Crop damage by wheat stem sawfly as related to soil water holding properties
by Jeanne Ann Kirchner Heilig

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

Abstract:
The wheat stem sawfly (Cephus cinctus Norton) has been recognized as an economically significant pest since the introduction of cereal grains in the northern Great Plains of the United States and the Prairie Provinces of Canada. This study was conducted to determine whether differences in soil water holding properties were responsible for the observed differences between damaged and undamaged winter and spring wheat fields in the Golden Triangle area of north central Montana. Wheat stem sawfly activity was observed and documented in fourteen wheat fields on a privately owned and operated farm near the western boundary of Hill County, Montana. Management and cultural practices had been the same for each of the fields for the past eight years, but some fields consistently sustained greater sawfly cutting damage than neighboring fields. Soil and plant samples were taken in each of the fields. Soil properties analyzed were percentage of clay in the top twelve inches of the soil profile, depth to calcium carbonate ($CaCO_3$), soil textural class, and plant available water holding capacity (PAWHC) throughout the soil profile. Plant samples were taken at each site to determine sawfly larval infestation and cutting damage. A strong negative relationship existed between total PAWHC and sawfly larval infestation. Also, as total PAWHC of the soil profile decreased, the actual cutting damage to the wheat increased. Based on soil textural classes, it may be possible to make management decisions that help minimize crop yield losses associated with sawfly cutting damage. The soil textural class of the soils in each field is related to the plant available water holding capacities of those soils. At some locations, total PAWHC of the soil and its relationship to sawfly damage could be a major factor to consider when deciding whether a sawfly-resistant solid stemmed cultivar or a higher yielding hollow stemmed cultivar is the best choice to optimize wheat production and economic return from each field.

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MONTANA STATE UNIVERSITY
Bozeman, Montana

December 1995

APPROVAL

of a thesis submitted by

Jeanne Ann Kirchner Heilig

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

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ACKNOWLEDGEMENTS

Sincere thanks go to Mr. Fred Elling for suggesting the topic of this research, and for the use of his farm for the collection of these data. A special thank you goes to Dr. Dale Clark of Western Plant Breeders Inc. for his invaluable assistance, endless patience, encouragement, and advice. Thanks to Western Plant Breeders Inc. for their financial support, and to all the staff for their help, humor, and encouragement throughout this entire project. I appreciate the time spent by Drs. Gerald Nielsen, Phil Bruckner, Dale Clark, Jeff Jacobsen, and Wendell Morrill for serving on my graduate committee. Sincere thanks go to Dr. Grant Jackson at the Western Triangle Agricultural Research Center at Conrad for the use of the Center's soil sampling equipment essential to completing the soil field investigation. Thanks to Bernie Schaff for his time and help with hand texturing the soil samples, and to Dr. Jack Martin for advice on the statistical analysis. Thanks also go to the MSU - Bozeman Department of Plant, Soil, and Environmental Sciences for the use of their facilities. Thanks also to my family and to my husband, Dave Heilig for helping me collect the soil samples, and for all of his patience and emotional and financial support throughout this project.

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ABSTRACT

The wheat stem sawfly (*Cephus cinctus* Norton) has been recognized as an economically significant pest since the introduction of cereal grains in the northern Great Plains of the United States and the Prairie Provinces of Canada. This study was conducted to determine whether differences in soil water holding properties were responsible for the observed differences between damaged and undamaged winter and spring wheat fields in the Golden Triangle area of north central Montana. Wheat stem sawfly activity was observed and documented in fourteen wheat fields on a privately owned and operated farm near the western boundary of Hill County, Montana. Management and cultural practices had been the same for each of the fields for the past eight years, but some fields consistently sustained greater sawfly cutting damage than neighboring fields. Soil and plant samples were taken in each of the fields. Soil properties analyzed were percentage of clay in the top twelve inches of the soil profile, depth to calcium carbonate ($CaCO_3$), soil textural class, and plant available water holding capacity (PAWHC) throughout the soil profile. Plant samples were taken at each site to determine sawfly larval infestation and cutting damage. A strong negative relationship existed between total PAWHC and sawfly larval infestation. Also, as total PAWHC of the soil profile decreased, the actual cutting damage to the wheat increased. Based on soil textural classes, it may be possible to make management decisions that help minimize crop yield losses associated with sawfly cutting damage. The soil textural class of the soils in each field is related to the plant available water holding capacities of those soils. At some locations, total PAWHC of the soil and its relationship to sawfly damage could be a major factor to consider when deciding whether a sawfly-resistant solid stemmed cultivar or a higher yielding hollow stemmed cultivar is the best choice to optimize wheat production and economic return from each field.

INTRODUCTION

The wheat stem sawfly (*Cephus cinctus* Norton) is an economically significant pest of cereal crops in the Northern Great Plains, especially in northern and eastern Montana, western North Dakota and areas of Saskatchewan, Manitoba and Alberta, Canada. Cereal grains currently affected include wheat (*Triticum aestivum* L.), durum (*Triticum durum* Desf.), barley (*Hordeum vulgare* L.), and rye (*Secale cereale* L.).

The life cycle of the wheat stem sawfly is closely synchronized with the physiological development of its host plants. Except for the brief time spent as an adult, the sawfly spends its entire life within the stem of the host plant, effectively avoiding attempts at biological or chemical control. Visible and infrared light transmitted through the ripening stem initiates the downward migration of the sawfly larva within the stem. The mature larva cuts a V-shaped notch around the inside of the stem near the soil surface, then plugs the stem to create a secure chamber in which the larva overwinters below the soil surface, protected against severe winter conditions. Cutting of the stem occurs in response to a decrease in moisture in the ripening stem, and occurs independently of light (Holmes, 1975). Wind or rain shortly before harvest causes the weakened stems to break where they were notched, usually about one inch above the soil surface.

Analysis of the damage caused by sawfly larvae shows that the sawfly causes economic losses in two ways. Physiological damage occurs as the sawfly larva tunnels through the stem destroying the vascular bundles, and thereby reducing the flow of water and nutrients to the developing kernels. This results in fewer kernels, lower test weights, and lower protein content in the harvested grain (Holmes, 1977; Weiss et al., 1987). Physical damage occurs when the sawfly larva notches the stem, causing the weakened stem to lodge and making it difficult or impossible to harvest.

Historical and current research has focused primarily on crop breeding and cultivation practices to reduce the economic losses from sawfly infestations. In 1945, H. L. Seamans described the seasonal weather conditions favorable for sawfly population increase, but also noted that the weather apparently affected the sawfly more through its influence on the host plants, rather than in any direct way. He concluded that future research regarding host plant development and sawfly larval survival must consider not only precipitation, but also the soil moisture and moisture storing capacity of the soil (Seamans, 1945).

