



Influence of a legume covercrop on volunteer wheat, the wheat curl mite, *Aceria tosichella* (K.) and wheat streak mosaic virus  
by Matthew Wyatt Carroll

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

The wheat curl mite (WCM) *Aceria tosichella* (Keifer) is the primary vector of wheat streak mosaic virus (WSMV), a sporadic and economically significant disease of wheat. Volunteer wheat in the wheat-fallow has been identified as the primary reservoir of the mite and virus and can perpetuate wheat streak mosaic reservoirs by sustaining the mite between spring and winter wheat crops. Replacing fallow with the incorporation of a non-host legume offers a possible control of volunteer wheat. A legume covercrop incorporated into the wheat-fallow was infested with varying densities of simulated volunteer wheat and examined for effects on the population dynamics of the WCM and the influence of WSMV on legume-wheat interactions in field and greenhouse trials. Significant treatment impacts were seen on mite populations in only 1 of 4 locations by years, that location was also the site with the overall greatest mite population. The one wheat and pea treatment combination in which mite populations showed significant increase in field trials occurred at the highest wheat-pea plant density. Environmental conditions were found to be directly influential on wheat curl mite populations and indirectly influential on the microenvironment in the canopy through mediation of the environment by wheat-pea treatments. Mite numbers were found to be strongly influenced by temperature and to a lesser extent by precipitation in the absence of peas. However, environmental influences changed in the presence of peas. Results obtained from the experiment indicate that the volunteer wheat densities studied in a pea crop do not adversely affect AWP biomass production at any wheat density in the field or in the greenhouse.

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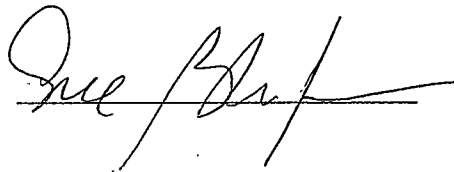
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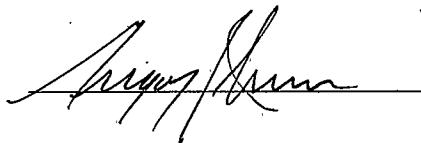
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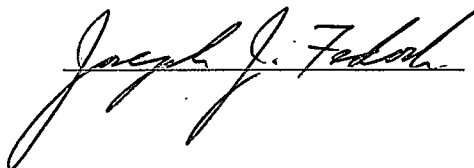
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**ABSTRACT**

The wheat curl mite (WCM) *Aceria tosichella* (Keifer) is the primary vector of wheat streak mosaic virus (WSMV), a sporadic and economically significant disease of wheat. Volunteer wheat in the wheat-fallow has been identified as the primary reservoir of the mite and virus and can perpetuate wheat streak mosaic reservoirs by sustaining the mite between spring and winter wheat crops. Replacing fallow with the incorporation of a non-host legume offers a possible control of volunteer wheat. A legume covercrop incorporated into the wheat-fallow was infested with varying densities of simulated volunteer wheat and examined for effects on the population dynamics of the WCM and the influence of WSMV on legume-wheat interactions in field and greenhouse trials. Significant treatment impacts were seen on mite populations in only 1 of 4 locations by years, that location was also the site with the overall greatest mite population. The one wheat and pea treatment combination in which mite populations showed significant increase in field trials occurred at the highest wheat-pea plant density. Environmental conditions were found to be directly influential on wheat curl mite populations and indirectly influential on the microenvironment in the canopy through mediation of the environment by wheat-pea treatments. Mite numbers were found to be strongly influenced by temperature and to a lesser extent by precipitation in the absence of peas. However, environmental influences changed in the presence of peas. Results obtained from the experiment indicate that the volunteer wheat densities studied in a pea crop do not adversely affect AWP biomass production at any wheat density in the field or in the greenhouse.

## INTRODUCTION

Wheat-summer fallow strip cropping is the most widespread dryland cropping system in the northern Great Plains. An estimated 6 million hectares are fallowed annually in the North American Great Plains region, stabilizing small grain production by conserving soil moisture and erosion in regions of sporadic or marginal rainfall. Weeds and volunteer plants from viable seed deposited during crop years can infest fallow areas whenever growing conditions are favorable. Weed management tactics are applied to fallowed strips to control weeds and volunteer grain. Methods of weed control in fallow strips include tillage and/or herbicides. There are few options for controlling seedling wheat plants in planted wheat fields.

The wheat curl mite (WCM), *Aceria tosichella* (K.) is a small mite, 150 to 250 $\mu$  in length, belonging to the family Eriophyidae. The WCM was recognized as an economic pest of wheat (*Triticum aestivum*) in 1953 when it was determined to be the vector of wheat streak mosaic virus (WSM) (Slykhuis 1953).

WSM is a disease in wheat that occurs sporadically in North America, Eastern Europe and Russia (Slykhuis 1967); it was first identified in Montana in 1954 on winter wheat (Bamford et al 1996). A combination of WCM feeding and the WSM disease produce symptoms that include leaf chlorosis of varying intensity, leaf roll, necrosis, stunting and plant death (Slykhuis 1955). Although the WCM is endemic to the north central Great Plains, outbreaks of WSM are responsible for substantial economic losses.

In 1988, WSM caused a 13% wheat yield loss, an estimated \$150 million loss in income, in Kansas (Sim and Willis 1988). During the last outbreak in Montana in 1993, WSM caused a \$12.7 million dollar loss to winter wheat revenues in Montana (P. Brukner, personal comm.).

The WCM is an efficient vector for the WSM disease but can acquire WSM only during immature stages by feeding on infected plant material (Slykhuis 1965). The virus is transmitted transtadially, so once virus acquisition occurs, the mite can transmit the virus through the remainder of its life (Slykhuis 1965). WCM have multiple generations and under ideal conditions WCM can increase quickly requiring only 10 days to complete their life cycle (Slykhuis 1955). Adult WCM are dispersed passively by wind and some insects and can spread readily into adjacent fields (Gibson and Painter 1957). The persistence of the virus through the life of the mite combined with the mites small size and ability to rapidly reproduce and spread into adjacent wheat fields (Slykhuis et al. 1957, Slykhuis 1962), makes the WCM an efficient vector of the WSM disease.

Sampling programs for detecting WCM have not been developed because disease outbreaks are sporadic and the ability to detect an economic population is costly and time consuming due to the small size of the WCM. Detection of the WCM relies on WSM disease symptoms. However, symptoms are not always a reliable means for identification of WSM, as the symptoms will vary with time, temperature, soil moisture, soil fertility and wheat variety (Staples and Allington 1956).

Presently, management strategies directed toward controlling the WCM emphasize cultural methods that prevent the buildup of host material that favors WCM population growth. Control of the WCM is focused on the elimination of the "green

bridge", the continuum of green host material for the WCM and WSMV that allows the carryover of the mite from one crop to the next. Continuously available green host material can result from variable planting times, germination of volunteer wheat or from wheat that germinates from mature seed heads shattered by hail. Germination and growth of host plants in fallowed areas can provide a green bridge for WCM during the fallow rotation between winter wheat crops or between winter wheat-spring wheat crops to a new winter wheat crop. In addition, hail and other weather events that cause mature seed heads in wheat fields to break, drop to the ground and germinate can produce a flush of seedling wheat plants within a wheat field that can also be utilized by the WCM. Delaying winter wheat planting breaks the "green bridge" and avoids WCM infestation from spring planted crops to fall seeded winter wheat (Slykhuis 1955, Bamford et al. 1996). Pest management programs for the WCM have been limited because, (i) there are no sampling procedures for monitoring WCM and (ii) once disease symptoms are observed it is too late to control the WCM vector.

A survey of potential annual and perennial grass hosts in Montana found few resident grasses that can act as an alternative host for either the WCM or WSM or both (Brey 1998). However, resident grasses in Montana are not thought to play a significant role in WSM epidemiology because of poor host switching by the WCM between different host plants (Rosario and Sill 1965, Brey 1998). Volunteer wheat in the wheat fallow has been identified as the primary reservoir for the WCM and WSM and is considered the most significant factor in WSM epidemiology (Brey 1998).

Currently, few alternate crops are included in the dryland cereal cropping system. Diversifying the wheat-summer fallow strip cropping system offers several benefits,

including breaking insect and disease cycles, improving soil fertility and offering growers alternative enterprises for greater economic stability. Climatic constraints limit the selection of alternative crops that can be produced economically in our region. Research conducted at MSU has identified legumes adapted to our region, such as Austrian winter peas (*Pisum sativum* L.), that are compatible with the dryland cropping system in the north central Great Plains region and are capable of replacing summer fallow in the wheat-fallow system (J.R. Simms 1994).

Incorporation of alternative non-host crops into the wheat-fallow strip cropping system offers a possible cultural method for controlling WSM through plant competition, between host and non-host plants, and through non-host influence on WCM population dynamics. This study investigates the impact of incorporating a non-host covercrop into fallow ground on the population dynamics of the WCM and incidence of WSM. The objectives of the study were twofold, (i) investigate the impact of intercropping a legume with simulated populations of volunteer wheat on the population dynamics of the wheat curl mite *Aceria tosichella* (K.) and (ii) investigate how infection of wheat by WSM effects plant-plant interactions in a legume-wheat intercrop.

Life History of *Aceria tosichella* (K.)

The wheat curl mite was first described by Keifer (1936) as *Aceria tulipae* (K.) collected from tulips in California. In 1970, Shevtchenko showed that the name *tulipae* should only apply to mites developing on Liliaceae and described a new species *Aceria tritici* for mites that utilize wheat as a host plant. However, in 1969 Keifer described an identical *Aceria* species, *Aceria tosichella*, collected from wheat in Yugoslavia. Because *Aceria tosichella* was published prior to *Aceria tritici*, the name *Aceria tosichella* takes priority by the Rules of Zoological Nomenclature.

Members of the family Eriophyidae are minute, soft-bodied, cigar shaped mites averaging 150 to 250 $\mu$  in length and have two pair of legs located at the anterior end of the body. The WCM can complete development in 6-7 days and averages 10 days from egg hatch to cessation of egg lay (Slykhuis 1955). Reproduction is primarily parthenogenetic and can begin as early as 7 days after egg hatch at 24°C to 27°C. Females lay an average of 12 eggs that incubate for 3 days (Slykhuis 1955, Staples and Allington 1956). *Aceria tosichella* has two nymphal instars. Each individual nymphal stage lasts 1½ days with ¾ of a day for molting (Staples and Allington 1956). The second nymphal stage ends in a resting period or "pseudopupa" during which the genitalia of the female form and protrude through the body wall (Slykhuis 1962). Males can occur but are rarely seen (Slykhuis 1962). *Aceria tosichella* (K.) transmits WSM easily between healthy wheat hosts. Eggs of the WCM do not carry WSM (Slykhuis

1965). Nymphs can acquire the virus by feeding on infected plant material for thirty minutes or longer, while adults do not seem capable of acquiring the virus (Slykhuis 1965). However, the virus is transmitted transtadially and once a mite has acquired the virus it is infective for life.

Eriophyid mites rely on passive dispersal. WCM are primarily wind dispersed but can also be moved by birds, insects and other carriers or mechanically by distribution of infested plant material. Gibson and Painter (1957) considered WCM dispersal by aphids as a secondary means of WCM dispersal but felt it could be a significant factor in placing WCM directly onto volunteer wheat or other suitable hosts.

Eriophyids are an economically important family and damage plants by the formation of galls, blisters, bud swelling, rolled leaves, russeting and erineum (Keifer et al. 1982). Although WCM do cause direct damage to their host plants, they are important as a vector of wheat streak mosaic (WSM) and high plains virus (HPV). Symptoms of WCM infestation are often masked by WSM disease symptoms. Feeding by WCM on wheat causes the margin of the wheat leaves to roll inward, forming a tightly rolled tube that catches the tip of the next emerging leaf causing it to form a loop. Orlob (1966) found that WCM prefer to feed in tightly rolled leaves or in the leaf whorl. The tightly rolled leaf has higher humidity (Orlob 1966) and offers some protection from adverse environmental conditions and natural enemies.

WCM prefer to feed on the newest growth of the plant. Immature WCM feed parallel to the leaf in the adaxial groove between the leaf veins. Adult WCM either occupied the same position or lay perpendicular to the vein, bending down to feed in the adaxial groove (Orlob 1966). WCM feed on cells from both sides of the groove and on

cells located at the bottom of the groove. WCM penetrate epidermal cells by firmly attaching to the leaf surface with their terminal pads and contracting the rostra, forcing their stylets into the leaf tissue (Orlob 1966).

Strains of the WCM have been identified that were collected from and adapted to wheat (*T. aestivum*), western wheat grass (*Agropyron smithii*), onion (*Allium cepa*) (Rosario and Sill 1965) and corn (*Zea mays*) (Nault and Briones 1967). Rosario and Sill (1965) reported that WCM occurring naturally on wheat adapted with difficulty to *A. smithii* and onion but adapted easily to corn. Their research indicated that most individuals died rapidly when cross infecting from other grass hosts to wheat. A few WCM fed and survived for short periods but did not reproduce and a minority of WCM survived and reproduced with their progeny generally surviving longer.

*A. tosichella* feeds on and damages a variety of cultivated and resident perennial and annual grass plants. Historically, extensive surveys have been performed to evaluate the suitability of a variety of perennial and annual grass species as hosts for the WCM and WSM and their importance in WSM epidemiology. These surveys were based on the assumption that resident perennial and annual grasses played an important role in the epidemiology of WSM by influencing the density and distribution of the WCM population and by providing an overwintering bridge for the WCM. However, in contrast to previous survey results, research conducted at Montana State University by Brey (1998) has found few resident perennial grasses that are suitable hosts for the mite and virus. Grass species positive for either WSMV or WCM (Table 1), including resident grasses found positive previous to Brey (1998), and grasses that are negative (Table 2) are summarized. For a resident grass population to be an important alternate

host in WSM epidemiology, several requirements must be met. Alternate host grasses must (i) function as an overwintering bridge for WSM, (ii) support sufficient WCM for an epidemic to occur, (iii) occur in sufficient densities near a susceptible crop, (iv) emerge before wheat maturation and survive until fall emergence of wheat crops, (v) be suitable carrier of WSM and (vi) allow multiplication of the virus to occur. (Christian and Willis 1993).

Historically, perennial grasses were considered the primary host of the WCM because they could provide a continuum of living tissue to serve as a green bridge between crops. However, perennial grasses are not implicated in major epidemics (Slykhuis 1965). Perennial grass may be a good host for the WCM but will not support WSMV or will support the virus but not the WCM vector (Staples and Allington 1956, Christian and Willis 1993). Host quality must also be sufficient for successful WCM reproduction to contribute to an epidemic.

Cultivated wheat crops, volunteer wheat and other annual plants are the major hosts involved in the epidemiology of WSM outbreaks (Slykhuis 1965). Resident perennial and annual grasses are considered native reservoirs but are not thought to influence disease propagation (Slykhuis 1955). While small numbers of mites have been detected on grass species considered to be poor hosts, it is considered unlikely that such small numbers could establish a successful disease foci in either volunteer or winter wheat (Staples and Allington 1956). This is further supported by the findings of Brey (1998) who found no resident perennial or annual grasses other than cultivated grains that could play a significant role in WSM epidemiology in Montana (C. Brey, personal comm.).

