29.0 for in-furrow applied phorate. Variation within treatments resulted in no significant yield differences ($P = .57$). Test weights ranged from 56.4 to 56.8 lb per bushel.

Analyses of grain yields for the late seeding date showed no significant difference between treatment yields ranging from 19.8 to 23.8 bushel per acre (Table 25). Although chlorpyrifos significantly lowered RWA numbers, there was no correlation between decreased RWA numbers and yield. Test weights averaged from 57.2 to 58.0 lb per bushel. Significant differences were not detected among treatments.

Table 22. Average number of RWA per tiller and percent infestation for spring wheat seeded April 23, 1990, Central Agricultural Research Center, Moccasin, MT.

	Average no. RWA/tiller (% infestation)							
	Sampling dates							
Treatments	5-8	5-28	6-6	6-18	6-26	7-3	7-12	7-25
<u>In-furrow</u>								
Disulfoton 15G	0	0	0	0	0	0a (0)	0.1a[1] (3)	0 (0)
Phorate 20G	0	0	0	0	0	<0.1a[1] (2)	0.1a (3)	0 (0)
<u>Post-emergence</u>								
Disulfoton 15G	0	0	0	0	0	0a (0)	0.5a <0.1a[1] (7)	0 (0)
Phorate 20G	0	0	0	0	0	0.1a[1] (2)	0a (0)	0 (0)
Chlorpyrifos 4E	0	0	0	0	0	0a (0)	0a (0)	0 (0)
<u>Untreated</u>	0	0	0	0	0	0a (0)	0.2a (2)	0 (0)
Overall Mean	0	0	0	0	0	<0.01	0.14	0
Plant growth stage (Zadocks)	12	21	25	31	33	45	65	87

Means within a column with the same letter are not significantly different ($P \leq 0.05$; LSD).
[1]OC = Oat bird cherry aphid.

Table 23. Average number of RWA per tiller and percent infestation for spring wheat seeded May 8, 1990, Central Agricultural Research Center, Moccasin, MT.

	Average no. RWA/tiller (% infestation)							
	Sampling dates							
Treatments	5-28	6-6	6-18	6-26	7-3	7-12	7-25	8-7
<u>In-furrow</u>								
Disulfoton 15G	0	0	0	0	0.1a (5)	0.3a (13)	6.8ab	20.6a
Phorate 20G	0	0	0	0	0.3a (2)	1.4a (7)	5.5a	19.6a
<u>Post-emergence</u>								
Disulfoton 15G	0	0	0	0	<0.1a (3)	0.2a (13)	9.2 b	26.1ab
Phorate 20G	0	0	0	0	0.2a (2)	0.4a (5)	8.8ab	36.8ab
Chlorpyrifos 4E	0	0	0	0	0a (0)	0.3a (22)	1.9a	22.0a
<u>Untreated</u>	0	0	0	0	<0.1a (2)	0.4a (12)	8.9 b	42.3 b
Overall Mean	0	0	0	0	0.13	0.5	6.8	27.9
Plant growth stage (Zadocks)	13	15	24	31	36	59	70	87

Means within a column with the same letter are not significantly different ($P \leq 0.05$; LSD).

Table 24. Average number of RWA per tiller and percent infestation for spring wheat seeded May 28, 1990, Central Agricultural Research Center, Moccasin, MT.

	Average no. RWA/tiller (% infestation)						
	Sampling dates						
Treatments	6-6	6-18	6-26	7-3	7-12	7-25	8-7
In-furrow							
Disulfoton 15G	0	0	0	<0.1a (2)	1.5a (23)	25.7 bc	37.2ab
Phorate 20G	0	0	0	0.1a (3)	0.4a (17)	28.4 d	43.3 b
Post-emergence							
Disulfoton 15G	0	0	0	0.1a (3)	1.5a (20)	16.6 bc	45.2 b
Phorate 20G	0	0	0	<0.1a (2)	1.8a (23)	14.2ab	51.2 b
Chlorpyrifos 4E	0	0	0	<0.1a (2)	1.0a (17)	5.7a	17.4a
Untreated	0	0	0	<0.1a (2)	1.8a (17)	17.5 bc	55.7 b
Overall Mean	0	0	0	0.1	1.3	18	41.6
Plant growth stage (Zadocks)	12	23	26	31	40	60	80

Means within a column with the same letter are not significantly different ($P \leq 0.05$; LSD).