Growers in the Golden Triangle of north central Montana have observed that some wheat fields consistently sustain greater physical damage from sawflies than neighboring or adjacent fields with similar management and cultural practices. If a relationship exists between soil water holding properties and sawfly infestations, then informed management decisions can be made to minimize damage. The objective of the present study was to determine whether variation in the water holding properties of the soil are responsible for the observed differences between damaged and undamaged fields of cereal grains in this region.

LITERATURE REVIEW

Historical and current research has focused primarily on crop breeding and cultivation practices to reduce economic losses from sawfly infestations. The existence of the western grass-stem sawfly was first documented in 1890 when Albert Koebele reared adults from larvae that were found in the stems of native grasses growing near Alameda, California (Koebele, 1890). The species was described under the name of *Cephus occidentalis* by Riley and Marlatt (1891) who suggested that, "The economic importance of this species arises from the fact that it may be expected at any time to abandon its natural food-plant in favor of the small grains, on which it can doubtless successfully develop."

C.N. Ainslie (1920) investigated and documented the habits and life cycle of the wheat stem sawfly, renamed *Cephus cinctus* Norton. Ainslie described the sawfly as an insect native to the United States, originally found in the North American native grasses of the *Agropyron* and *Elymus* genera. He noted during the early decades of the twentieth century that as cultivation increased and the acreage of native grasses decreased, pests such as the sawfly adapted to small grains as their preferred food supply. Since the sawfly larva is unable to move from one stem to another, the host stem must be large enough to afford both shelter and food during the entire larval and pupal stages. The stem diameters of wheat, rye, and barley are of an ideal size to house and feed the sawfly larvae, so it was a relatively easy step for these insects to gradually adapt to the more succulent and readily available cereal grains (Ainslie, 1920).

The wheat stem sawfly was recognized as a pest during the early part of this century as wheat acreage significantly expanded in the Northern Great Plains, and producers began utilizing a crop-fallow stripcropping sequence to conserve moisture and reduce soil loss from wind erosion. Norman Criddle, a farmer hired by the provincial government of Manitoba in 1910, was the first to explore, develop, and recommend various control strategies. Criddle's recommendations included deep moldboard plowing, early mowing of rye grasses for hay, refraining from mowing brome grass to permit emergence of a wheat stem sawfly parasite, planting trap crops of nonhost crops and grasses (females oviposit within the stem, but larvae do not complete development), planting nonhost crops, and early harvesting (Criddle, 1911). These control strategies were applied with moderate success, but were discontinued when they could no longer be used economically in a mechanized agriculture system. Today, the only methods that are still used to some extent are early swathing and crop rotation with nonhost crops. Unfortunately, the economics associated with continuous wheat production often make crop rotation to a nonhost unattractive to producers (Weiss and Morrill, 1992).

During 1933, the Canadian government initiated a research program to find an agronomically suitable wheat cultivar with a solid stem that was resistant to the wheat stem sawfly. The solid-stemmed spring cultivar 'Rescue' was released in 1947, and performed as hoped in sawfly infested areas. Losses for 'Rescue' did not exceed 5%, whereas losses in susceptible varieties reached 95% in 1947 in Teton County, Montana

(Platt et al., 1948). Unfortunately, the agronomic characteristics of 'Rescue' and successive solid-stemmed cultivars have not been as desirable as those of the hollow-stemmed cultivars. Wheat stem sawfly-resistant cultivars have historically exhibited lower yield potential, lower protein quality, reduced disease resistance, and inconsistency in expression of stem solidness caused by environmental conditions (Weiss and Morrill, 1992).

In May 1966, a new sawfly-resistant variety of spring wheat called 'Fortuna' was released jointly by the State Agricultural Experiment Stations of North Dakota and Montana. Fortuna combined leaf and stem rust resistance and a solid stem with yield comparable yield to the older hollow-stemmed varieties. Fortuna was only recommended for production in areas where sawflies were economically important wheat pests because of susceptibility to lodging and black chaff infections (McBride and Colberg, 1967).

The low acceptance by growers of wheat stem sawfly-resistant cultivars expanded the focus of sawfly research to include the effects of climatological conditions on sawfly population dynamics. H.L. Seamans (1945) first observed and reported the effects of weather on the development and survival of the sawfly. He noted that adults were active only on calm days during periods of bright sunshine when the temperature was between 64° and 90° Fahrenheit. Seamans described the seasonal weather conditions favorable for sawfly population increase, but also noted that weather apparently affected the sawfly more through its influence on the host plants, rather than in any direct way. He observed that excessive drought conditions were as detrimental to the sawfly as excessive moisture, but that only water in the form of precipitation had been considered. He concluded that future research regarding host plant development and sawfly larvae survival must consider not only precipitation, but also the soil water and the water storing capacity of the soil (Seamans, 1945).

By the 1950's, modern mechanical tillage practices to reduce sawfly larvae survival were being evaluated. Holmes and Farstad (1956) studied the effects of field exposure on the wheat stem sawfly during the larval and pupal life stages. They reported that effective control of the sawfly could be obtained by exposing the stubble on the soil surface in the fall, since most if not all of the mortality occurred during the winter. Large-scale fall tillage to destroy stubble is not a desirable agronomic practice, since standing stubble entraps snow during the winter and reduces soil erosion by wind. However, tillage could be restricted to field borders where sawfly infestations are usually concentrated (Morrill et al., 1993).

Holmes and Farstad also evaluated the timing of spring tillage as a sawfly control measure. They found the highest sawfly mortalities in stubble exposed during late May and early June near Regina, Saskatchewan, when most individuals were in the prepupal and pupal stages. Earlier exposure permitted increased numbers of larvae to survive the effects of exposure by re-entering diapause (Holmes and Farstad, 1956).

Regardless of tillage practices, sawfly larvae equally infested both the solid-stemmed and hollow-stemmed cultivars. Holmes and Peterson (1960) compared spring wheat varieties for susceptibility to sawfly infestation. Regardless of variety, the most attractive stems for oviposition were succulent, in the boot stage, and of a suitable diameter to be readily grasped by the ovipositing female. They concluded that solid-stemmed varieties were just as "infestable" as hollow-stemmed varieties, and that varietal differences in infestations were due to differences in the growth rates of the varieties rather than to differences in varietal resistance to oviposition (Holmes and Peterson, 1960). The heaviest sawfly infestations occurred in a variety when the stem internodes were optimal for oviposition, and that stage of the plant coincided with peak oviposition activity of the adult female sawfly. Loss from lodging was reduced if the solid-stem trait was strongly expressed, as then the larva generally was unable to tunnel to the base of the stem and girdle it before maturity of the wheat and harvest.