**Table 1. Annual and perennial grasses surveyed and found positive for WSMV and/or WCM.**

	<u>Scientific name</u>	<u>Common name</u>	<u>WSMV</u>	<u>WCM</u>	<u>Authority</u>
<u>Cultivated</u>	<i>Avena sativa</i> (L.)	Oats	Yes	No	McKinney (1937), Slykhuis (1952)
	<i>Hordeum vulgare</i> L.	Barley	Yes	Yes	McKinney (1937), Slykhuis (1952), Sill (1953)
	<i>Panicum miliaceum</i>	Pearl millet	Yes	No	Sill and Agusiobo (1955)
	<i>Panicum ramosum</i>	Pearl millet	Yes		Sill and Agusiobo (1955)
	<i>Secale cereale</i> L.	Rye	Yes	Yes	Slykhuis (1952)
	<i>Setaria italica</i> (L.) Beauv.	Italian millet	Yes	Yes	Slykhuis (1952), Sill and Agusiobo (1955)
	<i>Sorghum vulgare</i> Pers.	Sorghum cultivars	Yes		Harvey and Seifers (1991)
	<i>Triticum dicoccum</i> Schrank.	Wheat	Yes	Yes	Slykhuis (1955)
	<i>Triticum durum</i> Desf.	Wheat	Yes	Yes	Slykhuis (1955)
	<i>Triticum aestivum</i> L. (spring types)	Spring wheat	Yes	Yes	Slykhuis (1955)
	<i>Triticum aestivum</i> L. (winter types)	Winter wheat	Yes	Yes	Slykhuis (1955)
	<i>Zea mays</i> L.	Corn	Yes	Yes	McKinney (1937), McKinney and Fellows (1951), Slykhuis (1952, 1955) Sill and Agusiobo (1955)
	<u>Annuals</u>	<i>Aegilops crassa</i> Boiss.		Yes	
<i>A. cylindrica</i> Host		Jointed goatgrass	Yes		McKinney (1937), McKinney and Fellows (1951)
<i>A. ovata</i> L.			Yes		McKinney (1937), McKinney and Fellows (1951)

	<i>A. triuncialis</i> L.	Barbed goatgrass	Yes		McKinney (1937), McKinney and Fellows (1951)
	<i>A. ventricosa</i> Tausch		Yes		McKinney (1937), McKinney and Fellows (1951)
	<i>Bromus japonicus</i> Thunb.	Japanese chess	Yes	No	McKinney (1937), McKinney and Fellows (1951), Slykhuis (1952), Brey (1998)
	<i>B. secalinus</i> L.	Cheat	Yes	No	Slykhuis (1952)
	<i>B. tectorum</i> L.	Downy chess	Yes	No	Slykhuis (1952), Sill and Connin (1953), Brey (1998)
	<i>Digitaria ischaemum</i> Schreb.	Smooth crabgrass	Yes	No	McKinney (1937), McKinney and Fellows (1951)
	<i>D. sanguinalis</i> (L.) Scop.	Crabgrass	Yes		Slykhuis (1952)
	<i>Echinochloa crusgalli</i> (L.) Beauv.	Barnyard grass	Yes	Yes	Slykhuis (1952), Sill and Connin (1955)
	<i>Eragrostis cilianensis</i> (All.) Lutati	Stinkgrass	Yes	Yes	Slykhuis (1952)
	<i>Haynaldia villosa</i> Schur.		Yes		McKinney (1937), McKinney and Fellows (1951)
	<i>Panicum capillare</i> L.	Ticklegrass	Yes	No	Slykhuis (1952)
	<i>Phalaris paradoxa</i>		Yes		McKinney (1937), McKinney and Fellows (1951)
	<i>Setaria verticillata</i> (L.) Beauv.	Bur bristlegrass	Yes	Yes	Slykhuis (1952)
	<i>Setaria viridis</i> (L.) Beauv.	Green foxtail	Yes	Yes	Slykhuis (1952), Sill and Connin (1953), McKinney (1937), McKinney and Fellows (1951)
<b>Perennials</b>	<i>A. cristatum</i> (L.) Gaertn.	Crested wheatgrass	Yes	No	Brey (1998)
	<i>Agropyron lasianthum</i> Boiss.		Yes		McKinney and Fellows (1951)
	<i>A. trichophorum</i> (Link) Richt.		Yes		McKinney and Fellows (1951)
	<i>Bromus inermis</i> Leyss.	Smooth brome	Yes	Yes	Brey (1998)
	<i>Elymus canadensis</i> L.	Canada wild ryé	Yes		McKinney (1937), McKinney and Fellows (1951), Sill and

				Connin (1953)
<i>E. condensatus</i> Presl.	Giant wild rye	Yes		McKinney (1937), McKinney and Fellows (1951)
<i>E. giganteus</i> Vahl.		Yes		McKinney (1937), McKinney and Fellows (1951)
<i>E. virginicus</i> L.	Virginia wild rye	Yes		McKinney (1937), McKinney and Fellows (1951)
<i>Eragrostis trichodes</i> Nutt.	Sand lovegrass	Yes		McKinney (1937), McKinney and Fellows (1951), Sill and Connin (1953)
<i>Poa bulbosa</i> L.	Bulbous bluegrass	Yes		McKinney (1937), McKinney and Fellows (1951)
<i>P. compressa</i> L.	Canadian bluegrass	Yes		McKinney (1937), McKinney and Fellows (1951)
<i>P. pratense</i> L.	Kentucky bluegrass	Yes	Yes	Brey (1998)
<i>Stipa Comata</i>	Needle & Thread grass	Yes	No	Brey (1998)
<i>S. robusta</i> Scribn.	Sleepy grass	Yes		McKinney (1937), McKinney and Fellows (1951)
<i>S. viridula</i>		Yes	No	Brey (1998)

**Table 2. Cultivated and weedy and resident perennial and annual grasses surveyed and found negative as hosts for WSMV.**

	<u>Scientific name</u>	<u>Common name</u>	<u>Authority</u>
<u>Cultivated</u>	<i>Panicum glaucum</i>	Pearl millet	Sill and Agusiobo (1955)
	<i>Saccharum officinarum</i> L.	Sugar cane	Mckinney (1937), Sill and Agusiobo (1955)
	<i>Sorghum vulgare</i> Pers.	Sorghum	McKinney and Fellows (1951), Slykhuis (1952), Sill (1953), Sill and Agusiobo (1955)
<u>Perennials</u>	<i>Agropyron Cillare</i> (Trin) French.		Slykhuis (1952)
	<i>A. cristatum</i> (L.) Gaertn.	Crested wheatgrass	Slykhuis (1952),
	<i>A. dasystachyum</i> (Hook.) Scribn.	Thickspike wheatgrass	Slykhuis (1952)
	<i>A. desertorum</i> (Fisch.) Schult.	Desert wheatgrass	Slykhuis (1952)
	<i>A. elongatum</i> (Host.) Beauv.	Tall wheatgrass	Slykhuis (1952)
	<i>A. inerme</i> (Scribn. & Smith) Rydb.	Beardless wheatgrass	Slykhuis (1952)
	<i>A. intermedium</i> (Host.) Beauv.	Intermediate wheatgrass	Slykhuis (1952)
	<i>A. junceum</i> (L.) Beauv.		Slykhuis (1952)
	<i>A. pertense</i> (C. A. Myer) Nevski		Slykhuis (1952)
	<i>A. repens</i> (L.) Beauv.	Quackgrass	Slykhuis (1952), Sill and Connin (1953)
	<i>A. rigidum</i> Beauv.		Slykhuis (1952)
	<i>A. smithii</i> Rydb.	Western wheatgrass	Sill and Connin (1953)
	<i>A. trachycaulum</i> (Link) Malte.	Slender wheatgrass	Slykhuis (1952)
	<i>A. trichophorum</i> (Link) Richt.	Stiffhair wheatgrass	Slykhuis (1952)
<i>Andropogon gerhardi</i> Muhl.	Big bluestem	Sill and Connin (1953)	

<i>A. scoparius</i> Michx.	Little bluestem	Sill and Connin (1953)
<i>Bouteloa</i> spp.	Gramma grass	Sill and Connin (1953)
<i>Bromus inermis</i> Leyss.	Smooth brome	Slykhuis (1952)
<i>Cenchrus pauciflorus</i> Benth.	Sandbur	Sill and Connin (1953).
<i>Festuca rubra</i> L.	Red fescue	Slykhuis (1952)
<i>Oryzopsis hymenoides</i> (Roem& Schult.) Ricker	Indian ricegrass	McKinney (1937), McKinney and Fellows (1951)
<i>Panicum virgatum</i> L.	Switchgrass	Sill and Connin (1953)
<i>Phalaris arundinacea</i> L.	Reed Canarygrass	Slykhuis (1952)
<i>Phleum pratense</i> L.	Timothy	Slykhuis (1952)
<i>Poa pratense</i> L.	Kentucky bluegrass	Slykhuis (1952)
<i>P. stenantha</i> Trin.		McKinney (1937), McKinney and Fellows (1951)
<i>Sorghastrum nutans</i> (L.) Nash.	Indiangrass	Sill and Connin (1953)
<i>Sorghum halepense</i> (L.) Pers.	Johnsongrass	Sill and Connin (1953)
<i>Sorghum vulgare</i> Pers.	Sorghum	Sill (1955)
<i>Avena fatua</i> L.	Wild oats	Slykhuis (1952)
<i>Eleusine indica</i> (L.) Gaertn.	Goosegrass	Sill and Connin (1953)
<i>Hordeum jubatum</i> L.	Wild barley	Slykhuis (1952)
<i>Setaria lutescens</i> (Weigel) Hubb.	Yellow foxtail	Slykhuis (1952)

Annuals

Abiotic factors influence the population dynamics of the WCM and play a role in WSM epidemiology. Slykhuis (1955) found a positive relationship between increasing relative humidities and WCM survivorship at 5° C, 15° C and 25° C. Staples and Allington (1956) suggest that the WCM may be wind dispersed during warm periods in the winter and that WCM dispersal could occur throughout the year but could find no significant correlation between temperature and WCM dispersal. However, Nault and Styer (1969) did find a significant relationship between temperature and WCM dispersal in research on eriophyid mite dispersal. Events such as rainfall and hail can also influence the population dynamics of the WCM. Hail can shatter mature seed heads prior to harvest and provide a flush of volunteer wheat that can act as a "green bridge" between infected spring and winter wheat crops and can also initiate new tillering on hailed wheat plants (Bamford et al. 1996). Both cases provide new plant growth for the establishment of a WCM population. Other factors such as plant morphology can also influence WCM population dynamics. Harvey and Martin (1980) found that highly pubescent wheat had higher infestations of viruliferous WCM than glabrous varieties. Increased pubescence may alter the microclimate of the phylloplane resulting in higher humidity near the leaf surface.

Because of multiple generations, the WCM is important in perpetuating large virus and vector reservoirs under favorable conditions within and between years and is capable of rapidly spreading WSM from adjacent infected sources (Slykhuis et al. 1957, Slykhuis 1962). Fall infected winter wheat provides an overwintering refuge for the WCM and WSMV. The following spring the mites multiply and disperse, infecting any

suitable hosts, especially less mature spring or volunteer wheat, perpetuating the mite and virus reservoirs in green bridge plant hosts for infection of fall sown crops (Slykhuis 1962). For WCM populations to reach outbreak levels, conditions that favor WCM population growth and dispersal need to be present. Specifically, the WCM must have (i) immature host plants or host tissue to infest (Slykhuis 1955), (ii) warm conditions that allow a population increase followed by cooler conditions that favor dispersal (Bamford et. al. 1996), and (iii) sufficient density of a host or alternate host to maintain a WCM population throughout the summer (Christian and Willis 1993).

#### Wheat Streak Mosaic Virus

Matthews (1991) formally defined a virus as a set of one or more nucleic acid template molecules, normally encased in a protective coat or coats of protein or lipoprotein, with the ability to organize its own replication only within suitable host cells. Virus replication is (i) dependent on the host's protein synthesizing machinery, (ii) uses host cell's resources, (iii) located within the host cell not separated by a lipoprotein bilayer membrane and (iv) continually giving rise to virus variants through various kinds of change in the viral nucleic acid (Matthews 1991). Virus symptoms in plants exhibit a variety of macroscopic symptoms that include: chlorotic lesions from loss of chlorophyll and other pigments, reduction in plant size, mosaic patterning of the early leaf stage, yellowing of leaf tissue, development of rings on leaf or fruit, death of plant tissue, organs or whole plant, developmental abnormalities, wilting, reduced nodulation and

genetic effects such as an increase in genetic mutation or genetic abnormalities (Matthews 1991). Other agents capable of causing virus-like symptoms include: toxins produced by arthropods, cellular parasites, genetic abnormalities, nutritional deficiencies, high temperatures, hormone damage, pesticides and air pollutants (Matthews 1991).

Viral diseases have cytological effects that impact cell structure or virus-induced structures in the cytoplasm. The cytopathological effect on cell structure varies but can impact cell nuclei, mitochondria, chloroplasts, cell walls, bacteroidal cells, myelinlike bodies or cause cell death (Matthews 1991). Viruses affect cell nuclei by inducing intracellular inclusions, influencing the function of the nucleolus or altering the physical form of the nucleus despite lack of visible virus reproduction. Virus-induced structures resulting from a viral infection include crystalline inclusions that consist mainly of virus particles that accumulate in an infected cell then form crystalline arrays or pinwheel inclusions. The formation of cylindrical inclusions in the cytoplasm of effected cells is a characteristic of potyviruses such as WSMV (Matthews 1991, Shukla et al. 1994).

Frequently, disease symptoms expressed by the plant reflect histological changes within the plant. Symptoms such as necrosis are variable in both timing of expression and in the tissues or organs it impacts and commonly occur in combination with other histological changes (Matthews 1991). Hypoplasia, the incomplete or arrested development of an organ or plant part and hyperplasia, an abnormal increase and enlargement in the number of cells in an organ or a tissue with consequent enlargement, are two histological changes that are common to diseased plants. Plants expressing mosaic symptoms usually show hypoplasia in the yellowed areas. Hypoplasia results in a

thinner lamina than in the green areas, decreased differentiation of the mesophyll cells causing a reduction in chloroplast formation and the reduction or absence of intercellular spaces (Matthews 1991). Hyperplasia can cause enlarged cells near the vein, cell division in differentiated cells, or the abnormal division of cambial cells. Enlarged cells near the vein are at least partly responsible for vein-clearing symptoms caused by some viruses (Matthews 1991).