Table 25. Yield and test weight for 1990 spring wheat seeding date studies, Central Agricultural Research Center, Moccasin, MT.

Treatments	Early seeding Yield bu/ac	Early seeding Test wt	Mid seeding Yield bu/ac	Mid seeding Test wt	Late seeding Yield bu/ac	Late seeding Test wt
<u>In-furrow</u>						
Disulfoton 15G	23.1ab	56.8a	22.6a	56.8a	21.1a	57.6a
Phorate 20G	20.1 b	56.4a	29.0a	56.4a	23.4a	57.5a
<u>Post-emergence</u>						
Disulfoton 15G	22.8ab	56.8a	28.3a	56.8a	19.8a	57.2a
Phorate 20G	22.8ab	56.4a	24.8a	56.4a	22.6a	57.8a
Chlorpyrifos 4E	21.5ab	56.4a	24.5a	56.4a	23.7a	58.0a
<u>Untreated</u>	24.6a	56.4a	26.5a	56.8a	23.8a	57.3a
Overall Mean	22.5	56.5	25.9	56.6	22.4	57.6

Means within a column with the same letter are not significantly different ($P \leq 0.05$; LSD).

Molt, MT: Early Seeding (6 April 1990)

Insecticide Treatments. Granular in-furrow treatments were aphid free from crop emergence to crop maturity (Table 26). At the booting stage untreated plots averaged <0.1 RWA per tiller. RWA densities for the untreated peaked on July 5 averaging 2.3 RWA per tiller. Samples taken during the soft and hard dough stage (Zadocks 85 and 87) were aphid free. Post-emergence treatments were not applied.

Molt, MT: Mid Seeding (19 April 1990)

Insecticide Treatments. Plots remained aphid free for eight weeks after planting (Table 27). Russian wheat aphid increases were apparent on July 19, at the 3rd joint growth stage. The untreated plots averaged 75.0 RWA per tiller compared to 37.0 and 43.4 for disulfoton and phorate, respectively. RWA densities on July 31 declined to 38.8 RWA per tiller for the untreated and 22.7 and 27.1 for disulfoton and phorate.

Post-emergence treatments were applied on June 27. One week post-treatment, chlorpyrifos treated plots averaged 0.2 RWA per tiller compared to 2.0 for the untreated. Post-emergence application of granular insecticides did not reduce RWA numbers.

Molt, MT: Late Seeding (9 May 1990)

Insecticide Treatments. Five weeks after planting, plots receiving in-furrow granular treatments were infested. Although these treatments had lower RWA densities than the untreated they were not always significantly lower. Disulfoton significantly reduced the number of RWA compared to the untreated on July 5 and 19 (Table 28). At this date phorate plots averaged 6.4 RWA per tiller. On the last sampling date the untreated, phorate and disulfoton plots averaged 144.5, 154.4 and 172.7 RWA per tiller.

Post-emergence treatments were applied at the first joint stage on June 27 (Table 28). Granular insecticide treatments did not reduce RWA densities compared to the untreated. Chlorpyrifos, nine days post-treatment, significantly reduced RWA densities compared to the untreated. At this sampling date chlorpyrifos was 45% infested compared to 57% for the untreated, however, RWA densities per tiller were much lower, 3.1 for chlorpyrifos compared to 16.1 for the untreated.

Yield and Test Weights

Grain yields ranged from 14.8 to 16.6 bushels per acre for the early seeding date (Table 29). Significant differences were not detected at the 0.05 level. Test weights averaged from 56.4 to 56.8 lb per bushel.

Grain yields for the mid seeding date ranged from 22.6 to 19.6 bushels per acre for the treatments tested. Insecticide treated plots did not have significantly higher yield when compared to the untreated (Table 29). The untreated plots had the lowest average test weight (55.5 lb/bu).