After determining that the life cycle of the wheat stem sawfly was closely synchronized with the development of the host plant, Holmes (1975) focused on the effects of moisture, gravity, and light on the behavior of the sawfly larvae. Upon hatching, the larvae tunnel through all of the stem internodes, feeding on parenchyma and vascular tissues in the stem wall as they tunnel. Visible and infrared light transmitted through the ripening stem initiates the downward migration of the larvae. The absence of light below the soil surface appears to be the stimulus that enables the larva to select the proper site at which to cut the stem. In laboratory experiments, Holmes (1975) removed infested stems from the field in late July and stored them in darkness under various moisture conditions. Without the stimulus of light, the larvae were unaffected by gravity or stem moisture, and they cut the stems at random locations. The negative response of the larvae to light transmitted through ripening stems appears to be the mechanism that insures that the larvae are at ground level when they cut the stem, and thus are protected against adverse conditions. Larvae in stubble exposed above ground do not survive the winters in the northern Great Plains (Morrill et al., 1993). The actual cutting occurs in response to a decrease in moisture in the ripening stem, and occurs independently of light (Holmes, 1975).

Analysis of the damage caused by the sawfly larvae shows that the sawfly causes economic losses both physically by causing the plant to lodge so that these stems are difficult or impossible to harvest, and physiologically because larval tunneling cuts vascular bundles and reduces the flow of water and nutrients to the developing kernels. Physiological losses are difficult to assess, though. Holmes (1977) demonstrated that the sawfly females preferred to oviposit into the earlier developing, larger stems that normally would have produced heavier kernels with higher protein content, and that the later, smaller uninfested stems did not provide an unbiased comparison for determining the effects of the larvae on kernel weight or protein content. Tunneling and feeding by the larvae early in the development of the host plant stem reduces the area of the phloem, and thus reduces the number of kernels. After comparing similar diameter stems, Holmes (1977) found a range in yield reduction of 10.8% - 22.3% attributable to reductions in the number and size of kernels. The loss in protein content ranged from 0.6% - 1.2%.

Morrill et al., (1992) also determined that wheat stem sawfly infestation was usually higher in the larger stems that had the potential for producing the heaviest heads. Accurate estimations of physiological loss could be made only by comparing reductions in yield and quality between infested and uninfested stems of similar size.

Solid-stemmed spring wheat cultivars have been used since 1945 to reduce sawfly losses, and experimental lines of solid-stemmed winter wheat have recently been developed by crossing solid-stemmed spring wheat and hollow-stemmed winter wheat (Bruckner et al., 1993). As with spring wheat, the sawfly larvae have difficulty tunneling through the solid stems to overwinter below ground. Fewer cut stems and greater overwinter mortality were evident in solid-stemmed winter wheat plants than in hollow-stemmed plants. Stem solidness does not appear to have a detrimental effect on the two predominant *Bracon* species that parasitize sawfly larvae (Morrill et al., 1994).

The use of sawfly-resistant, solid-stemmed varieties of spring wheat and early swathing to reduce harvest losses are currently the most widely used practices for controlling losses from sawflies in the northern Great Plains. Early swathing reduced harvest losses (Holmes and Peterson, 1965), but increased harvest costs. Therefore, swathing is desirable only if the crop is severely infested. The slow and tedious task of stem dissection is the primary method used by growers and consultants to determine infestation levels and make harvest decisions.

Infestations can also be detected by the presence of dark stem spots which are caused by boring larvae (Morrill et al., 1992). Feeding by the wheat stem sawfly larva at a node in the stem interrupts upward transport of carbohydrates, and results in a dark spot below the node that is visible on the stem exterior. The occurrence of these spots was used by Morrill et al. (1992) to predict infestation. Infestation estimations based on subnodal stem spots could be made as early as the soft dough stage with only 4.7% error.

Subnodal stem spots were found to be reliable indicators of sawfly infestation in wheat, and can be a useful tool for growers and consultants. However, caution should be used because stem spots may occur naturally in some cultivars or may be caused by plant pathogens. The percentage of infested stems that justify management practices are difficult to establish, since the subsequent lodging is a function of wind, rain, and elapsed time between maturity and harvest (Morrill et al., 1992).

MATERIALS AND METHODS

Site Description

Wheat stem sawfly activity was observed and documented in 1994 and 1995 on fourteen fields on the Fred Elling farm. This privately owned and operated farm is eleven miles south of Inverness and Rudyard near the western boundary of Hill County, Montana (Fig. 1). Situated entirely on glaciated upland, Mr. Elling's dryland wheat operation is a crop fallow rotation system. The fields are in north-south windstrips to minimize erosion caused by the prevailing west winds. All of the fields are on well drained soils developed from glacial till parent material. Management and fertilization have been the same for each of the fields for the past eight years. Historically, hard red winter wheat was grown on all of these fields, but lack of fall moisture in 1994 necessitated the planting of hard red spring wheat during the 1995 crop year. Fields in three different sections were chosen for sampling, since they were observed to historically exhibit a wide range of visible sawfly damage.

The south half of Section 29, Township 31 North, Range 8 East is divided into nine windstrips (Fig. 2). The fields were numbered from west to east, and the odd numbered fields were planted to 'Judith' hard red winter wheat during the 1994 crop year.