The effects of viruses like WSMV on plant metabolism are extremely variable and are subject to a range of biotic and abiotic conditions. Plant stage, diurnal and seasonal variation and wound response all interact to provide a continuum of changing conditions that determines the effect a virus has on the host. Viral impact on a hosts metabolism include: changing plant membranes, alteration of carbohydrate synthesis or translocation or both, changes in respiration rate, reduction in photosynthetic activity, reduced transpiration, a decrease in auxin and gibberellin production, an increase in abscisic acid levels, an increase in one or both amides glutamine and asparagine, and a reduction in leaf pigments (Matthews 1991).

There are numerous vectors that transmit plant viruses. However, within the invertebrates there are species in only two phyla, the Nematoda and Arthropoda, who have many members that feed on terrestrial plants and have species that transmit viral diseases (Matthews 1991). Ninety-nine percent of all known vectors of plant viruses are insects (Harris 1981).

Only Hexapoda and Arachnida, of the Arthropoda, contain members that feed on plants. The important hexapod vectors of plant viruses are considered to be in the

Coleoptera, Thysanoptera and Homoptera (Harris 1981, Matthews 1991). Among the Arachnida two families within the Acari, Tetranychidae and Eriophyidae, have been found to vector viruses (Harris 1981, Matthews 1991).

Virus transmission from the invertebrate vector to a host can occur mechanically, by feeding or through injury to the plant. The piercing-sucking mouthparts of the homopterans makes them the most important vectors of plant viruses and allows viruses to be transmitted easily from diseased tissues or cells to healthy host plants (Matthews 1991). Eriophyid mites are known to transmit at least six viruses by puncturing the plant cells and sucking out the contents; transmission occurs when virus laden saliva is ejected during probing and feeding. *A. tosichella* is known to transmit three viruses simultaneously, wheat streak mosaic, high plains disease and wheat spot mosaic (Matthews 1991). There is no evidence of virus replication within mite vectors. However, WSMV is circulative based on finding WSMV particles in the midgut, body cavity and salivary glands, non-propagative within *Aceria tosichella* and is persistent for the lifetime of the mite (Matthews 1991).

Mosaic diseases of wheat were first observed in the United States in the spring of 1919 in fields of winter wheat near East St. Louis and Granite City, IL. When first diagnosed, the disease was mistakenly identified as take-all (McKinney 1937). Wheat streak mosaic virus (family Potyviridae), was first described in 1937 by McKinney (McKinney 1937). Slykhuis (1953) identified the wheat curl mite, *Aceria tosichella* (K.) as the primary vector for WSM in 1953. Although the WCM is the primary vector for WSM, some virus transmission did occur in experiments with leafhoppers (Slykhuis

1952) and aphids (McKinney 1937). WSM currently occurs in North America, Eastern Europe and Russia (Slykhuis 1967).

Abiotic factors such as temperature and biotic factors such as age of a host affect the incidence, severity and survival of WSMV in plant tissues at the time of inoculation. Temperature influences the duration of WSMV infectivity and incubation time. WSMV remains infective for up to 8 months at 4°C and -20°C and for approximately 1 month at room temperature (Sill 1953). Incubation period of WSMV within a host plant decreases with increasing temperatures. Sill and Fellows (1953) showed that average incubation time in wheat was 5 days with an ambient air temperature at 27.8°C, 7 days at 23.9°C, 9 days at 20°C, 15 days at 15.6°C and 23 days at 7.8°C with a soil temperature of 7.8°C.

Plant age influences the severity of the WSM disease. Slykhuis (1952) and observed that wheat plants infected at an early plant growth stage were affected more severely by the disease. Sill and Fellows (1953) reported that plants mechanically inoculated early in the two-leaf stage showed a lower incidence of infection but once infected were highly susceptible to damage by the virus and became severely stunted with strong mosaic symptoms. Plants inoculated at the third leaf stage to the 3-4 tiller stage were all inoculated successfully and always showed severe disease symptoms. However, infective WSMV was not found in wheat stubble or in the leaves of brown, fully dead plants (Sill 1953). This was confirmed by Slykhuis (1952) who showed that WSMV lost its infectivity quickly after the normal death of the host and found that infected green tissues stored under moist conditions lost infectivity more quickly than when air dried or desiccated. There is no evidence for WSM transmission by soil from

diseased wheat fields, by seed from diseased wheat, abrasive root contact, normal leaf contact in the greenhouse between diseased and healthy plants or through gentle handling (Slykhuis 1952).

Wheat that is heavily infected at early plant stages exhibits a variety of symptoms. Early symptoms usually begin with a faint green chlorotic mottling of the leaves that runs parallel to the leaf veins. The chlorotic mottling becomes more pronounced over time and eventually leads to complete necrosis. Later symptoms include visible plant stunting and extreme reduction in tiller height between tillers from the same plant, recumbent plant growth, complete or partial seed head sterility, poor kernel filling and in severe cases little or no seed head production in infected plants (Slykhuis 1952, Staples and Allington 1956, Atkinson and Grant 1967). Severely stunted plants may die without producing seed, severely impacting yield (Slykhuis 1965).

### Cropping System

The most common dryland cropping system in the semi-arid Great Plains and Intermountain West farm region is an alternating wheat-summer fallow strip cropping system. This system relies on the fallow rotation to store soil moisture for a subsequent grain crop. However, fallowed areas must be managed for weeds to prevent depletion of soil moisture. Management relies on tillage or herbicides. Traditionally, this cropping system is dominated by cereal grain production. Alternative crops such as oil seed, or pulse crops are infrequently incorporated into the fallow rotation.

Legume crops, adapted to the Northern Great Plains, offer a way to diversify the wheat summer-fallow strip cropping system and offer benefits in pest management, soil fertility and soil structure (Risch et al. 1983, Reynolds et al. 1994). Legumes seeded into a fallow strip can benefit growers by reducing insect damage, breaking insect and disease pest cycles, improving soil fertility and reducing nitrogen applications. Additionally, legumes offer flexibility in cropping system management to growers as forage or seed crops or by use as a green manure through early incorporation. The flexibility of the cropping system allows growers to make or change previous management decisions in response to environmental and economic changes. Other positive responses that are attributed to green manure or legume intercrops include increased yields of subsequent cash crop (Oyer and Touchton 1990, Bauer et al. 1993, Torbert et al. 1996) and nitrogen fixation by legumes in intercropped wheat and barley (Reynolds et al. 1994).

Legumes used as green manure crops can reduce the amount of applied chemical nitrogen fertilizers by fixing atmospheric nitrogen into the soil. Rates of nitrogen fixation and the amount of nitrogen provided by incorporating plant material into the soil vary by legume species. Research by Mahler and Hemamda (1993) on the nitrogen fixation ability of Austrian winter peas in Idaho (AWP) (*Pisum sativum* (L.) Poir) incorporated three rates of semi-dried AWP material (1, 2 and 3 Mg ha<sup>-1</sup>) into the soil. The incorporated AWP material added 28-29 kg ha<sup>-1</sup>, 56-58 kg ha<sup>-1</sup> and 84-87 kg ha<sup>-1</sup> of nitrogen to the soil at 1, 2 and 3 Mg ha<sup>-1</sup> respectively recovering an estimated 77% of available nitrogen from the AWP material after incorporation. This compares favorably with earlier research conducted by Mahler and Auld (1989) that evaluated three cropping

rotations. Their results showed incorporating AWP as a green manure resulted in a nitrogen fertilizer equivalent of  $94 \text{ kg ha}^{-1}$  compared to  $68 \text{ kg ha}^{-1}$  left by the summer fallow rotation. Although the summer fallow rotation is an economical rotation it eventually depleted the finite organic matter component of the soil. Research conducted by Reddy et al. (1994) and Sweeny and Moyer (1994) on legume cover crops also indicates nitrogen availability from cover crops.

The organic matter added to the soil by a crop contributes to the physical structure and fertility of the soil and helps prevent erosion. Legume cover crops or intercrops aid in stabilizing erodible soil. Legumes intercropped with wheat or barley provide increased ground cover that partially retards soil erosion and can physically improve the soil characteristics, stabilizing erodible soils by increasing soil organic matter (Biederbeck et al. 1993, Decker et al. 1994, Reynolds et al. 1994 Tanaka et al. 1997).

Soil moisture restricts the choice and management of cover crops. Cover crop biomass production is strongly influenced by variable or sporadic precipitation (Tanaka et al. 1997). Because water is a limiting factor, research has been done to evaluate water use by annual legumes used as green manure in a dryland cropping system. Biederbeck and Bouman (1994) evaluated water use of and residual soil moisture for black lentil, Tangier flatpea, chickling vetch and feed pea cover crops. They reported that in wet years legume cover crops significantly reduced downward water movement compared with fallow and lowered the risk of nutrient leaching and increased salinization. In addition, Biederbeck and Bouman (1994) report that legumes only used water from the top 0.6 m of the soil. By tilling the legumes into the soil, water content in the top 0.6 m

increased until freeze up. They concluded that early incorporation of legumes for soil-water conservation was essential for replacing fallow with green manures.

Cover crops can aid in breaking disease and pest cycles. Risch et al. (1983) noted that by diversifying an agricultural habitat, the density of herbivore populations is frequently lowered. Vegetative heterogeneity that involves species mixtures and spatial arrangements within a field, has a major influence on insect population growth and results in islands or patches of favorable habitats for the insect (Power and Kareiva 1990). Because monophagous insect herbivores tend to be less abundant in plant communities of higher vegetative diversity, several hypotheses have been offered to explain why the presence of a non-host plant affects herbivore abundance. One proposed hypothesis is that insects are confused by the odors of non-host plants and are unable to find their host plants. This explanation is largely unsupported by evidence and is not applicable to many homopteran insects (Power and Kareiva 1990). A more accepted hypothesis is that lower numbers of monophagous herbivores in diverse habitats is a result of non-host plants affecting the emigration rates of herbivores rather than their colonization rates (Powers and Kareiva 1990). Additionally, a diversified agroecosystem would provide benefits over monocultures that include land conservation, reduced pesticide usage and decreasing pesticide resistance (Risch et al. 1983).

Lower numbers of monophagous herbivores in a diverse agricultural habitat should result in less damage to crop plants. Ampong-Nyarko et al. (1994) evaluated cowpea-sorghum intercrops on stem borer yield loss and reported a 28% loss to sorghum production in a monocrop compared to a 15% yield loss in intercropped sorghum and a

94% loss to a cow pea monocrop compared to a 51% loss when intercropped.

Additionally, Riggin-Bucci and Gould (1997) showed that diamondback moth populations in toxic and nontoxic plant mixtures may decline even when populations in nontoxic monocrop fields are increasing.

The theory of managing plant diseases through agricultural diversification is similar to the theory used for arthropod pests. In a review of diseases under conservation tillage, Baily (1996) concluded that eliminating monocultures and diversifying crops in a rotation would lower the risk of diseases in cereal and oilseed crops. Yield loss in wheat from common root rot was 11% less in diverse rotations such as wheat-canola-spring wheat-lentil, spring wheat-pea-spring wheat-lentil, spring wheat-flax-winter wheat-peas, wheat-canola-canary seed-lentil than in a continuous wheat crop. Wheat loss to leaf spot infection was 28% greater in consecutive wheat crops than in rotations where wheat was not grown consecutively (Baily 1996). In experiments on aphid-vectored potyviruses in monocultures and polycultures of gamagrass spp., Piper et al. (1996) reported a decrease in the severity and incidence of disease on eastern gamagrass in two species mixtures with wildrye and two species mixtures with bundleflower and three species mixtures with bundleflower and wildrye. Research conducted by Ristaino et al. (1996), Akanda and Mundt (1997), and Colbach et al. (1997) also support reduced disease incidence through diversification of cropping systems.

Often there is a negative correlation between host density and disease incidence when infections result from a primary cycle and inoculum is limiting. The incidence of many aphid-vectored diseases is negatively correlated with host plant density. As host

density is increased, the number of infected plants increases at a slower rate than uninfected plants in the population, resulting in a lower proportion of infected plants (Mundt 1990).

Incorporation of annual plants, such as legumes, into the dryland wheat summer-fallow strip cropping system can be an important management strategy for insect and disease control. The primary WCM and WSM reservoir is volunteer wheat in the fallowed areas, annual and perennial grasses are not significant reservoirs in WSM epidemiology because of the lack of host cross infectivity by the WCM. Diversification of the fallow by incorporating a non-host of the WCM should decrease WCM populations and reduce the incidence of plant diseases, specifically WSM, while increasing soil fertility and soil structure. Incorporation of alternative crops into the wheat summer-fallow strip cropping system will offer growers a cropping system that can be flexibly managed for current economic and environmental conditions while reducing applications of chemical fertilizers such as nitrogen.

## GREENHOUSE RESEARCH

### Introduction

Diversifying the traditional wheat summer-fallow strip cropping system offers several benefits including breaking insect and disease cycles, improving soil fertility and greater economic stability by offering growers alternative enterprises. Although climatic constraints limit the selection of alternative crops that can be produced economically in our region, research conducted at MSU has identified legumes adapted to our region, such as Austrian winter peas (*Pisum sativum* L.) (AWP). Incorporation of a non-host legume, for both WCM and WSMV, into wheat fallow offers a potential cultural method for controlling WSM.

This study investigates WCM population dynamics and plant interactions using simulated volunteer wheat seeded into two different seeding rates of AWP and in wheat alone plots. The controlled conditions of the greenhouse should remove or minimize the influence of abiotic factors on WCM population dynamics and on wheat-pea interactions. Controlling inputs such as watering, temperature and fertilizer should allow the WCM population to develop and disperse under less variable conditions. The interaction between the wheat and peas under non-stressed greenhouse conditions was evaluated for

competition effects both in the presence and absence of WSM. Results obtained from the greenhouse experiments will offer insight into larger scale field trials under conditions more typical of the Northern Great Plains.

### Materials and Methods

Greenhouse experiments were conducted at the Montana State University Plant Growth Center, Bozeman Montana. Six boxes measuring 0.91 m by 3.04 m by 0.20 m deep were divided into three 0.91 m by 0.91 m plots by using two 0.91 m sections of 5.1 cm by 15.24 cm board. Boxes were filled with 17.78 cm of soil consisting of a 60/40 mix of sand and loam, allowing a 2.54 cm space at the top for watering. Soil was fertilized with 15% N / 30%P<sub>2</sub>O<sub>5</sub> / 15% K<sub>2</sub>O fertilizer prior to planting and as needed during the experiment. Greenhouse temperature was maintained at 23.8°C during the day and 20°C to 21.1°C at night throughout the experiment.

A split plot factorial design was used with WCM infested and non-infested treatments as main plots. Subplot treatment combinations were randomly assigned within the main plots and consisted of three seeding rates (3, 14, 22 kg/ha) of spring wheat variety 'Fortuna', and three seeding rates (0, 45, 90 kg/ha) of AWP arranged in a 3 by 3 factorial design. Treatments were replicated three consecutive times. Wheat rates were chosen to simulate low, medium and high populations of volunteer wheat. AWP densities were seeded at one-half and full recommended seeding rates to simulate poor and good stands of AWP, respectively. Main plots were designed to measure the effect

of plant competition and WCM infestation on biomass. Subplots within main plot treatments were grouped together to prevent WCM infestation of uninfested plots. A 3.96 m long 3.8 m high barrier constructed out of opaque 6 mil plastic (Carlisle Plastics, Inc., Minneapolis, MN) divided the greenhouse separating the main plots. The material of the barrier was later changed to a clear 6 mil plastic to allow more light to pass through to plots close to the barrier. Subplots were planted by hand at 5.08 cm row spacings in 0.86 m long rows.