Average yields for the late-seeding date were below 10 bushels per acre (Table 29). Untreated plots yielded the lowest (7.3 bu/acre) and chlorpyrifos and phorate applied post-emergence yielded the highest (9.0 bu/acre). Test weights were several pounds below the standard test weight for No. 1 hard red spring wheat. Significant differences were not detected for grain yields or test weights.

Table 26. Average number of RWA per tiller and percent infestation for spring wheat seeded April 6, 1990, Molt, MT.

	Average no. RWA/tiller (% infestation)						
	Sampling dates						
Treatment	5-9	5-30	6-19	6-27	7-5	7-19	7-31
<u>In-furrow</u>							
Disulfoton 15G	0	0	0a (0)	0a (0)	0a (0)	0 (0)	0 (0)
Phorate 20G	0	0	0a (0)	0a (0)	0a (0)	0 (0)	0 (0)
<u>Post-emergence</u>							
Disulfoton 15G	0	0	0.1 b (7)	<0.1a (5)	0.2a (3)	0 (0)	0 (0)
Phorate 20G	0	0	0a (0)	0a (0)	0a (0)	0 (0)	0 (0)
Chlorpyrifos 4E	0	0	<0.1a (2)	0.6a (5)	0a (0)	0 (0)	0 (0)
<u>Untreated</u>	0	0	<0.1ab (3)	<0.1a (3)	2.3 (5)	0 (0)	0 (0)
Overall Mean	0	0	0.05	0.13	0.41	0	0
Plant growth stage (Zadocks)	13	25	40	59	70	85	87

Means within a column with the same letter are not significantly different ($P \leq 0.05$; LSD).

Table 27. Average number of RWA per tiller and percent infestation for spring wheat seeded April 19, 1990, Molt, MT.

	Average no. RWA/tiller (% infestation)						
	Sampling dates						
Treatments	5-9	5-30	6-19	6-27	7-5	7-19	7-31
<u>In-furrow</u>							
Disulfoton 15G	0	0	0a (0)	<0.1a (2)	1.3a (3)	37.0a	22.7a
Phorate 20G	0	0	0a (0)	0.4a (7)	0.2a (3)	43.4a	27.1a
<u>Post-emergence</u>							
Disulfoton 15G	0	0	<0.1a (3)	0.7a (10)	0.8a (5)	94.4 bc	46.0a
Phorate 20G	0	0	0a (0)	0.6a (5)	0.4a (3)	90.1 bc	28.3a
Chlorpyrifos 4E	0	0	0.4a (5)	0.7a (10)	0.2a (10)	28.5a	25.0a
<u>Untreated</u>	0	0	0a (0)	0.6a (17)	2.0a (10)	75.0 bc	38.8a
Overall Mean	0	0	0.08	0.51	0.6	61.4	31.3
Plant growth stage (Zadocks)	12	23	33	45	59	69	80

Means within a column with the same letter are not significantly different ($P \leq 0.05$; LSD).

Table 28. Average number of RWA per tiller and percent infestation for spring wheat seeded May 9, 1990, Molt, MT.

	Average no. RWA/tiller (% infestation)					
	Sampling dates					
Treatments	5-30	6-19	6-27	7-5	7-19	7-31
<u>In-furrow</u>						
Disulfoton 15G	0	<0.1a (3)	0.6a (17)	1.6a (32)	54.0a	172.7a
Phorate 20G	0	0.1a (7)	0.8a (25)	6.4ab (45)	134.0abc	154.4a
<u>Post-emergence</u>						
Disulfoton 15G	0	0.1a (5)	1.9ab (42)	16.4 b (65)	204.0 c	215.0a
Phorate 20G	0	0.3a (5)	3.6 b (33)	9.9ab (58)	109.0abc	126.2a
Chlorpyrifos 4E	0	0.5a (3)	2.4ab (37)	3.1a (45)	70.0ab	128.7a
<u>Untreated</u>	0	0.3a (7)	2.0ab (52)	16.1 b (57)	159.4 bc	144.5a
Overall Mean	0	0.23	1.8	8.9	121	156.6
Plant growth stage (Zadocks)	13	23	31	40	59	77

Means within a column with the same letter are not significantly different ($P \leq 0.05$; LSD).