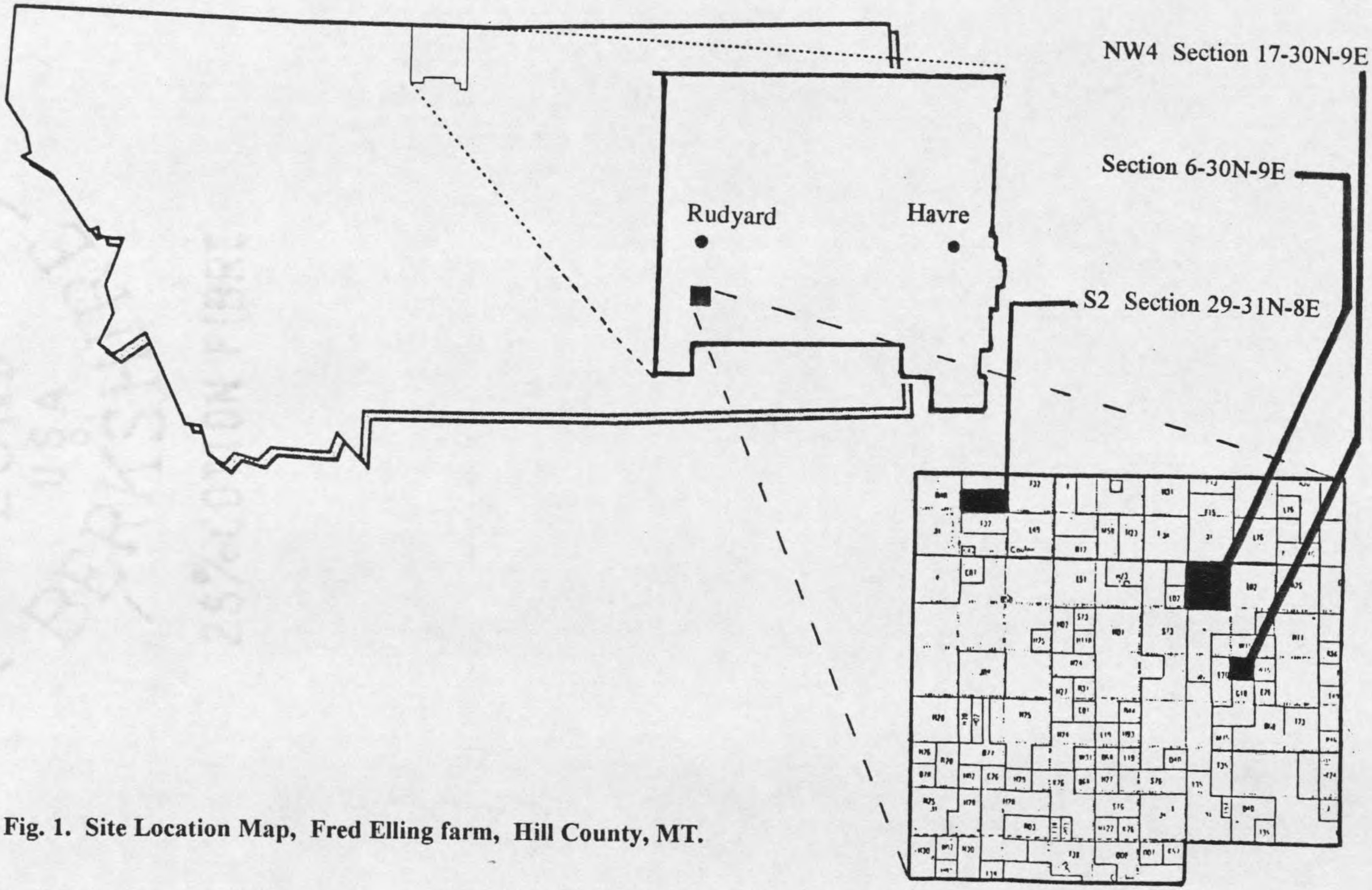

Fig. 1. Site Location Map, Fred Elling farm, Hill County, MT.

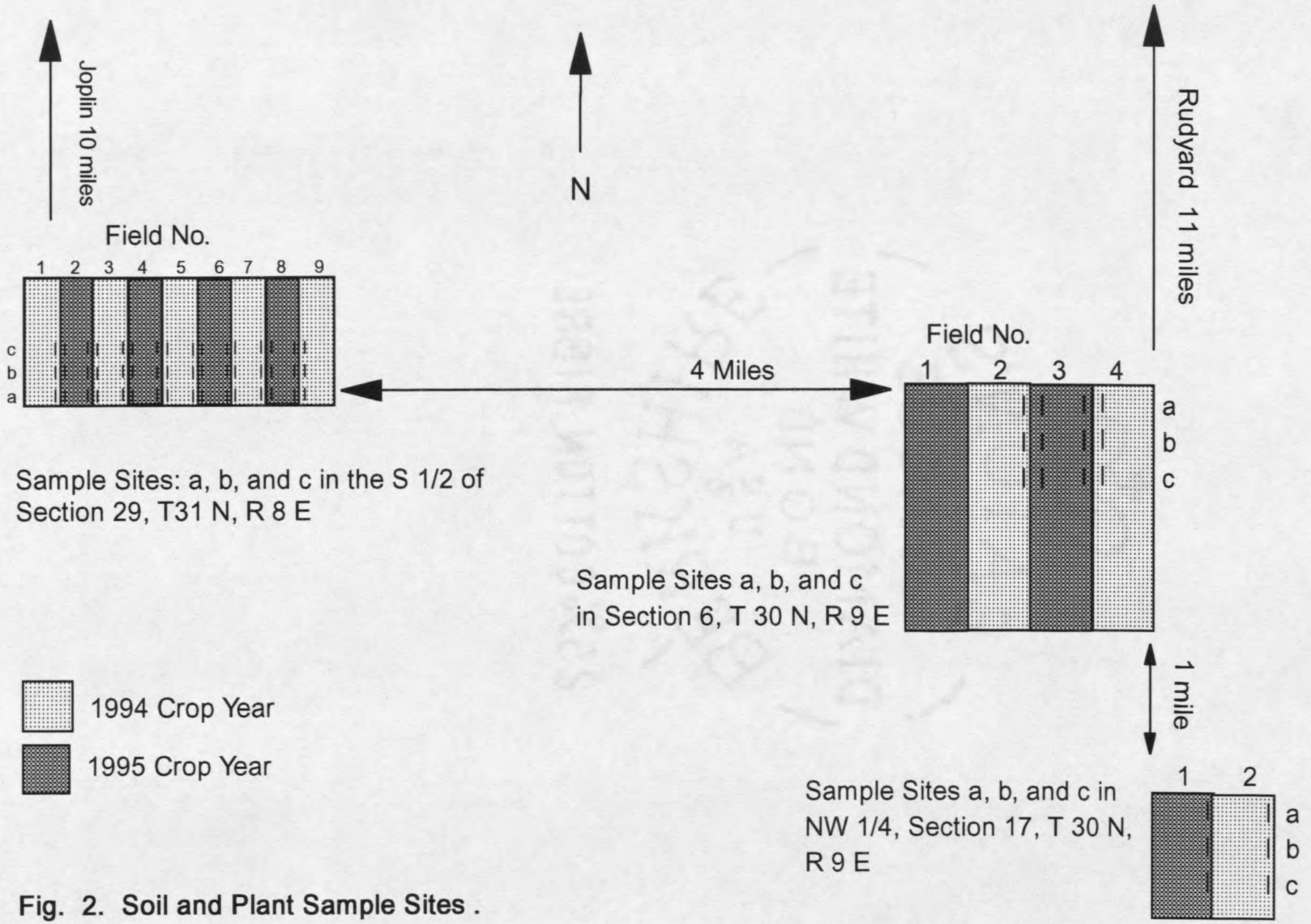

Fig. 2. Soil and Plant Sample Sites .

In 1995, the alternate fields were planted to hard red spring wheat with 'Hi-Line' in fields 2 and 4 and 'Stoa' in fields 6 and 8.

The soils in Fields 1 through 4 on the west side of Section 29 are primarily Phillips (fine, montmorillonitic Borollic Paleargids) and Elloam (fine, montmorillonitic Borollic Natrargids) clay loams with 0 to 4 percent slopes. The predominant soils in Fields 5 through 9 on the east side are Phillips clay loam and Kevin loam (fine loamy, mixed Aridic Argiborolls) with 0 to 4 percent slopes (Soil Survey Staff, 1995 Interim).

Section 6, Township 30 North, Range 9 East is divided into four strips (Fig. 2). Fields 2 and 4 were planted to Judith hard red winter wheat in 1994. Hi-Line hard red spring wheat was planted in Fields 1 and 3 in 1995. The soils on Section 6 are also Phillips and Elloam clay loams with 0 to 4 percent slopes.