To reduce the impact of aphids and thrips in the plots and to eliminate WCM in the uninfested plots, a variety of chemical and biological control measures were used. Acephate (Valent, Walnut Creek, CA), aldicarb (Rhone-Poulenc, Research Triangle Park, NC) and primicarb (Zeneca Ag Products, Des Moines, IA) were used as needed to reduce the interference by other arthropods. Foliar applications were applied using a hand sprayer. Minute pirate bugs (*Orius* spp.) and predatory mites (*Phytoseiulus persimilis*) were used to control thrips infestations. Lady bird beetles (*Hippodamia convergens*) were released to control periodic Russian wheat aphid (*Diuraphis noxia*) infestations.

Evaluation of primicarb and acephate indicate that at the applied rates no WCM mortality was detected. Acephate can act as a herbicide on some plants and did negatively effect the AWP, causing treated leaves on some plants to have brown, patchy necrotic areas and become dry and brittle. Plants showing these symptoms usually died despite repeated applications with fertilizer.

### WCM Infestation

Infested main plots were inoculated at Zadok stage 23 (main shoot with three tillers at the second leaf stage) (Zadoks et al. 1974) with viruliferous WCM from a colony maintained by the Department of Entomology at Montana State University. Prior to inoculation, mean number of mites per gram of plant material was determined by randomly selecting and weighing ten WCM infested spring wheat plants and counting the number of WCM present. WCM infested leaf material used for inoculation was cut into fragments approximately 2 cm in length, weighed, and then divided into 2 to 3 gram units containing approximately 168 WSM viruliferous mites. Each unit was individually packaged in a resealable plastic bag. One package of infested spring wheat leaf material was used to inoculate each subplot within the infested main plot. Infested plant material was sprinkled onto spring wheat in the individual plots. Because a successful infestation was vital, plots were observed for WSM symptoms after 10 days. If no symptoms were observed, plots were reinoculated with an additional gram of infested plant material.

### Plant Stand and Biomass

Wheat and pea stand densities were assessed on 27 October and 6 November, 1995 for replication 1, 8 and 16 April 1996 for replication 2 and 4 and 18 March, 1997 for replication 3 by counting the total number of wheat and AWP plants present in each subplot. Cereal grain development stage was determined at this time using the Zadok scale.

Plant samples were taken on 13, 20 and 30 November and 6 December, 1995 for replication 1, 28 May and 5 June, 1996 for replication 2 and 18 April and 15 May, 1997 for replication 3. Samples were collected for biomass by randomly throwing a 0.1m<sup>2</sup> hoop and clipping all plant material in the defined area at the soil surface. Plant biomass was separated by species, placed into paper bags and dried at 48°C for 14 days. Dry weights were recorded after drying.

#### WCM Population

WCM were sampled at 5 day intervals beginning 20 October 1995 for replication 1, 18 April 1996 for replication 2 and 28 March 1997 for replication 3. WCM sampling consisted of randomly selecting one fifth of the total number of wheat plants determined by the seeding density and removing the last fully expanded leaf below the ligule. Samples were placed into plastic bags and held in a freezer until examination. Leaves were visually inspected for WCM with the aid of a 50x Zeiss dissecting microscope (Carl Zeiss Inc., Thornwood, NY). Mean number of mites per leaf and percentage of leaves infected were determined.

#### Data Analysis

Mean number of mites, percent infestation and biomass were subjected to an analysis of variance using Proc GLM in SAS (SAS Institute 1996). Linear regressions

were performed on the dependent variables: mean number of mites, percent infestation and biomass, using Sigma Plot (SPSS 1997).

### Results and Discussion

#### WCM

There was a significant wheat main effect for mean number of mites per leaf ( $F = 6.12$ ;  $df = 2$ ;  $P > 0.01$ ) and percent infestation of sample ( $F = 11.21$ ;  $df = 2$ ;  $P > 0.001$ ) (Table 3). The interaction between the wheat and pea plant densities was significant for percent infestation of sample ( $F = 3.70$ ;  $df = 4$ ;  $P > 0.03$ ), but there was no interaction between these factors for mean number of mites per leaf.

Table 3. Analysis of variance for mean percent sample infestation and mean number of mites per leaf in the greenhouse.  $\alpha = 0.05$ .

Source of variation	Greenhouse			
	Percent infestation		Mean no. mites / leaf	
	F-test	p > F	F-test	p > F
Model	<i>10.80</i>	<i>0.0001</i>	<i>9.18</i>	<i>0.0001</i>
<b>R<sup>2</sup></b>		<b>0.87</b>		<b>0.85</b>
Wheat	<i>11.21</i>	<i>0.0009</i>	<i>6.12</i>	<i>0.011</i>
Pea	0.90	0.43	0.29	0.75
Wheat*Pea	<i>3.70</i>	<i>0.03</i>	0.53	0.72

Percent infestation. The percentage of plants infested increased over the duration of the sampling period in all treatment combinations (Fig. 1A-C). The change in percent infestation by WCM increased at similar rates in the zero and low-density pea plots for all densities of simulated volunteer wheat (Figs. 1A and 1B). However, at the high seeding density of peas the rate of increase of percent-infested plants at the high wheat density (slope = 0.10) was lower compared with the low (slope = 0.18) and medium (slope = 0.15) densities of wheat. The high wheat and pea density plots had the greatest total plant density and may have interfered with the WCM ability to disperse under greenhouse conditions resulting in a lower rate of increase in the percent plants infested by the WCM. Summarizing across sample dates, percent infested plants generally decreased with increasing densities of the wheat host (Table 4). The percent infestation at the 3 kg/ha wheat and 45kg/ha AWP seeding rates was significantly different than the percent infestation at all pea densities at the high rate of simulated volunteer wheat (Table 4).

Wheat density was a significant factor in percent infestation. The rate of percent infestation increased and tended to be greatest at the lower wheat densities, decreasing with increasing densities of wheat (Table 4). Mite dispersal, represented by percent infestation, was favored at the lowest density of volunteer wheat (Table 4).

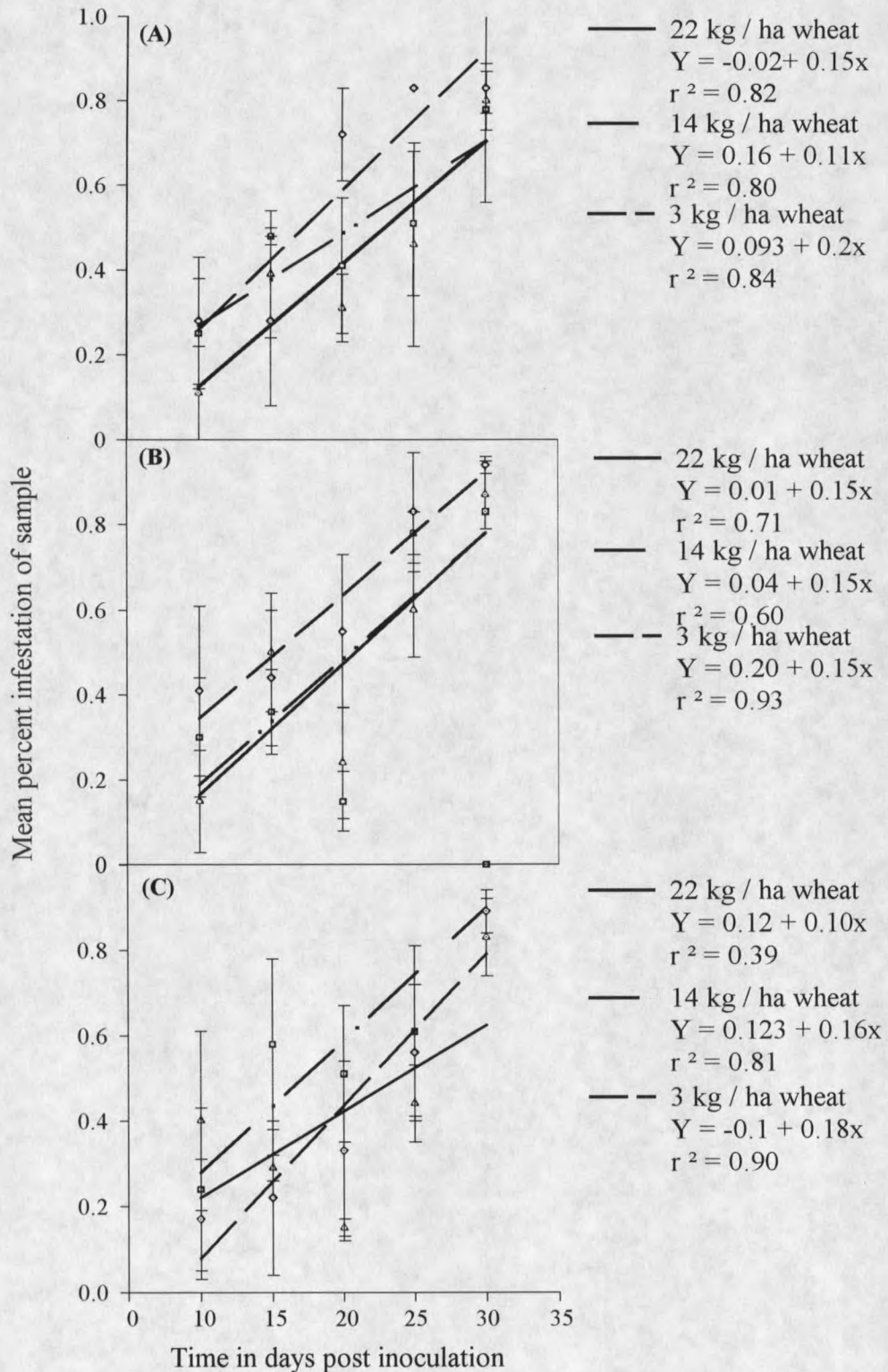
The WCM use wind to passively disperse and are unable to actively direct their movement to a suitable host plant. Population pressure (Power and Kareiva 1990), host quality (Perring et al. 1986, Margolies 1987) and abiotic factors such as wind and temperature (Staples and Allington 1956, Nault and Styer 1969) can all influence

Table 4. Mean separation of wheat-pea combinations for percent sample infestation in the greenhouse.

<b>Greenhouse</b>		
Wheat rate	Pea rate	Percent infestation
22	90	43.0 C
22	45	49.0 BC
22	0	48.0 BC
14	90	65.0 AB
14	45	54.0 ABC
14	0	56.0 ABC
3	90	51.0 ABC
3	45	69.0 A
3	0	63.0 ABC
$\alpha = 0.05$	Std Err	0.04

\*Means with the same letter are not significant.

Figure 1. Mean percent plant infestation from inoculation through time for 3, 14 and 22 kg/ha at (A) 0 kg/ha, (B) 45 kg/ha and (C) 90 kg/ha AWP. Greenhouse 1995-1997.



dispersal behavior in small arthropods, like the WCM. By controlling inputs such as temperature, water and fertilizer, a favorable greenhouse environment is maintained for both the mite and the wheat host. Mite dispersal in the greenhouse could be elicited by population pressure, decreased host quality resulting from maturity or disease, or through an interaction between plant maturity and population pressure. Because the dispersal reflected by the percent infested plants was relatively constant, mite dispersal in the greenhouse may be a good estimate of natural rates of emigration caused by population pressure in the absence of variable abiotic factors. Under more realistic conditions found in the field, mite dispersal is highly influenced by the interaction between abiotic factors, plant stress and plant maturity (Perring et al. 1986). In the absence of interactions resulting from variable abiotic conditions, it is not unreasonable to assume that the factors influencing WCM dispersal are primarily WCM density dependent. Air currents used in dispersal come from the natural movement of air provided by the ventilation system and were not subject to the same type of variation found in the field. This allows for stable dispersal through the system. WCM were able to locate wheat host plants and were able to colonize them effectively as indicated by the similar slopes between the percent infestation and time with increasing densities of non-host AWP. Numbers of dispersing mites may have been sufficient to overcome the interference provided by the presence of a non-host. While percent infested plants were seemingly unaffected by increasing densities of non-host, the lower rate of increase of percent infestation seen at the 22 kg/ha wheat rate at the high density of AWP (Fig. 1C) may indicate that there is a density of plants that can interfere with the WCM ability to disperse.

WCM population. Wheat density is a significant factor influencing the mean number of mites ( $F = 6.12$ ;  $df = 2$ ;  $P < 0.01$ ). Mean number of mites per leaf at the 3 kg/ha seeding rate was significantly different from the 22 kg/ha wheat seeding density (Table 5). The rate of increase for mean numbers of mites during the sampling period tended to be higher in the lower wheat densities, indicated by the higher slope of the regression of mite population on time, decreasing consistently with increasing densities of simulated volunteer wheat (Figs. 2A-C and 3). However, as the density of volunteer wheat increases the per plant population of WCM decreases. Examining the effect that both wheat and pea densities together had on mite populations indicates that the strong effect that wheat density had on mite populations (Fig. 3). One possible explanation for lower populations of WCM with increasing densities of wheat is a combination of decreased susceptibility to both the WCM and WSM as the plant matures and plant tillering that provides new material at a rate that exceeds the WCM ability to colonize (Power and Kareiva 1990). However, it is more likely that greenhouse conditions favorable at the low wheat densities become less favorable for WCM populations as wheat density increases. In addition, by decreasing plant stress and maintaining factors such as temperature that are influential to WCM population development, higher populations of mites can be maintained on individual plants at all planting densities as seen by higher mite numbers in the greenhouse than in the field.

Figure 2. Mean number of mites per leaf from inoculation through time at (A) 3 kg/ha, (B) 14 kg/ha and (C) 22 kg/ha combined across 0, 45, 90 kg/ha AWP planting rates. Greenhouse 1995-1997.