Table 29. Yield and test weight for 1990 spring wheat seeding date studies, Molt, MT.

Treatments	Early seeding		Mid seeding		Late seeding	
	Yield bu/ac	Test wt	Yield bu/ac	Test wt	Yield bu/ac	Test wt
<u>In-furrow</u>						
Disulfoton 15G	15.6a	56.8a	20.0ab	56.0a	8.8a	54.0a
Phorate 20G	16.5a	56.4a	21.0ab	56.0a	8.3a	52.8a
<u>Post-emergence</u>						
Disulfoton 15G	16.6a	56.8a	19.6 b	57.2a	8.3a	53.6a
Phorate 20G	14.8a	56.4a	22.6a	56.4a	9.0a	52.8a
Chlorpyrifos 4E	16.5a	56.4a	20.3ab	56.0a	9.0a	53.2a
<u>Untreated</u>	16.6a	56.4a	21.2ab	55.5a	7.3a	53.2a
Overall Mean	16.1	56.5	20.8	56.1	8.4	53.2

Means within a column with the same letter are not significantly different ($P \leq 0.05$; LSD).

DISCUSSION

Winter Wheat Studies

Studies at all locations showed that RWA infestations during the autumn declined with later seeding dates. Russian wheat aphid infestation levels, at three locations (MSU-CARC 1988, MSU-CARC 1989, and Molt 1989), in the untreated plots for the early, mid, and late seeding dates were as follows: early seeding dates 18, 27, and 40%; mid seeding dates 7, 7, and 7%; and late seeding dates 0, 3, and 15% infested. Our results suggest that delayed seeding of winter wheat until September 15, or thereafter would mostly avoid autumn RWA infestations above 10%. Data collected from aphid suction traps in six locations throughout Montana shows that RWA flight activity is highest in late July and August (Johnson unpublished data). A sharp decline in flight activity is evident in suction trap samples taken between September 1-15. This implies that the flight activity of the RWA is suppressed when mean daily temperatures decrease. Hammon et al. (1990) found that winter wheat emergence date in western Colorado is closely correlated with autumn RWA infestation levels, earlier planted winter wheat tends to have higher RWA infestations than later planted winter wheat.

Delayed seeding has also been found to decrease Hessian fly infestations (Horton et al. 1943). Growers are recommended to seed winter wheat after Hessian fly flight is decreased in the autumn (Horton & Haseman 1944, Walkden et al. 1944, Packard & Cartwright 1949). The wheat curl mite transmits wheat streak mosaic virus to early emerging winter wheat. Mites become less active as temperatures decrease in the autumn (Cook & Veseth 1991). Delayed winter wheat seeding is an effective tool to reduce wheat streak mosaic. However, insect, disease and weed free winter wheat may not be an economical goal. Consequences of seeding winter wheat late in Montana has been shown to lower yields, test weights, stand establishment, winter-hardiness and increase soil erosion. Delayed seeding to reduce pest infestations is a viable tool but too much delay could cause more damage than the pests controlled. Stand establishment when moisture conditions allow may be the single most important goal for winter wheat producers in Montana.

Results from seeding studies show that autumn RWA infestation levels of 18, 27 and 40% did not prove to adversely affect crop yield or test weight when compared to plots kept aphid free. For example, in the early seeding date at Molt in 1989 (untreated 27% infested) plots treated with in-furrow application of granular insecticide produced mixed results. Disulfoton yielded four bushels per acre higher than the untreated however phorate only yielded 0.8 bushels higher. Both treatments controlled RWA equally well throughout the autumn sampling period. At the MSU-CARC in 1989 a 40%