The northwest quarter of Section 17, Township 30 North, Range 9 East is separated into two fields (Fig. 2). Judith hard red winter wheat was planted in Field 2 in 1994. In 1995, Hi-Line hard red spring wheat was grown in Field 1. The soils are Telstad and Joplin loams (fine-loamy, mixed Aridic Argiborolls) with 0 to 4 percent slopes (Soil Survey Staff, 1995 Interim).

Sampling Methods

Plant and soil samples were taken at the same relative locations in each of the fields. Three soil samples were taken near the east and the west edge of each field. The first sample was taken 200 feet from the end of the field, and subsequent samples were taken at 60 foot intervals. Sampling sites were numbered by field number, east or west edge of the field, and the letter designating the sample site. For example, sample 2e - a is the first site on the east edge of Field 2. No samples were collected from the edges of those fields bordered by grasslands of Conservation Reserve Program (CRP) fields.

Sixty-six 1.25 inch diameter soil core samples were taken to a depth of 48 inches using a Giddings soil probe. Of these, 48 samples were taken from Section 29, twelve from Section 6, and six from Section 17. As each sample was taken, moist soil color was determined with the Munsell color chart for each 12 inches of soil core sample. Also, depth to calcium carbonate ($CaCO_3$) was measured using 1N HCl, then each sample was divided into one foot segments. Each one foot segment was weighed, dried and ground. Mechanical analysis was used to determine texture of the surface foot of soil, and the lower horizons were hand textured to determine soil textural class and percent clay. The soil samples that were analyzed with the hydrometer served as checks when the soil samples from the lower horizons were hand textured (B. Schaff, 1994, personal communication).

Total plant available water holding capacity (PAWHC) for soil at each site was determined using the "Plant Available Water Capacities for Soil Textural Classes in Montana" method reported by Paul L. Brown (Juhnke and Baldridge, 1984).

The farmer reported no visible cutting damage to the winter wheat in 1993, so prior to tillage in the spring of 1994, the 1993 winter wheat stubble was sampled at each soil sampling site to determine the presence of surviving sawfly larvae overwintering below ground in the stubble. Sawfly larvae were found in the winter wheat stubble in all fields. Plant samples of the winter wheat in 1994 and the spring wheat in 1995 were taken two days before harvest at each site to determine sawfly larval infestations and cutting damage. Three replicated samples of wheat stems were collected at each sampling site. Each sample consisted of all of the plants in a one foot length of row, which was the fifth complete row (14 inch drill spacing) from the field's edge. Replications were ten feet apart.

Cut stems were counted as damaged, and all remaining stems were split longitudinally to determine presence of sawfly larvae within the stems. Cutting damage was calculated as a percentage of the cut stems to the total number of stems in each of the three replications. Infestation was the percentage of cut stems plus the uncut stems containing sawfly larvae. Mean infestation and cutting damage percentages were then calculated for each site.

The data were analyzed using MSUSTAT (Lund, 1988) to determine correlations between insect activity and plant available water holding capacity, percent clay, or depth to $CaCO_3$. The data from each section were analyzed separately, then the data from all three sections were combined and analyzed together.

No stem cutting data were available from fields in Section 29 for the 1994 crop year. Those fields were damaged by hail on June 18th. Examination of the hail damaged stems revealed extensive sawfly infestation, but high larval mortality due to the broken and exposed stems.

RESULTS

The estimated PAWHC of the soils ranged from 1.4 inches per foot of soil for moderately coarse textured sandy loams to 2.2 inches per foot of soil for moderately fine textured clay loams. Total PAWHC of the soil profile was calculated for the top 36 inches of the soil profile. Total PAWHC throughout the profile for all of the soil cores sampled ranged from 4.5 to 6.6 inches.

Moist soil color hues of 2.5Y were the predominant soil colors throughout the profile at all sites. Based on the moist soil color, organic matter ranged between 1.3 and 3.0 percent (Zelenak, 1994). The percentage of clay in the top 12 inches of each soil profile ranged from 16 to 40 percent clay (Table 1). Based on the "feel" of the mechanically analyzed samples, relative percentages of clay in the lower horizons were estimated and ranged between 15 and 43 percent clay. Depth to calcium carbonate ($CaCO_3$) varied from 2.5 inches to 23.5 inches below the soil surface (Table 1).

Total sawfly larval infestation and sawfly cutting damage varied across soil textural classes and field locations. Table 1 indicates that in Section 29, the soil textures were primarily clay loams and loams with estimated PAWHC ranging from 5.8 to 6.6 inches. Total infestation ranged from 2.0 to 25.7 percent of the stems sampled. Cutting

TABLE 1. Soil textural class, clay content and plant available water holding capacity (PAWHC) for three soil depth increments and depth to calcium carbonate in relation to sawfly damage and infestation at 42 sampling sites.

	0 - 12 inches			12 - 24 inches			24 - 36 inches			0 - 36 in			
Site	Soil texture ++	Clay content	PAWHC	Soil texture ++	Clay content	PAWHC	Soil texture ++	Clay content	PAWHC	Total PAWHC	Depth to CaCO3	Mean Damage	Mean Infestation
		%	in/ft		%	in/ft		%	in/ft	in		%	
Section 29													
2w - a	CL	32	2.2	CL	34	2.2	CL	30	2.2	6.6	7.0	4.7	6.1
2w - b	CL	30	2.2	CL	34	2.2	SCL	30	2.2	6.6	7.0	1.8	12.5
2w - c	L	20	2.1	CL	30	2.2	SCL	35	2.2	6.5	9.0	4.7	9.3
2e - a	L	24	2.1	CL	28	2.2	SCL	25	2.2	6.5	8.5	3.5	4.1
2e - b	CL	32	2.2	CL	30	2.2	SC	38	1.9	6.3	4.5	0.0	2.0
2e - c	CL	28	2.2	CL	30	2.2	SCL	30	2.2	6.6	7.0	2.0	6.0
4w - a	L	22	2.1	SCL	35	2.2	SCL	35	2.2	6.5	12.0	0.9	7.6
4w - b	L	22	2.1	CL	34	2.2	CL	40	2.0	6.3	10.0	2.2	5.1
4w - c	SCL	20	2.2	CL	32	2.2	SL	20	1.5	5.9	9.0	6.3	13.3
4e - a	CL	28	2.2	CL	30	2.2	SCL	35	2.2	6.6	4.0	2.2	4.3
4e - b	CL	34	2.2	CL	36	2.2	CL	40	2.2	6.6	4.5	4.6	5.7
4e - c	CL	36	2.2	CL	40	2.2	CL	38	2.2	6.6	6.0	1.0	2.1
6w - a	CL	34	2.2	CL	38	2.2	CL	36	2.2	6.6	4.5	13.2	21.7

TABLE 1. Soil textural class, clay content and plant available water holding capacity (PAWHC) for three soil depth increments and depth to calcium carbonate in relation to sawfly damage and infestation at 42 sampling sites.