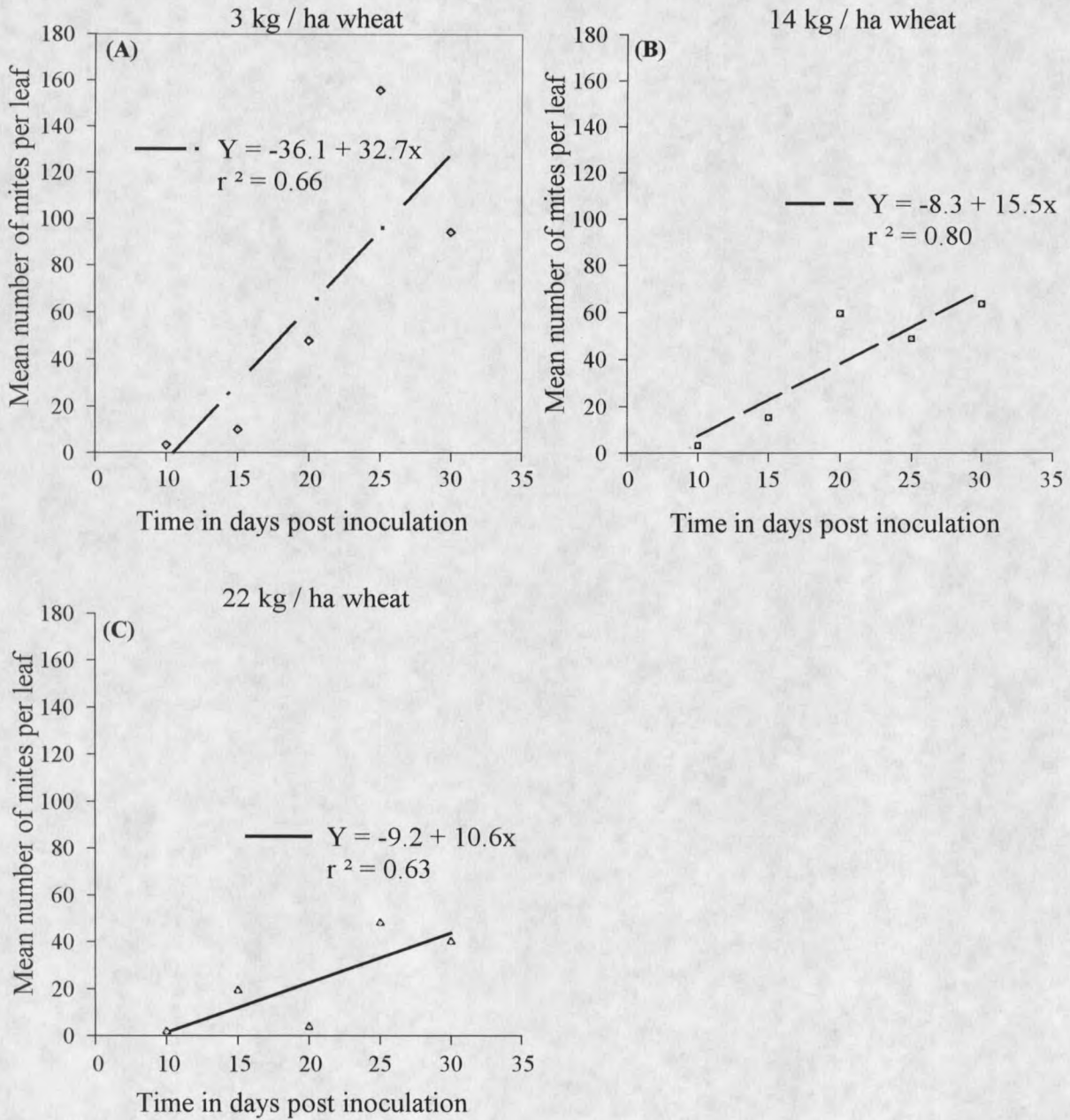


Figure 3. Mean number of mites per leaf over increasing wheat and AWP seeding rates in kg / ha. Greenhouse 1995-1997.

$$Z = 62.2 - 1.25\text{wheat\_rt} - 0.14\text{pea\_rt}$$
$$r^2 = 0.31$$

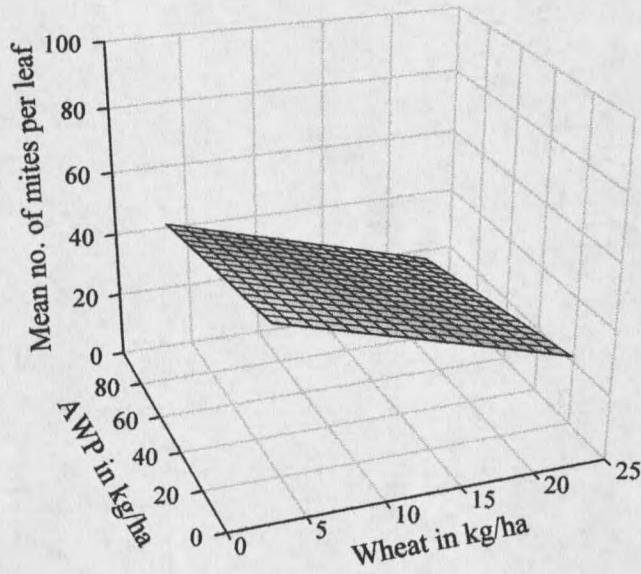


Table 5. Mean separation of wheat seeding rates for mean number of mites per leaf in the green house.

<b>Greenhouse</b>		
Wheat rate	Mean numbers of mites per leaf	
3	80.0	A
14	59.4	AB
22	21.5	B
<b>Std Err</b>	<b>28.8</b>	$\alpha = 0.05$

\*Means with the same letter are not significant.

### Plant competition

A significant difference in wheat biomass ( $F = 7.31$ ;  $df = 18$ ;  $P > 0.02$ ) was detected for the wheat main effects (Table 6). The significant difference for mean wheat biomass is not surprising given the three rates of wheat selected, 3 kg/ha, 14 kg/ha and 22 kg/ha, for the experiment. No significant differences in mean wheat biomass were observed for the AWP main effect or for the wheat-AWP interaction (Table 6) indicating that AWP rates did not influence the production of wheat biomass. Alternatively, AWP biomass production was not affected by wheat density (Table 7). Neither AWP or wheat biomass was influenced by WCM infestation or the presence of the WSM disease. Although symptoms were present, infection by WSMV had no effect on biomass production in plots infested with WCM and no difference was observed in wheat biomass production between infested and uninfested plots (Table 6). Although WSM symptoms were observed, under greenhouse conditions wheat plants were able to compensate for the disease.

The apparent lack of competition between wheat and AWP in the presence of sufficient nutrient, moisture and light resources could indicate that AWP and wheat do not compete for resources that would limit the growth of either plant in an intercropped system when emerging simultaneously.

Table 6. Analysis of variance of plant-plant interactions between AWP and wheat on mean wheat biomass  $g \cdot m^{-2}$ .  $\alpha = 0.05$ .

<b>Greenhouse</b>		
Mean wheat biomass in grams		
Source of variation	F-test	p > F
Model	5.35	0.03
<b>R<sup>2</sup></b>		<b>0.98</b>
Infested	1.32	0.3021
Wheat / m <sup>2</sup>	7.31	0.02
AWP / m <sup>2</sup>	1.34	0.39
Wheat/m <sup>2</sup> *AWP/m <sup>2</sup>	1.84	0.25

Table 7. Analysis of variance of plant-plant interactions between AWP and wheat on mean AWP biomass  $g \cdot m^{-2}$ .  $\alpha = 0.05$ .

<b>Greenhouse</b>		
Mean AWP biomass in grams		
Source of variation	F-test	p > F
Model	4.16	0.05
<b>R<sup>2</sup></b>		<b>0.98</b>
Infested	0.00	1.00
Wheat / m <sup>2</sup>	0.34	0.96
AWP / m <sup>2</sup>	6.79	0.02
Wheat/m <sup>2</sup> *AWP/m <sup>2</sup>	0.44	0.80

## FIELD RESEARCH

### Introduction

Wheat summer-fallow strip cropping is the traditional cropping system of the Northern Great Plains and is used to conserve soil moisture for subsequent grain crops. Northern Great Plains producers are examining and increasing the acreage of non-traditional crops such as lentils, peas, canola, safflower and others (Blodgett personal comm.). Diversifying the traditional wheat-summer fallow strip cropping system through use of alternate crops offers several benefits including breaking insect and disease cycles, improving soil fertility and offers growers alternative enterprises for greater economic stability. Although, climatic constraints limit the selection of alternative crops that can be produced economically in our region, research conducted at MSU has identified legumes adapted to our region, such as Austrian winter peas (*Pisum sativum* L.). Incorporation of a non-host legume into the wheat fallow offers a possible cultural method for controlling WSM.

Field trials conducted over two successive years at two locations examined the population dynamics of the wheat curl mite on simulated populations of volunteer wheat in a AWP intercrop. Additionally, the interaction between wheat and peas was evaluated for competition effects in the presence and absence of the WSM disease.

An experiment was designed to study WCM population changes in the various treatments over time should provide information on conditions favoring WCM outbreaks.

### Materials and Methods

Field studies were conducted in 1996 and 1997 at the MSU Northern Agricultural Research Center (NARC) located near Havre, Montana, and the MSU Western Triangle Agricultural Research Center (WTARC) located near Conrad, Montana. Treatments consisted of three seeding rates (3, 14, 22 kg/ha) of spring wheat variety 'Fortuna' and three seeding rates (0, 45, 90 kg/ha) of Austrian Winter peas 'unknown variety', arranged in a three by three factorial design. Wheat rates were chosen to simulate low, medium and high populations of volunteer wheat. The AWP densities were seeded at one-half and full recommended seeding rates to simulate poor and good stands of AWP, respectively. A split-plot factorial design was used with WCM infested and non-infested plots as main plots. Subplot treatments within the main plots were randomly assigned a wheat-pea planting combination resulting in a randomized plot arrangement.

Subplots were replicated three times within main plot treatments and grouped together to prevent WCM infestation of uninfested main plots. Subplots measured 3.6 m by 6.0 m. Subplot treatments, wheat-pea combinations, were planted simultaneously. Main plots were replicated by field location with one replicate of each main plot planted at each site. Main plots were designed to measure the effect of plant competition and WCM infestation on plant biomass. Because maintaining the uninfested plots WCM free

was important for comparisons with the infested main plots, chlorfenapyr, an acaricide (American Cyanamid, Princeton, NJ) was applied as needed to control WCM when symptoms were observed. Chlorfenapyr was applied at 35.181 ml ai/ha at both locations in 1997 on 26 June at WTARC and 25 June at NARC using a CO<sub>2</sub> pressurized backpack sprayer equipped with TeeJet#XR8002VS nozzles, calibrated to deliver 77.53 l/ha at 30 psi. Four rows of sweet corn 'Spirit' were planted to separate main plots.

Plots were located on land previously fallowed at both sites in 1996. In 1997 plots were located on previously fallowed land at the WTARC location, while plots at NARC were recropped on the experiments 1996 location. Soils were prepared prior to planting following current agronomic recommendations for spring wheat planting. No insecticides were used prior to planting at either location but diclofop-methyl herbicide (Hoechst Schering AgrEvo USA Company, Wilmington, DE) was applied to control wild oats, *Avena fatua*, at the WTARC site. Plots were seeded on 13 May 1996 and 12 May 1997 at WTARC and on 14 May 1996 and 2 May 1997 at NARC. Subplots at both sites were planted using a cone seeder at 30 cm row spacings in 6.0 m long rows. Row length at NARC was trimmed to 5.4 m. Uninfested plots were checked weekly for early symptoms of WCM infestation.

### Environment

Environmental conditions for 1996 and 1997 were monitored by weather stations located at or near WTARC and NARC. Precipitation and minimum and maximum

temperatures were recorded at both locations on a daily basis in both years. Temperature and precipitation data were used to determine mean daily temperature and mean daily precipitation over the sampling periods for 1996 and 1997. Mean daily temperature for the sampling period was determined by calculating the mean daily temperature for the 5 to 7 day period prior to each WCM sample date. Mean daily precipitation was determined by taking the mean of the daily precipitation events over the 5 to 7 day period prior to each WCM sample date.

#### WCM Infestation

Infested plots were inoculated when the wheat stage reached Zadok 23 (Zadoks et al. 1974) with viruliferous WCM from a colony maintained by the Department of Entomology at Montana State University. Inoculum was prepared by harvesting WCM infested spring wheat plants. Mean number of WCM per gram was determined by randomly selecting and weighing ten WCM infested spring wheat plants and counting the number of WCM present on each plant. Leaf material for inoculation was cut into small pieces approximately 2 cm long, weighed and divided into 46g units containing approximately 120 viruliferous mites per gram. Each 46 g unit was packaged in a resealable plastic bag and was used to inoculate each infested plot. Infested plant material was sprinkled along the length of the center two rows of each plot. Plants were infested 4 June 1996 and 7 June 1997 at WTARC and 5 June 1996 and 28 May 1997 at NARC.

### Plant Stand and Biomass

Wheat and pea stand densities were assessed on 4 June 1996 at WTARC and 5 June 1996 at NARC and at both locations on 28 May 1997 by randomly throwing a 0.1m<sup>2</sup> hoop three times into each plot and counting wheat and pea plants within the defined area. Cereal grain development stage was determined at this time using the Zadoks scale.

Plant biomass was collected to evaluate plant-plant interactions. Biomass samples were taken on 11 July 1996 at WTARC and 15 July 1996 at NARC and on 9 and 31 July 1997 at WTARC and 4 and 22 July 1997 at NARC by randomly throwing a 0.1 m<sup>2</sup> hoop and clipping all plant material in the defined area at the soil surface. Plant biomass was separated by species, placed into paper bags and dried at 48°C for 14 days. Dry weights were recorded after drying the plant material.

### WCM Population:

WCM were sampled weekly at both locations beginning 20 June 1996 and 19 June 1997 at WTARC and 21 June 1996 and 13 June 1997 at NARC. WCM sampling consisted of randomly selecting 30 tillers from each small plot and removing the last fully expanded leaf below the ligule. This leaf has been found to be a good indicator of whole plant mite numbers (Blodgett, unpublished data). Samples were placed into plastic bags, stored on ice in an ice chest during transportation and held in a freezer until their examination. Leaves were visually inspected for WCM with the aid of a 50x Zeiss

dissecting microscope (Carl Zeiss Inc., Thornwood, NY). Mean number of mites per leaf and percentage of leaves infected were determined.

### Data Analysis

Mean number of mites, percent infestation, biomass and stem heights were subjected to an analysis of variance using Proc GLM in SAS (SAS Institute, 1996). Mean separations were obtained using Tukey's studentized range test (HSD) and Proc. LSMEANS in SAS (SAS Institute, 1996). Treatment combinations were ranked from highest to lowest using the results from the LSMEANS procedure. Linear regressions were performed on dependent variables, mean number of mites, percent infestation and biomass using Sigma Plot (SPSS 1997).

## Results and Discussion

### WCM

There was a significant year and location effect for both mean number of mites per leaf ( $F = 37.77$ ;  $df = 1$ ;  $P < 0.0001$ ) and percent infestation of sample ( $F = 54.56$ ;  $df = 1$ ;  $P < 0.0001$ ) (Table 8). Because environmental factors such as temperature and humidity influence WCM populations (Slykhuis 1955, Staples and Allington 1956), an environmental analysis was done for each location and year. Environmental data from

Table 8. Analysis of variance for percent sample infestation and mean number of mites per leaf for location and year.  $\alpha = 0.05$ .

Source of variation	Percent infestation		Mean no. mites / leaf	
	F-test	P > F	F-test	p > F
Model	<i>10.24</i>	<i>0.0001</i>	<i>9.57</i>	<i>0.0001</i>
<b>R<sup>2</sup></b>		0.51		0.49
Year	<i>54.56</i>	<i>0.0001</i>	<i>46.54</i>	<i>0.0001</i>
Location	<i>41.78</i>	<i>0.0001</i>	<i>37.82</i>	<i>0.0001</i>

Table 9. Mean daily precipitation and mean daily maximum and minimum temperatures for the 1996 and 1997 sampling periods at WTARC and NARC.