infestation did not reduce yields compared to in-furrow application of disulfoton that kept infestation levels ≤3.0% for the autumn sampling period. However, at the same site an application of chlorpyrifos at a 20% infestation level increased yields by three bushels per acre over the untreated. Studies in eastern Washington found that winter wheat infested with individual or combinations of Rhopalosiphum padi (L.) and S. graminum can cause significant yielded losses (Pike & Schaffner 1985). In this study an infestation of R. padi and S. graminum did not always cause yield damage but the time of infestation did. If winter wheat plants were infested at the two leaf stage by individual or combinations of R. padi and S. graminum yield losses were significant; however, if the plant was infested at the four leaf and two tiller stages yield losses were not significant (Pike & Schaffner 1985). Studies by Johnson and Kammerzell (1990) showed that winter wheat plants infested with RWA at the 1-2 leaf stage had 62% winter survival averaging 2.3 tillers per plant in the spring compared to plants infested at the tillering stage that had 100% winter survival averaging 5.8 tillers per plant. In our studies, at all locations, infestation levels were <10% at the 1-2 leaf stage increasing substantially as plants developed into the tillering stage. In these studies, one would expect if RWA infestation levels were higher at the 1-2 leaf stage, RWA feeding damage may have significantly decreased yields in the untreated plots.

These field studies showed that delayed winter wheat seeding, up to 2 weeks, reduces the percent RWA infestation without sacrificing yield. Winter wheat yields tend to be higher for the early and mid-seeding dates but were considerably lower for the late-seeding date. However at the Moccasin site in 1988 the late seeding date yielded higher than the early and mid seeding dates. Increased yields for the late seeding date may be from a combination of variables. A hail storm in July shattered wheat heads in the early and mid seedings. The late seeding was at an earlier growth stage preventing head shatter. Downy brome heavily infested the early and mid seeding dates. Downy brome density in the untreated plots for the early and mid seeding was 9.9 and 8.2 tillers per ft^2 compared to 0.1 in the late seeding date. Densities of 2.6, 4.4 and 7.2 downy brome plants per ft row reduced wheat yields by 10, 15, and 20%, respectively (Stahlman & Miller 1990). Downy brome, after emergence, can be effectively controlled before planting with autumn tillage (Rydrych 1974).

Trials comparing the performance of in-furrow, micro-tube injected and post-emergence insecticides were conducted on winter wheat for autumn RWA control. Results show that granular insecticides applied in-furrow had good efficacy from plant emergence to soil freeze up, approximately 7-8 weeks for the early seeding. Up to twelve weeks of control was observed for granular phorate and disulfoton on winter wheat in South

Africa (Du Toit 1984). Reduced control was observed when granular insecticides were applied with a cone-type drill. During application, granules were observed to slip by the cone distributor. At MSU-CARC in 1988, micro-tube injection of disulfoton provided adequate control, but carbofuran did not. Chlorpyrifos, applied as a spray, proved to be the superior post-emergence treatment. Post-emergence granular treatments did not effectively reduce RWA numbers. Activation of granules is dependent on adequate precipitation to leach the insecticide into the root zone. Adequate precipitation to leach insecticide for uptake is approximately 0.25 inch or more depending on soil type (Ron Brenchly, 1992, personal communication).

Organophosphate insecticides, disulfoton and phorate, applied in-furrow often produced lower standcounts than the untreated. This was especially true in the early and mid-seeding dates. Data collected on the early-seeding date in Molt 1989 showed leaf burning was evident at soil freeze up with the disulfoton treatment incorporated with the seed; a condition that may be attributed to increased insecticide uptake in the sandy type soils at Molt. Wallace (1962) showed that spring wheat seeds treated with disulfoton and phorate at 1 lb AI per bushel reduce standcounts by 90%. In-furrow applications of disulfoton and phorate with the seed may promote plant phytotoxicity thus reducing standcount.

Winter-hardiness of winter wheat plants is affected by the plant growth stage at the onset of winter (Cook and Veseth 1991). Winter wheat plants in the early seeding dates at each location had produced as many as 4-5 tillers by soil freeze up compared to plants in the late seedings that were from one leaf to one tiller. Winter wheat plants that are in the 3 or 4 leaf stage (Zadocks 13 to 14) and have a good root system are at the ideal stage of development for winter survival (Cook and Veseth 1991). Plants with many tillers, such as those seeded at an early date, harden less and remain more vulnerable to winterkill than younger plants (Cook and Veseth 1991). Seeding date studies showed standcounts taken in the spring were highest for the early seedings and lowest for late seedings. Winter survival was not affected by plant growth stage in these studies.