	0 - 12 inches			12 - 24 inches			24 - 36 inches			0 - 36 in			
Site	Soil texture ++	Clay content	PAWHC	Soil texture ++	Clay content	PAWHC	Soil texture ++	Clay content	PAWHC	Total PAWHC	Depth to CaCO3	Mean Damage	Mean Infestation
		%	in/ft		%	in/ft		%	in/ft	in		%	
Continued.													
6w - b	CL	32	2.2	CL	38	2.2	SL	15	1.4	5.8	10.0	16.2	25.7
6w - c	L	22	2.1	CL	28	2.2	SCL	28	2.2	6.5	5.0	9.4	16.7
6e - a	CL	30	2.2	CL	32	2.2	SCL	32	2.2	6.6	17.0	0.9	5.7
6e - b	CL	32	2.2	CL	38	2.2	SL	18	1.5	5.9	8.0	16.0	19.0
6e - c	CL	28	2.2	CL	32	2.2	C	42	2.0	6.4	11.0	3.4	12.7
8w - a	CL	36	2.2	CL	38	2.2	SL	18	1.5	5.9	6.5	8.8	13.2
8w - b	CL	34	2.2	CL	36	2.2	SL	15	1.4	5.8	13.0	5.2	13.9
8w - c	L	24	2.1	CL	36	2.2	CL	34	2.2	6.5	16.0	6.8	11.9
8e - a	C	40	2.0	C	42	2.0	SC	40	1.9	5.9	2.0	12.9	21.8
8e - b	CL	36	2.2	CL	38	2.2	C	42	2.0	6.4	3.0	12.4	17.5
8e - c	CL	34	2.2	CL	36	2.2	SC	40	1.9	6.3	9.5	12.6	23.2
Mean		30	2.2		34	2.2		32	2.0	6.3	8.1	6.3	11.7
SE Sample Mean		1.20	0.01		0.80	0.01		1.80	0.06	0.06	0.78	0.01	0.01

TABLE 1. Soil textural class, clay content and plant available water holding capacity (PAWHC) for three soil depth increments and depth to calcium carbonate in relation to sawfly damage and infestation at 42 sampling sites.

	0 - 12 inches			12 - 24 inches			24 - 36 inches			0 - 36 in			
Site	Soil texture ++	Clay content	PAWHC	Soil texture ++	Clay content	PAWHC	Soil texture ++	Clay content	PAWHC	Total PAWHC	Depth to CaCO3	Mean Damage	Mean Infestation
		%	in/ft		%	in/ft		%	in/ft	—— in——		——— % ———	
Section 6													
* 2e - a	L	28	2.1	CL	34	2.2	CL	30	2.2	6.5	13.0	0.7	0.7
* 2e - b	CL	30	2.2	CL	28	2.2	CL	35	2.2	6.6	13.0	1.4	12.2
* 2e - c	CL	32	2.2	CL	34	2.2	SCL	28	2.2	6.6	15.5	4.5	7.7
3w - a	L	26	2.1	CL	35	2.2	CL	35	2.2	6.5	14.5	11.3	22.6
3w - b	CL	30	2.2	CL	34	2.2	SiC	40	2.0	6.4	13.0	11.8	21.8
3w - c	CL	36	2.2	CL	38	2.2	SC	40	2.0	6.4	14.0	13.8	23.3
3e - a	L	22	2.1	CL	35	2.2	SCL	35	2.2	6.5	17.0	7.6	15.2
3e - b	L	26	2.1	CL	38	2.2	CL	38	2.2	6.5	8.0	11.1	20.8
3e - c	C	40	2.0	C	43	2.0	CL	38	2.2	6.2	2.5	4.6	10.3
* 4w - a	CL	32	2.2	CL	38	2.2	SC	42	2.0	6.4	10.0	10.8	15.4
* 4w - b	L	22	2.1	CL	30	2.2	SCL	34	2.2	6.5	17.0	6.0	13.4
* 4w - c	CL	28	2.2	CL	30	2.2	SCL	27	2.2	6.6	8.0	5.5	15.0
Mean		29	2.1		35	2.2		35	2.2	6.5	12.1	7.4	14.9
SE Sample Mean		0.02	0.02		0.01	0.02		0.01	0.03	0.03	1.24	0.01	0.02

TABLE 1. Soil textural class, clay content and plant available water holding capacity (PAWHC) for three soil depth increments and depth to calcium carbonate in relation to sawfly damage and infestation at 42 sampling sites.

	0 - 12 inches			12 - 24 inches			24 - 36 inches			0 - 36 in			
Site	Soil texture ++	Clay content	PAWHC	Soil texture ++	Clay content	PAWHC	Soil texture ++	Clay content	PAWHC	Total PAWHC	Depth to CaCO3	Mean Damage	Mean Infestation
		%	in/ft		%	in/ft		%	in/ft	in		%	
Section 17													
1e - a	CL	30	2.2	CL	34	2.2	CL	34	2.2	6.6	12.0	8.3	10.1
1e - b	CL	28	2.2	CL	30	2.2	SL	20	1.6	6.0	12.0	18.3	21.5
1e - c	CL	28	2.2	CL	32	2.2	SL	18	1.5	5.9	11.5	18.1	22.1
* 2e - a	SL	16	1.5	SL	18	1.5	SCL	28	2.2	5.2	23.5	27.8	48.1
* 2e - b	SL	18	1.5	SCL	25	2.2	SL	17	1.5	5.2	14.0	19.0	46.2
* 2e - c	SL	18	1.5	SL	20	1.5	SL	15	1.5	4.5	14.0	41.5	56.3
Mean		23	1.9		27	2.0		22	1.7	5.6	14.5	22.2	34.0
SE Sample Mean		0.03	0.16		0.03	0.15		0.03	0.15	0.31	1.85	0.05	0.08

* Fields cropped during the 1994 crop year. The other fields were cropped in 1995.

++ SL = sandy loam; L = loam; SCL = sandy clay loam; CL = clay loam; SC = sandy clay; SiC = Silty Clay; C = clay damage varied from 0 to 16.2 percent of the total stems sampled (Fig. 3 and Table 1).

The soil textural classes in Section 6 were predominately clay loams with relatively high estimated PAWHC. Total PAWHCs of the soils in Section 6 had very little variability. They ranged from 6.2 to 6.6 inches, with most sites clustered between 6.4 and 6.6 inches total PAWHC. There was no apparent association between total PAWHC and larval infestation or cutting damage at this site. Total sawfly infestation ranged from 0.7 to 23.2 percent of the total wheat stems sampled. Cutting damage varied from 0.7 to 13.8 percent of the total stems sampled (Fig. 4 and Table 1).

The soils in Section 17 had the most variability in total PAWHC of all three of the sections. The soils varied from moderately coarse textured sandy loams with low total PAWHC to moderately fine textured clay loams with relatively high total PAWHC. Figure 5 illustrates the range in total PAWHC for the soils of Section 17 from 4.5 to 6.6 inches. Sawfly infestation ranged from 10.1 percent on clay loam soil to 56.3 percent on sandy loam soil, and cutting damage varied from 8.3 to 41.5 percent (Fig. 5 and Table 1).