Source	NARC		WTARC	
	1996	1997	1996	1997
Mean daily maximum temperature	27.4 °C	25.0 °C	24.1 °C	22.8 °C
Mean daily minimum temperature	10.2 °C	10.2 °C	10.1 °C	10.5 °C
Mean daily precipitation	0.15 cm	0.28 cm	0.10 cm	0.09 cm

weather stations at each site were examined and evaluated for potential impact on the mite population dynamics. Mean daily temperature and precipitation was examined for the sampling period beginning ten days prior to the first WCM sample date and ending at the experiment's termination. Temperature and moisture stress influenced plant growth and disease symptoms of the peas and wheat.

Environmental Influence. Mean daily maximum temperatures were higher during the sampling period in 1996 than in 1997 at both sites (Table 9). Mean daily maximum temperatures were higher at NARC than WTARC in both years (Table 9). Mean daily minimum temperatures ranging from 10.1 °C to 10.5 °C differed very little for both locations and years. Mean daily precipitation at NARC during the 1997 sampling period increased 87% over the 1996 levels while mean daily precipitation at WTARC was nearly identical in both years during the sampling period (Table 9). Overall, NARC had one and half times the mean daily precipitation of WTARC in 1996 and three times the precipitation of WTARC in 1997. Changes in the mean number of mites per leaf are shown with maximum daily temperatures for each site by location (Fig. 4A-B and Fig. 5A-B). Generally, mite populations declined as max temperatures exceeded 30 °C for 2 or more days. The environmental data supports observations that were made in 1996 at both locations in which plants were seen to prematurely senesce in response to moisture and temperature stress.

WCM population

The locations, WTARC and NARC, had significant differences in mean number of mites per leaf ( $F = 35.98$ ;  $df = 9$ ;  $P < 0.0001$ ) and percent infestation of sample ( $F = 124$ ;  $df = 9$ ;  $P < 0.0001$ ) in 1997 but not in 1996 (Table 10). There were significant

Figure 4. Mean number of mites per leaf and maximum daily temperatures over days post WCM inoculation for (A) NARC and (B) WTARC in 1996.

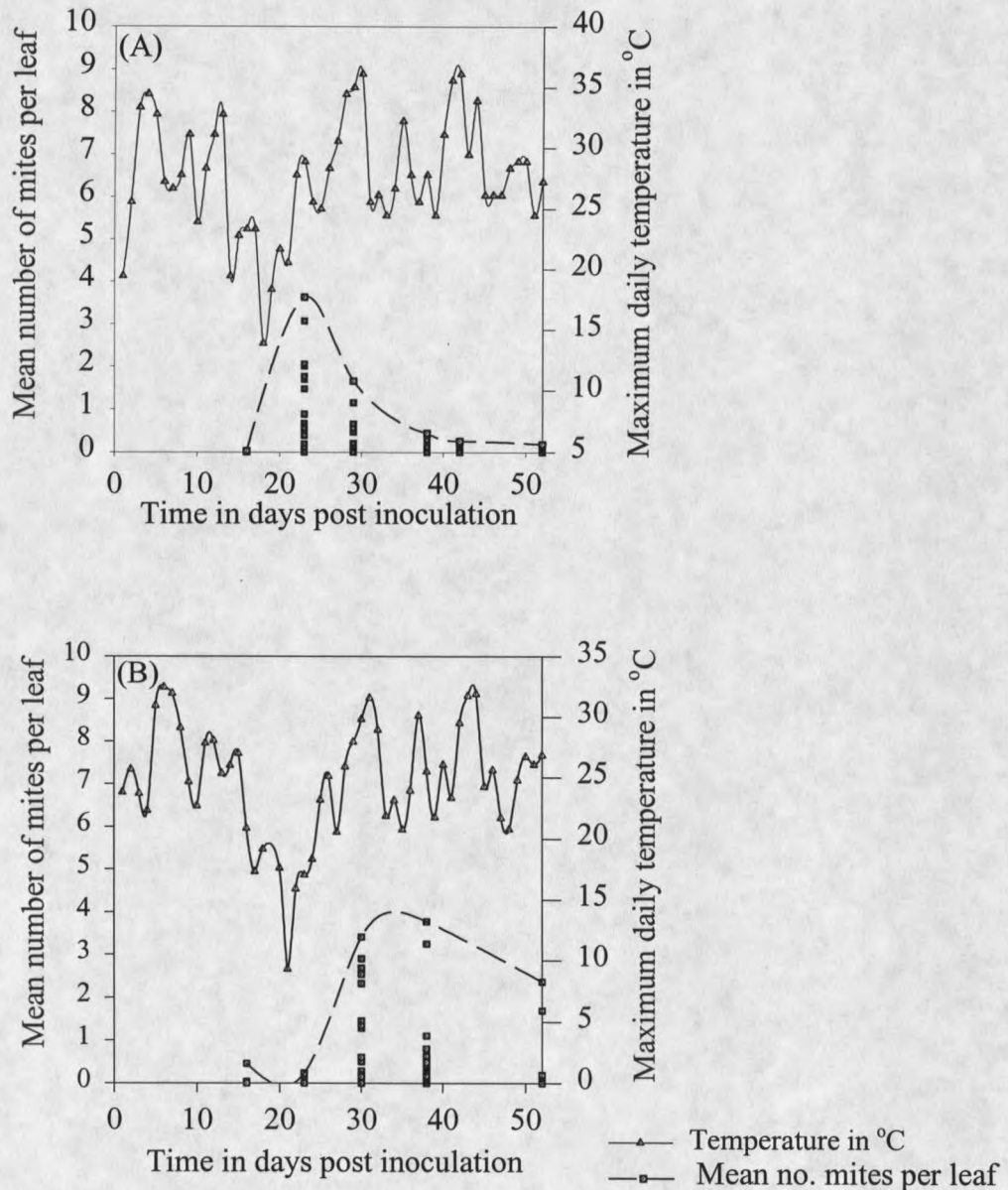


Figure 5. Mean number of mites per leaf and maximum daily temperatures over days post WCM inoculation for (A) NARC and (B) WTARC in 1997.

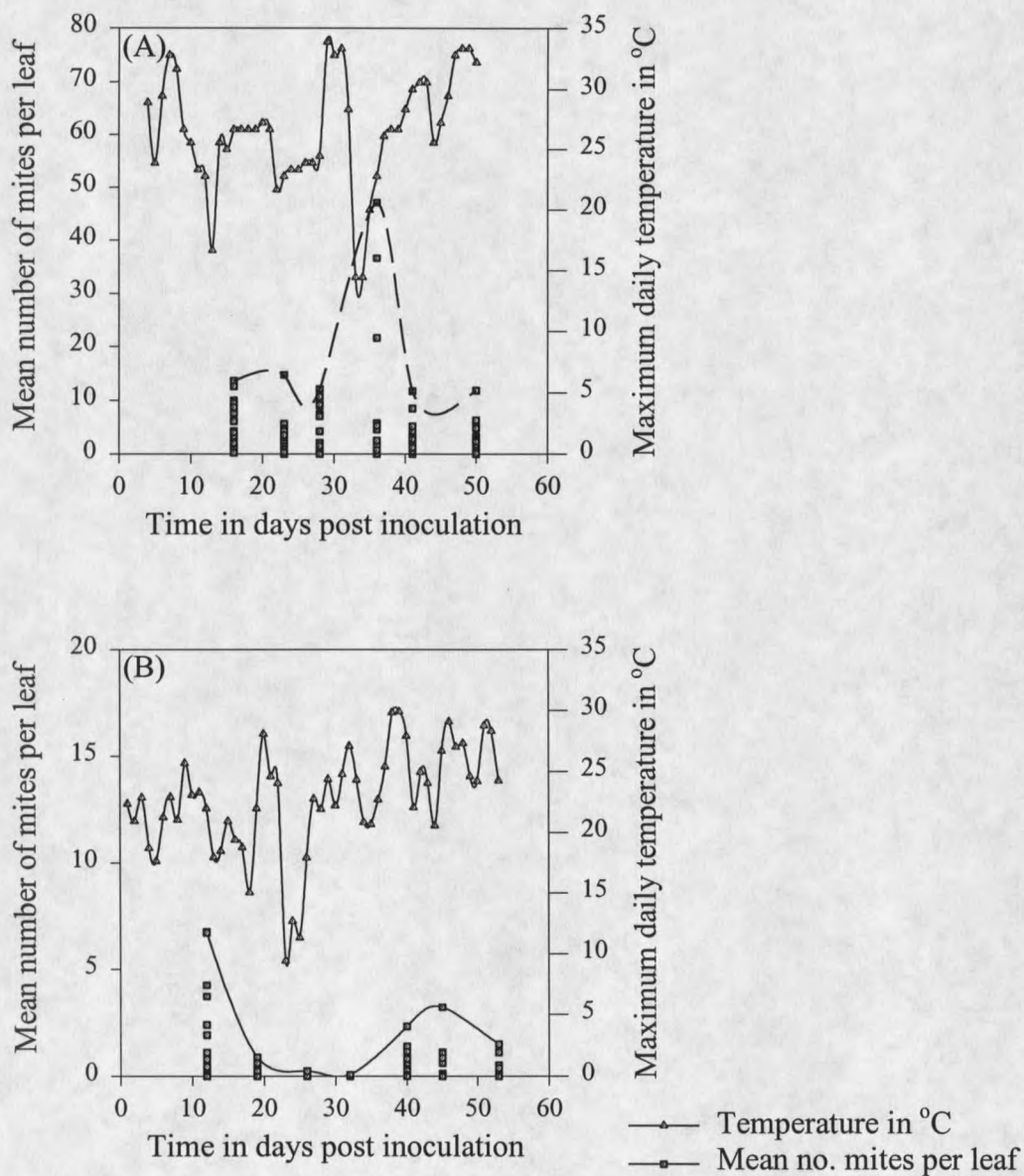


Table 10. Analysis of variance for percent sample infestation and mean number of mites per leaf between locations for 1996 and 1997.  $\alpha = 0.05$ .

Source of variation	Percent infestation				Mean no. mites / leaf			
	1996		1997		1996		1997	
	F-test	p > F	F-test	p > F	F-test	p > F	F-test	p > F
Model	0.57	0.81	15.42	0.0001	0.65	0.75	6.18	0.0001
<b>R<sup>2</sup></b>		0.10		0.76		0.12		0.56
Location	0.54	0.46	124.0	0.0001	1.15	0.29	35.98	0.0001
Wheat	0.80	0.45	3.10	0.05	0.88	0.42	4.84	0.01
Pea	0.45	0.64	0.19	0.83	0.94	0.40	0.39	0.68
Wheat*Pea	0.52	0.72	2.17	0.09	0.26	0.90	2.34	0.07

differences between years at NARC in mean number of mites per leaf ( $F = 144.06$ ;  $df = 11$ ;  $P < 0.0001$ ) and percent infestation of sample ( $F = 146.51$ ;  $df = 11$ ;  $P < 0.0001$ ) (Table 11). There were no significant differences between years at WTARC for mean number of mites per leaf or percent infestation of sample (Table 11).

1996. Significant differences were not detected in the percent infestation of sample and mean number of mites per leaf for the wheat and pea main effects and the wheat-pea interaction at NARC or WTARC in 1996 (Table 12). No significant differences in stand densities were observed at either NARC or WTARC for percent infestation of sample or for mean number of mites per leaf in 1996 (Table 12). Hotter and dryer conditions at both sites caused plants to senesce early, only one plant biomass sample was collected.

1997. Differences ( $P = 0.13$ ) were found for wheat ( $F = 2.77$ ;  $df = 2$ ;  $P < 0.09$ ) and wheat-pea interactions ( $F = 2.56$ ;  $df = 4$ ;  $P < 0.08$ ) for percent infestation of sample. Mean number of mites per leaf was significantly different at both locations for the wheat main effect and for the wheat-pea interaction at NARC (Table 12). Mean numbers of mites per leaf from NARC were regressed on wheat rates over the sampling period for 0, 45 and 90 kg/ha rates of AWP (Fig. 6). Results indicate that in the absence of AWP, WCM populations increased slightly at 3 kg/ha and decreased at 14 and 22 kg/ha. WCM populations decreased at 3 and 22 kg/ha and increased slightly at 14 kg/ha at the 45 kg/ha rate of AWP. WCM populations in 90 kg/ha AWP increased at 22 kg/ha, decreased at 3 kg/ha and did not change at 14 kg/ha. During the sampling period at NARC, mite populations per plant generally decreased, increasing slightly in 2 out of 9 wheat and pea

Table 11. Analysis of variance for differences between years for percent sample infestation and mean number of mites per leaf at NARC and WTARC.  $\alpha = 0.05$ .