Spring Wheat Studies

Studies at each location showed that RWA densities increased from early to late seedings. RWA densities per tiller ranged from 0 to 2.3 for the early seeding, 0 to 75.0 for the mid seeding and 0 to 159.4 for the late seeding. In Colorado, if winter wheat is not infested in the autumn, research has shown that migrating RWA in the spring often infest late seeded winter wheat (less mature plants) to a greater magnitude than early seeded winter wheat (Walker et al. 1990).

Insecticide treatments applied to spring wheat did not significantly increase yields or test weights when compared to the untreated plots. In-furrow granular treatments significantly reduce RWA densities when compared to untreated plots up to 8 weeks after application, however acceptable (90%) control was not always obtained. These treatments allowed RWA to infest plants sometimes as early as four weeks after application. By mid July these treatments showed no control. Foliar applied chlorpyrifos was the superior post-emergence treatment, but aphid numbers quickly rebounded after two weeks post-treatment. Post-emergence granules did not reduce aphid numbers when compared to the untreated.

Seeding date studies at five agricultural research stations in Montana show that spring wheat yields are up to 25% lower if planted after May 10 (Juhnke & Baldridge 1983). Spring wheat yields in my seeding date studies usually yielded higher in the early and mid seedings and lowest in the late seeding. However, at the MSU-CARC site in 1990 spring wheat yields averaged 24.6, 26.5 and 23.8 bushels per acre for the early, mid and late-seeding dates, respectively. Late precipitation in July may have been utilized better by the mid and late-seeding dates to produce yields comparable to the early-seeding date. Aphid densities followed a predictable trend, on August 7, the early seeding date averaged 0.2 aphid per tiller compared to 42.3 and 55.7 for the mid and late seeding date.

Spring seeding studies were initially set up to evaluate seeding dates and insecticide efficacy for controlling RWA. After evaluating the information obtained a very important question arose. Did the RWA reduce yields in the seeding date studies? Results from seeding date studies were unable to show yield responses with the insecticide treatments applied. An aphid free control plot incorporated into my studies could have shown yield response to the level of RWA for each seeding date.

CONCLUSIONS

Delayed seeding, in areas with an extensive autumn RWA population, has proven to be a viable control strategy to reduce RWA infestations in autumn seeded winter wheat. However, if seeding dates are delayed to the point that plants do not reach the tillering stage before the onset of winter, a substantial yield reduction will occur. In these studies winter wheat yield was not adversely affected by RWA infestation levels up to 40%. Increased feeding pressure at an earlier growth stage (1-2 leaf) may have drastically changed the results. In general, establishing a good stand of winter wheat when moisture conditions allow may outweigh the benefits of delayed seeding to prevent RWA infestations.

The performance of autumn applied insecticides was enhanced by the application technique used. Granular insecticides applied in-furrow provided excellent control throughout the autumn growing season. Organophoshate insecticides applied in-furrow reduced winter wheat standcounts. Thus a modified application technique could be adapted to place insecticide granules above or below the seed with a soil buffer. Chlorpyrifos, applied as a spray, proved to be the superior post-emergence treatment. Poor control results were recorded at each location when granular insecticides were applied after crop emergence. This was likely due to inadequate precipitation to move the insecticide into the root zone.

Seeding spring wheat in early to mid April has proven to be an effective agronomic practice to enhance grain yields and to avoid major spring infestations of RWA. At planting, insecticide applied in-furrow showed decreased effectiveness in late June and early July. Data from aphid suction traps indicates that RWA flight activity begins in late June and peaks in late July and August. At spring planting, an insecticide starts to lose effectiveness at the same time the RWA flight begins. Post-emergence granules were not effective at all locations. Chlorpyrifos spray effectively reduces RWA densities, but late seeded spring wheat quickly becomes reinfested. Insecticide treatments were unable to keep plants aphid free during the growing season. This research was unable to determine the yield reduction caused by levels of RWA obtained in each seeding date. However, to avoid RWA infestations and shortfalls in precipitation, spring wheat should be seeded in early spring to maximize yields.

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