The combination of the data from all sampling sites gives a similar picture of the relationships between the total PAWHC of the soils based on soil textural class and sawfly infestation with subsequent cutting damage by the wheat stem sawfly larvae. With the wider range of total PAWHC and larger sampling size, total PAWHC of the entire soil profile was negatively correlated with wheat stem sawfly larval infestation and cutting damage (Table 2 and Fig. 6). Sawfly larval infestation and cutting damage were closely associated, regardless of whether the sections were considered individually or all of the

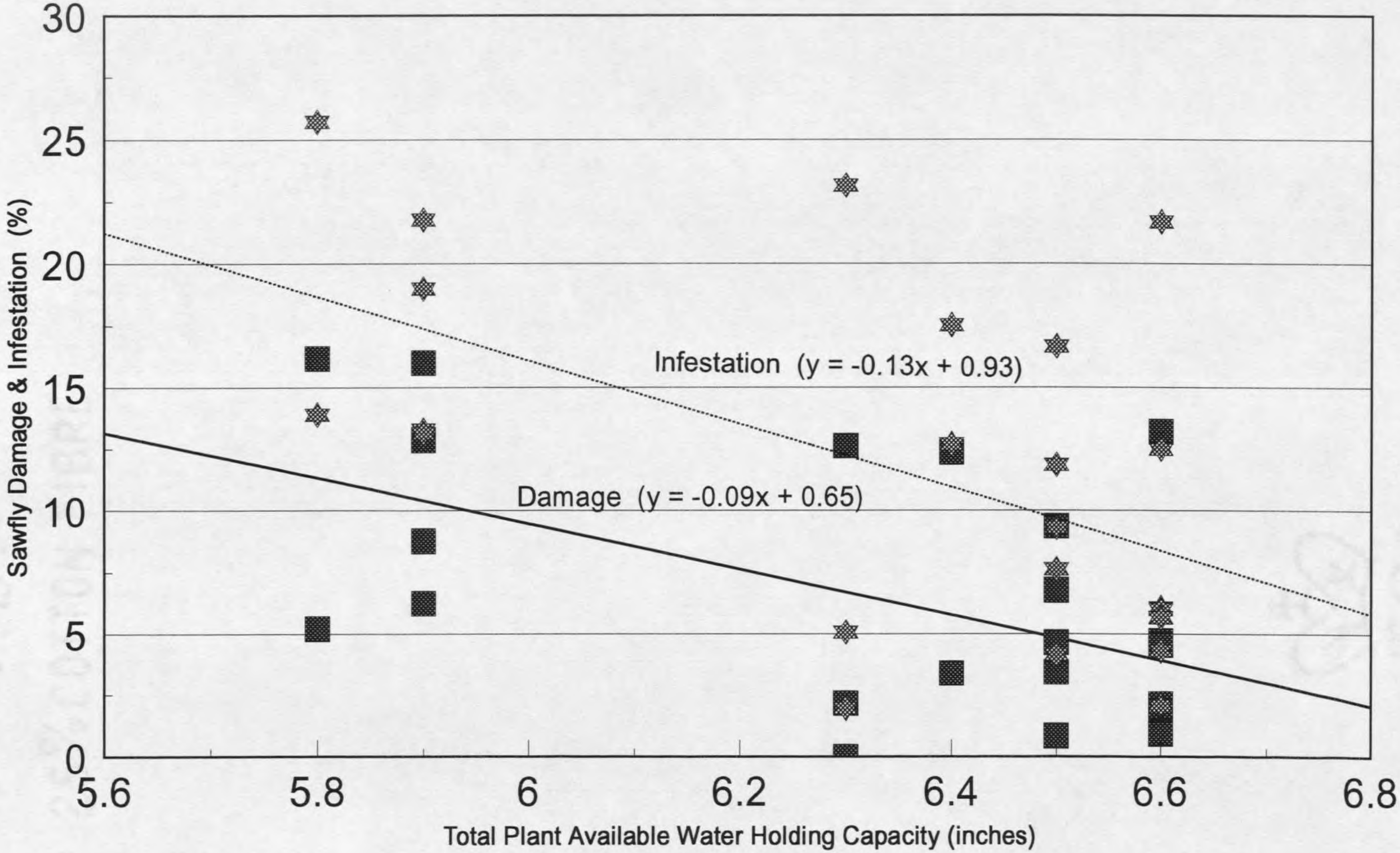

Fig. 3. Comparison of total plant available water holding capacity (PAWHC) to sawfly damage and infestation in Section 29 : ■ = Damage, ✡ = Infestation.