<b>NARC</b>				
Source of variation	Percent infestation		Mean no. mites / leaf	
	F-test	p > F	F-test	P > F
Model	14.78	0.0001	15.52	0.0001
<b>R<sup>2</sup></b>		0.79		0.80
Year	146.51	0.0001	144.06	0.0001
Wheat	3.22	0.04	5.50	0.01
Pea	0.66	0.52	0.02	0.98
Wheat*Pea	1.75	0.15	2.60	0.05

<b>WTARC</b>				
Source of variation	Percent infestation		Mean no. mites / leaf	
	F-test	p > F	F-test	P > F
Model	0.67	0.75	1.33	0.24
<b>R<sup>2</sup></b>		0.15		0.26
Year	0.31	0.58	0.00	0.97
Wheat	0.16	0.84	2.39	0.10
Pea	1.42	0.25	1.58	0.22
Wheat*Pea	0.97	0.43	0.35	0.84

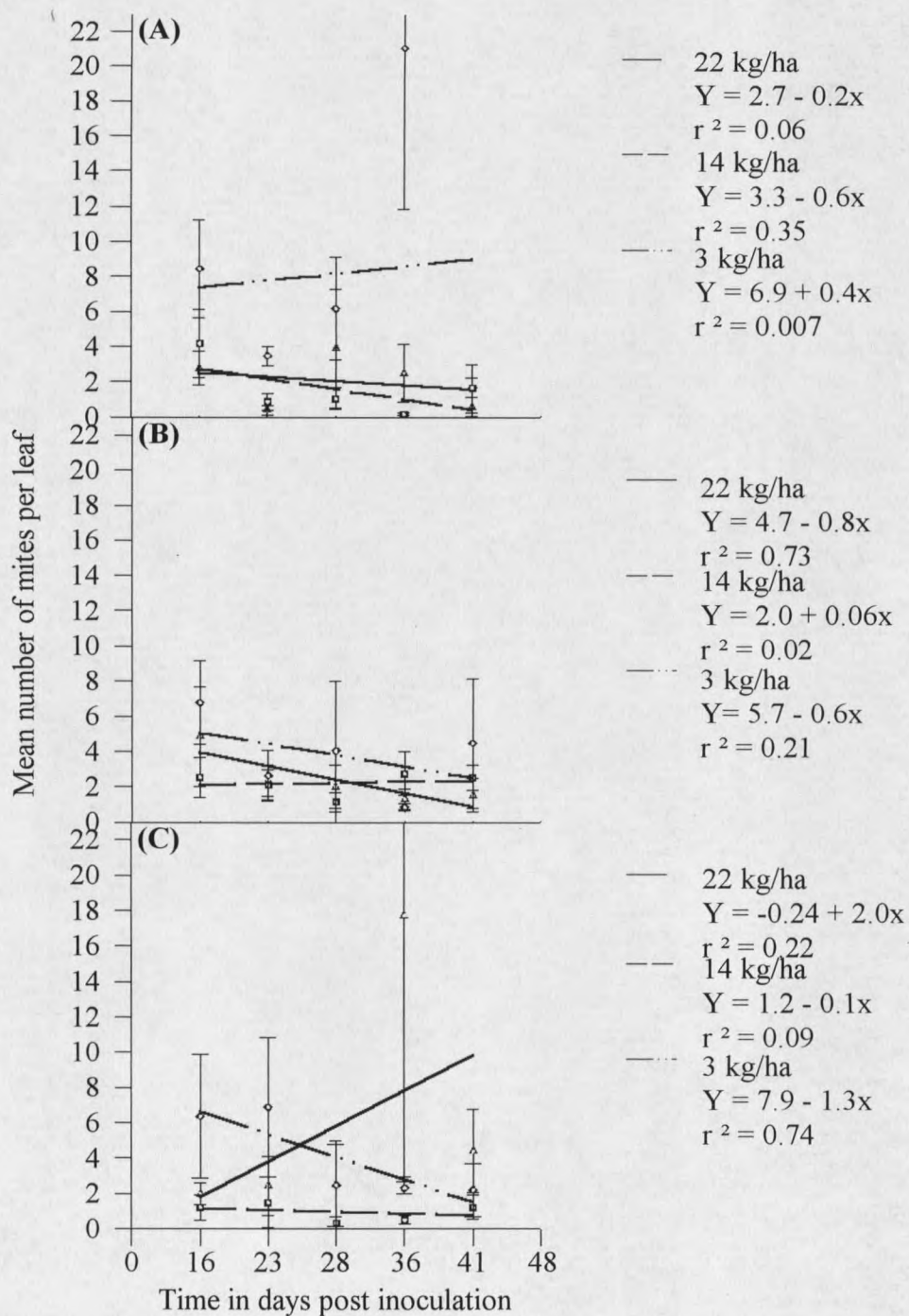
Table 12 Analysis of variance for percent sample infestation and mean number of mites per leaf at WTARC and NARC.  $\alpha = 0.05$ .

		NARC							
		Percent infestation				Mean no. mites / leaf			
		1996		1997		1996		1997	
Source of variation		F-test	p > F	F-test	p > F	F-test	p > F	F-test	p > F
Model		0.57	0.82	1.83	0.13	1.43	0.25	2.78	0.03
$R^2$			0.26		0.53		0.46		0.64
Wheat		1.25	0.31	2.77	0.09	1.91	0.18	6.55	0.01
Pea		0.18	0.83	0.60	0.56	0.79	0.47	0.06	0.95
Wheat*Pea		0.41	0.80	2.56	0.08	0.92	0.47	2.87	0.06

		WTARC							
		Percent infestation				Mean no. mites / leaf			
		1996		1997		1996		1997	
Source of variation		F-test	p > F	F-test	p > F	F-test	p > F	F-test	p > F
Model		0.60	0.79	1.20	0.36	0.66	0.74	2.01	0.10
$R^2$			0.27		0.43		0.32		0.54
Wheat		0.20	0.82	0.58	0.57	0.23	0.80	4.20	0.03
Pea		0.30	0.75	1.74	0.21	0.79	0.47	1.21	0.32
Wheat*Pea		1.04	0.41	1.45	0.26	0.74	0.58	0.76	0.57

Figure 6. Regression of mean number of mites per leaf on days post inoculation for 3, 14 and 22 kg/ha wheat at (A) 0 kg/ha, (B) 45 kg/ha and (C) 90 kg/ha AWP at NARC, 1997.



combinations, with the exception of a strong mite population increase in the highest density wheat-pea combination. Because this dramatic population increase occurred in the treatment with the highest total plant density, there may have been an influence of crop canopy increasing the humidity and offering protection from the ambient temperature (Jackson 1982), conditions known to be favorable to WCM (Slykhuis 1955). Additionally, the highest plant density, represented by the high wheat-pea treatment combination, was the only treatment in which mite populations were found to strongly increase. Although not significant  $\alpha = 0.10$ , similar trends were observed for the WCM population at WTARC in 1997 (Fig. 7).

Examining the mite response to temperature and precipitation encountered during the sampling period, mean numbers of WCM per leaf decreased at the lowest and highest wheat rates with increasing mean daily temperatures in the absence of AWP in 1997 at NARC explaining 61 and 84% of the variability respectively (Figs. 8 A-C). There was a weak positive relationship between mean number of WCM per leaf and increasing temperatures observed at the 14 kg/ha wheat rate (Fig. 8 B). wheat rates with increasing mean daily temperatures in the absence of AWP in 1997 at NARC explaining 61 and 84% of the variability respectively (Figs. 8 A-C). There was a weak positive relationship between mean number of WCM per leaf and increasing temperatures observed at the 14 kg/ha wheat rate (Fig. 8 B). This suggests that the higher density of wheat is better able to buffer the effect of temperature on the mite population over that of the lower wheat density (Fig. 8 A-C). At the low density of wheat, the WCM populations increased across mean daily temperatures with the relationship weakening with increasing wheat

Figure 7. Regression of mean number of mites per leaf on days post WCM inoculation for 3, 14 and 22 kg/ha wheat at (A) 0 kg/ha, (B) 45 kg/ha and (C) 90 kg/ha AWP at WTARC, 1997.

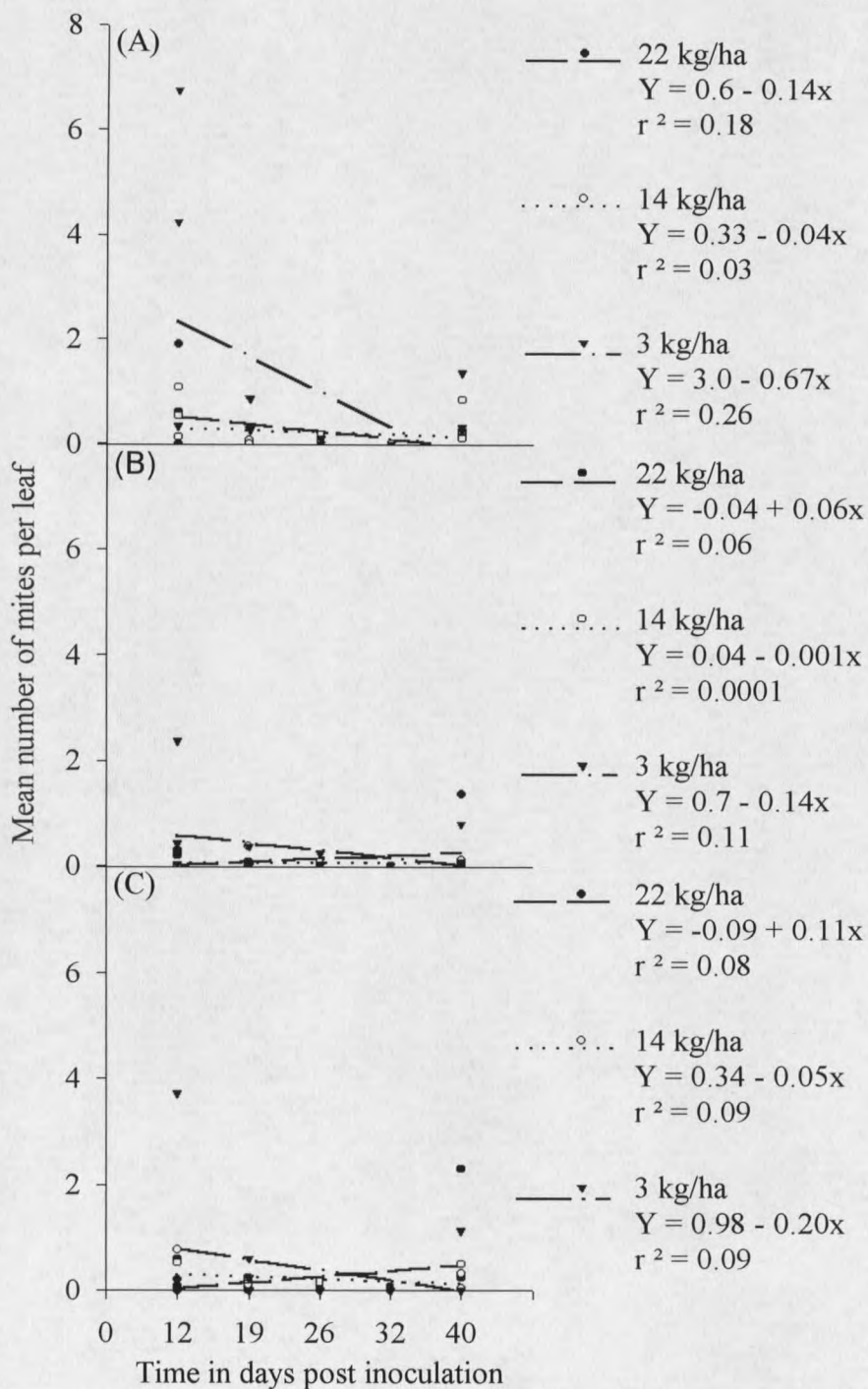
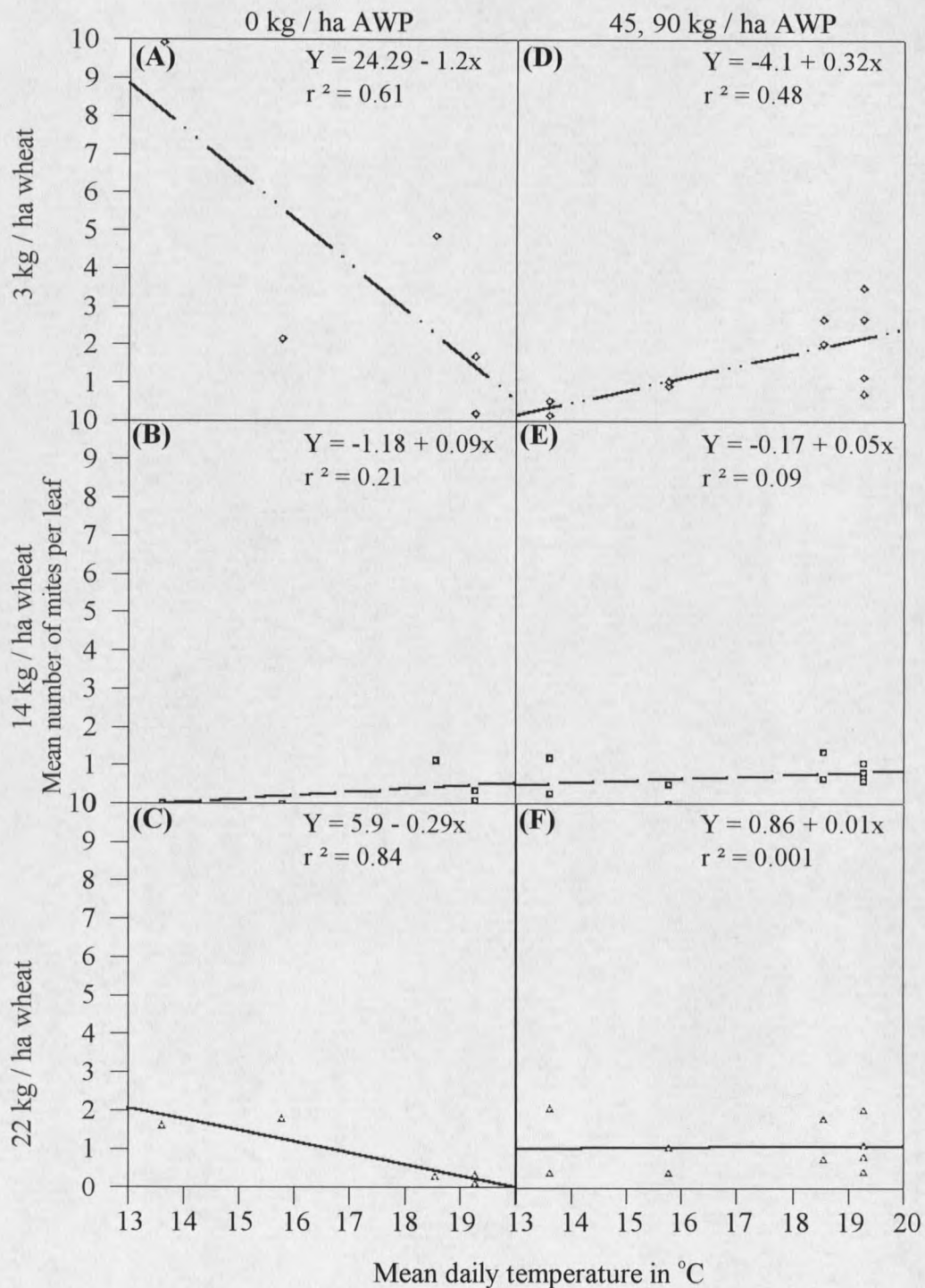


Figure 8. Regression of mean number of mites per leaf on the mean daily temperature of the sampling period in °C at 3, 14 and 22 kg/ha wheat in the absence of AWP (A-C) and in the presence of AWP (D-F) at NARC, 1997.

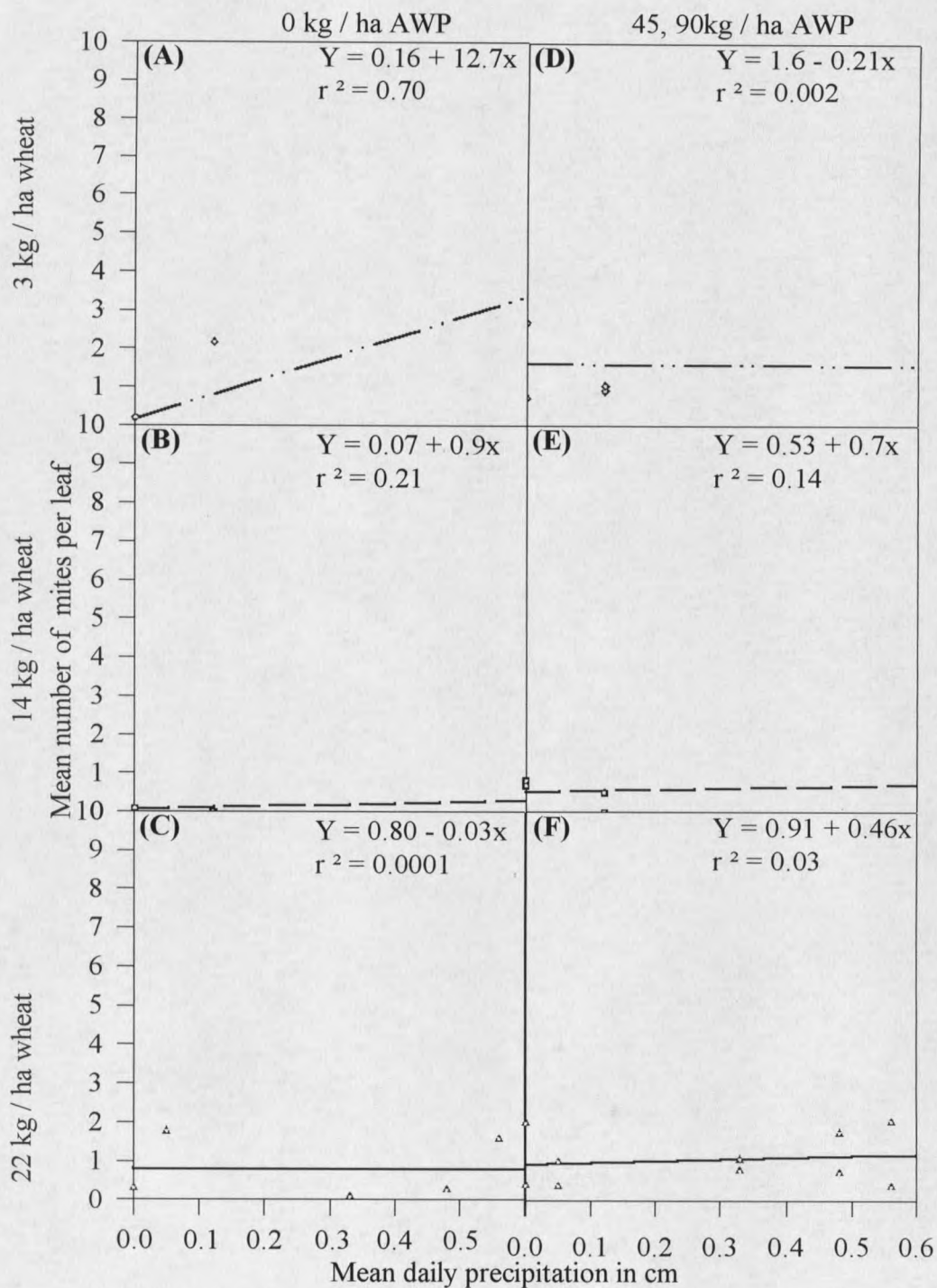


densities (Fig. 8 D-F). The stronger positive relationship between the WCM population and temperature at the low density of wheat (Fig. 8 D;  $R^2 = 0.48$ ), in contrast to the negative relationship in the absence of peas (Fig. 8 A), suggests that the canopy provided by the peas is providing a favorable microhabitat for mite population growth by buffering the effects of temperature. Overall, the effect of temperature on the WCM population is weakly positive in the presence of peas at all densities of wheat at NARC in 1997. A similar relationship was observed for mean number of mites in wheat alone plots at NARC in 1996.

The relationship between the mite population and precipitation was strongest at the low density of wheat in the absence of peas (Fig. 9 A). In general, no consistent relationship was observed between mean number of mites per leaf and mean daily precipitation in the absence or presence of AWP (Figs. 9 B-F) in 1997 at NARC.

Both temperature and precipitation seemed to influence WCM population development consistently in plots established at NARC. Overall, WCM populations were greatest at NARC in 1997, the site with the highest mean daily precipitation. This was the only site and year where WCM and WSM symptoms could be found in adjacent uninfested plots and required treatment. Higher daily temperatures (Fig. 4 A and B) combined with lower precipitation in 1996 may have been responsible for low populations of WCM at both locations and early plant senescence that truncated the experiment in the 1996 year. The difference in the relationship between mite numbers

Figure 9. Regression of mean number of mites per leaf on the mean daily precipitation of the sampling period in cm at 3, 14 and 22 kg/ha wheat in the absence of AWP (A-C) and in the presence of AWP (D-F) at NARC, 1997.



and mean daily temperature could be due to the impact of the canopy provided by the AWP. The canopy may buffer the temperature and humidity of the WCM microhabitat. Higher temperatures in the field, in plots not buffered by the presence of AWP had a strong negative effect on mite populations. This observation is supported by research conducted by Slykhuis (1955) on WCM survival at different temperature and humidity levels. His results show that WCM mortality increases with decreasing humidity and increasing temperatures. It is likely that temperature and moisture or humidity conditions interact and influence the population dynamics of the WCM. Research on the fecundity and development of the eriophyid mites *Phyllocoptruta oleivora*, the citrus rust mite (Bergh 1994), and *Epitirmerus pyri*, the pear rust mite (Allen et al. 1995), indicate that temperature may be the most important factor in eriophyid mite development.

Since the lowest mean daily temperatures occurred at WTARC in 1997 (Table 9), the lower temperatures may have resulted in less plant stress at lower precipitation. WCM utilize the new, tender plant growth, colonizing the newest leaves and/or younger volunteer plants that emerge in response to rainfall. Moisture limited situations could reduce plant tillering and the growth and development of new leaf material favored by the WCM, negatively influencing WCM populations. For WCM populations to increase to epidemic levels, the critical factors seem to be the presence of a wheat host at an immature plant growth stage and favorable moisture and temperature conditions (Perring et al. 1986).

### Plant competition

There were significant differences in mean wheat biomass in the wheat ( $F = 3.96$ ;  $df = 27$ ;  $p < 0.06$ ) and pea ( $F = 3.14$ ;  $df = 14$ ;  $p < 0.07$ ) main effects at WTARC in 1997 (Table 13). A significant pea main effect was detected at NARC in 1996 ( $F = 4.28$ ;  $df = 15$ ;  $p < 0.02$ ) and a wheat main effect was weakly observed. Infested and uninfested plots were significantly different at NARC in 1997 ( $F = 11.05$ ;  $df = 1$ ;  $p < 0.01$ ) indicating that the high mite population pressure observed at this site was sufficient to produce a significant difference in wheat biomass between WCM infested and uninfested plots. The NARC location in 1997 was the location with the highest mite population. No differences between WCM infested and uninfested plots could be detected at either location in 1996 or at WTARC in 1997 (Table 13). No wheat by pea interaction was observed in either year at both locations.

Significant differences were observed in mean pea biomass for the pea main effect ( $F = 5.70$ ;  $df = 14$ ;  $p < 0.03$ ) at WTARC in 1997 (Table 14). There were significant differences in mean pea biomass for the wheat main effect ( $F = 20.04$ ;  $df = 2$ ;  $p < 0.0001$ ), the pea main effect ( $F = 371.83$ ;  $df = 2$ ;  $p < 0.0001$ ) and the wheat by pea interaction ( $F = 5.12$ ;  $df = 4$ ;  $p < 0.002$ ) at NARC in 1996 (Table 14). A significant difference in mean pea biomass was detected between WCM infested and uninfested plots ( $F = 5.01$ ;  $df = 1$ ;  $p < 0.03$ ) at NARC in 1996 (Table 14). No differences in mean pea biomass between WCM infested and uninfested plots could be detected at either location in 1997 or at WTARC in 1996.

Table 13. Analysis of variance of plant-plant interactions between AWP and wheat on mean wheat biomass  $\text{g}\cdot\text{m}^{-2}$ .  $\alpha = 0.05$ .

WTARC	Wheat biomass in grams			
	1996		1997	
	F-test	p > F	F-test	p > F
Model	1.01	0.62	3.91	0.06
$R^2$		0.96		0.97
Infested	0.02	0.90	3.14	0.13
Wheat / $\text{m}^2$	0.82	0.68	3.69	0.07
AWP / $\text{m}^2$	0.18	0.77	3.66	0.07
Wheat/ $\text{m}^2$ *AWP/ $\text{m}^2$	0.97	0.54	2.57	0.16

NARC	Wheat biomass in grams			
	1996		1997	
	F-test	p > F	F-test	p > F
Model	3.65	0.03	2.54	0.05
$R^2$		0.96		0.91
Infested	1.25	0.30	11.05	0.007
Wheat / $\text{m}^2$	2.62	0.10	1.82	0.17
AWP / $\text{m}^2$	4.28	0.02	1.83	0.16
Wheat/ $\text{m}^2$ *AWP/ $\text{m}^2$	1.73	0.24	1.42	0.29

Table 14. Analysis of variance of plant-plant interactions between AWP and wheat on mean AWP biomass  $\text{g}\cdot\text{m}^{-2}$ .  $\alpha = 0.05$ .

WTARC	AWP biomass in grams			
	1996		1997	
	F-test	p > F	F-test	p > F
Model	4.01	0.22	3.75	0.07
$R^2$		0.99		0.97
Infested	0.00	1.00	0.00	1.00
Wheat / $\text{m}^2$	0.22	0.97	1.88	0.25
AWP / $\text{m}^2$	5.68	0.16	5.70	0.03
Wheat/ $\text{m}^2$ *AWP/ $\text{m}^2$	0.13	0.93	5.20	0.05

NARC	AWP biomass in grams			
	1996		1997	
	F-test	p > F	F-test	p > F
Model	89.92	0.0001	2.08	0.11
$R^2$		0.95		0.91
Infested	5.01	0.03	0.59	0.46
Wheat / $\text{m}^2$	20.04	0.0001	0.97	0.54
AWP / $\text{m}^2$	371.83	0.0001	3.10	0.04
Wheat/ $\text{m}^2$ *AWP/ $\text{m}^2$	5.12	0.002	0.41	0.93

Dryland cropping systems in the Northern Great Plains are limited by available moisture. A major function of fallow in the dryland crop rotation is to store and conserve moisture for the next grain crop. Weeds growing in the fallow utilize resources such as water and nitrogen that could be used by the subsequent grain cash crop. It is important to apply weed control measures to limit the loss of resources by weeds such as volunteer wheat. Additionally, control of weeds such as volunteer wheat eliminates a potential oversummering bridge for the WCM.

Lack of significant results for mean wheat biomass in 1996 at both locations could be attributed to plant stress caused by low precipitation and high mean daily maximum temperatures resulting in lower biomass production and less competition. Early plant senescence observed in 1996 supports this conclusion. WTARC had the lowest mean daily maximum temperatures in 1997 (Table 9) with approximately the same precipitation as 1996. The lower temperatures at WTARC in 1997 may account for the significant wheat and pea effects on wheat biomass (Table 13). Lower temperatures reduced plant stress and enabled sufficient biomass production even in reduced moisture situations by allowing the plants to increase biomass production over that from 1996.

Competition between the wheat and peas was not apparent. Because the legumes and simulated volunteer wheat were simultaneously planted, there was no emergence advantage to either crop. Temperature and precipitation interact and influence the growth and development of the wheat and pea plants. The canopy development of peas, in turn, influences the temperature in the plant canopies of the various treatments. Temperatures

within a canopy are influenced by available humidity and can differ as much as a 15° C from the air outside the canopy (Jackson 1982). Canopy temperatures in humid climates are near or above air temperature while arid areas tend to be near or below air temperature (Jackson 1982). It is entirely possible then that the canopy produced by the wheat-pea treatment combinations has a lower overall temperature relative to both the air temperature and the temperature present in the wheat alone plots. Additionally, high temperatures combined with low precipitation may negatively affect the more succulent AWP to a greater extent, than wheat bred for dryland production. While wheat and AWP compete for available moisture and light, temperature could be a more important factor in plant survivability and competition between the two species in a dryland setting.

## CONCLUSIONS

Significant treatment impacts were seen on mite populations in only 1 of 4 locations by years, that location was also the site with the overall greatest mite population. The wheat and pea treatment combination in which mite populations showed significant increase in field trials occurred at the highest wheat-pea plant density. Environmental conditions were influential on wheat curl mite populations and on the microenvironment in the canopy provided by wheat-pea treatment combinations. Mite numbers were strongly negatively influenced by temperature and less strongly influenced by precipitation in the absence of peas. Additionally, the volunteer wheat densities studied in a pea crop did not adversely affect AWP biomass production at any wheat density in the field or in the greenhouse.

The wheat-summer fallow strip cropping system in the semi-arid Great Plains and Mountain farm regions relies on the fallow portion of the rotation to replenish soil moisture for a subsequent grain crop. However, fallowed areas must be managed for weeds to prevent depletion of soil moisture. Substituting an alternate crop, such as AWP, into the crop rotation provides benefits in soil conservation, water management and disease and insect pest management (Risch et al. 1983, Biederbeck and Bouman 1994, Reynolds et al. 1994, Baily 1996) while offering growers greater flexibility in cropping system management and increased economic opportunities. However, management of this system must consider water usage by the legume crop so that soil moisture for the

subsequent cereal crop is not compromised. Information from my study suggests a beneficial effect to WCM populations at high plant densities. However, outbreaks of WCM and WSM that cause severe losses to wheat revenues occur only periodically. The potential benefits to a grower of including an alternate crop, such as AWP, in the crop rotation outweighs future concerns associated with the WCM.

Because of the sporadic nature of WCM and WSM outbreaks and the small size of the mite, management for the WCM is difficult and generally limited to cultural measures designed to break the overwintering bridge between spring and winter grain crops. Currently, management of the WCM does not use predictive models, economic thresholds or monitoring methods, such as sentinel crops, which would aid in WCM management.

To develop a model that is capable of predicting potential WCM outbreaks, a developmental threshold needs to be established for the WCM. Research that provides more detailed information on how temperature and humidity influence WCM dispersal, survivorship, fecundity and developmental time (Allen et al. 1995) also needs to be conducted. Such information would enable the creation of developmental models similar to those for the European corn borer, (*Ostrinia nubilalis* (Hubner)), (Got et al. 1996) and would establish a quantitative relationship between temperatures and WCM developmental time and fecundity. To develop a model capable of forecasting WCM populations on a regional and local basis, it is necessary to have information that relates temperature-based developmental models to ecological variation resulting from differences in altitude, latitude and longitude (Regniere 1996).

The development of an economic injury level (EIL) is considered a prerequisite for a modern pest management program (Stern 1973) and is needed to distinguish between a WCM present at low densities and one that is economically damaging. To develop an EIL for the WCM, information is needed that relates plant injury at different growth stages to plant yield. This is fundamental to the development of an EIL and provides the biological foundation for all economic and practical constraints (Pedigo et al. 1986). Specifically, information is needed that relates the time of injury, plant part injured, type of injury and intensity of injury to the plants response (Pedigo et al. 1986). Additionally, information is needed on the damage response of individual plants versus the damage response of plant stands as they often differ in tolerance, compensation and overcompensation (Funderburk and Pedigo 1983, Higgins et al. 1984).

Applied to WCM management, development of a geographic, temperature based predictive model would allow the identification of years favorable to WCM population growth and regions susceptible to WCM outbreaks. Use of WCM susceptible wheat varieties as a sentinel crop in regions and years targeted by a predictive model would increase the chances of detecting a WCM population. Establishment of an EIL would then allow pest managers to differentiate between damaging and non-damaging WCM populations.

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