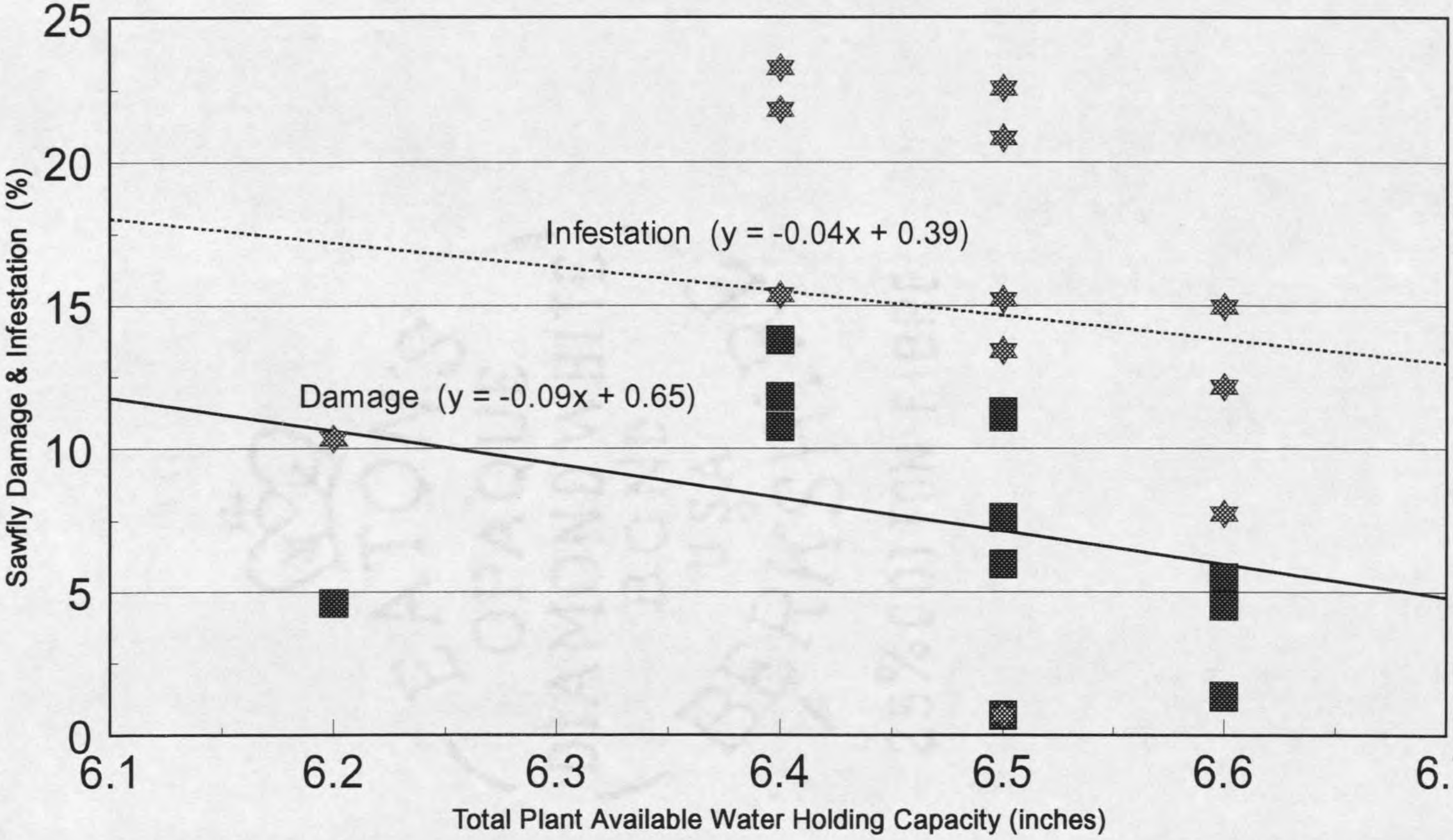

Fig. 4. Comparison of total plant available water holding capacity (PAWHC) to sawfly damage and infestation in Section 6: ■ = Damage, ✡ = Infestation.

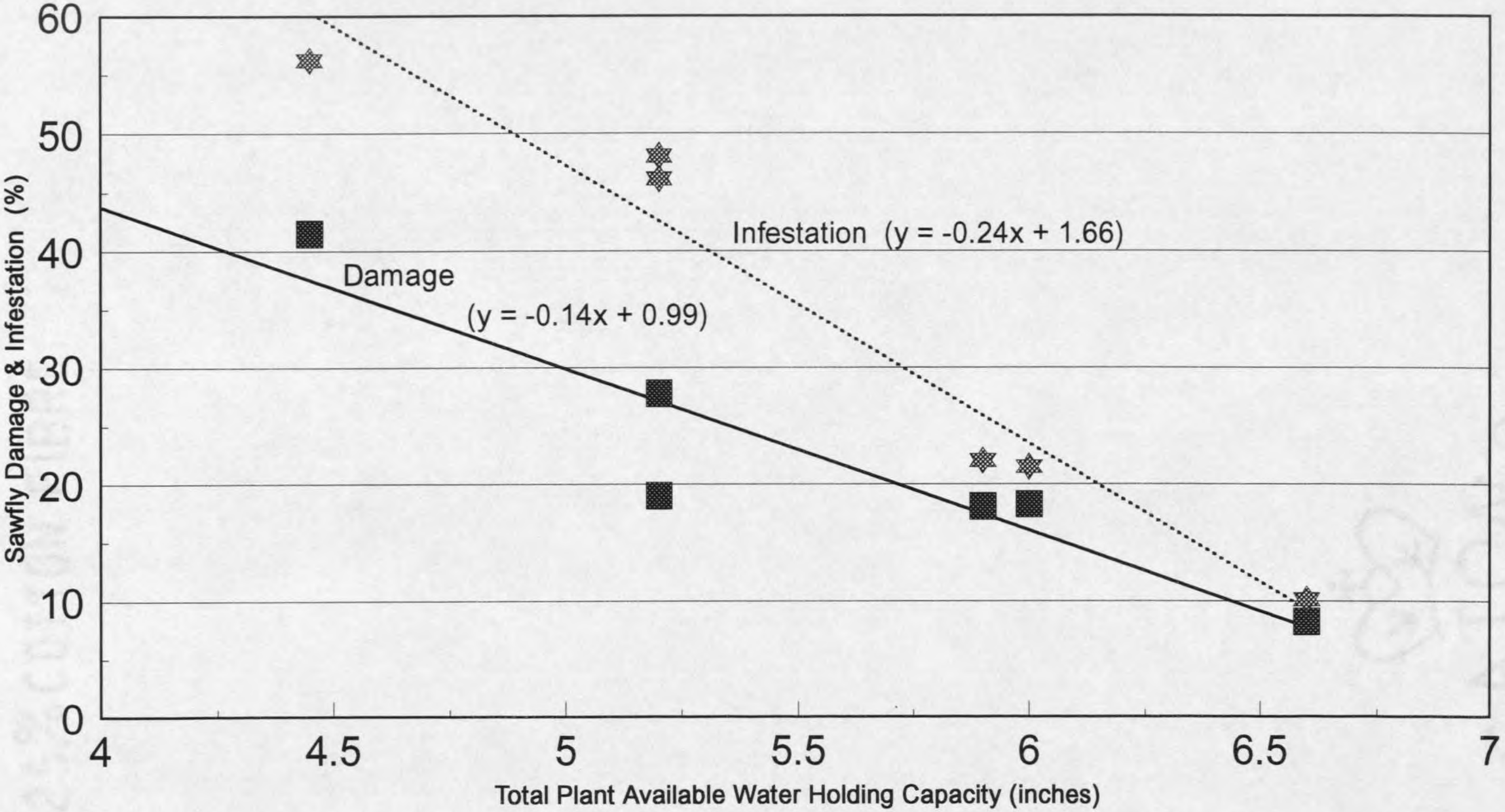

Fig. 5. Comparison of total plant available water holding capacity (PAWHC) to sawfly damage and infestation in Section 17: ■ = Damage, ✡ = Infestation.

Table 2. The relationship between sawfly cutting damage and total infestation to total plant available water holding capacity (PAWHC).

	Section 29	Section 6	Section 17	For All Sections
		Total plant available water holding capacity		
Cutting Damage	-0.54**	-0.23^{ns}	-0.93**	-0.81**
Infestation	-0.54**	-0.06^{ns}	-0.98**	-0.81**
Significant Values (5 %)	0.404	0.576	0.811	0.304
Significant Values (1 %)	0.515	0.708	0.917	0.393
Sample Size	24	12	6	42

** Significant at .01 probability level
ns Not significant

sampling sites were combined (Table 3). The total PAWHC of soil corresponding to the rooting depth of the wheat should be considered. The correlation between PAWHC of the soil and sawfly infestation and damage became stronger as the PAWHC of the surface horizon was combined with the PAWHCs of the lower soil depths (Table 4).

Depth to $CaCO_3$ in the soil profile and clay content in the upper 12 inches of the soil profile were not correlated with sawfly cutting damage, although there were weak correlations between the percent clay in the top 12 inches of the profile and sawfly larval infestation (Table 5).

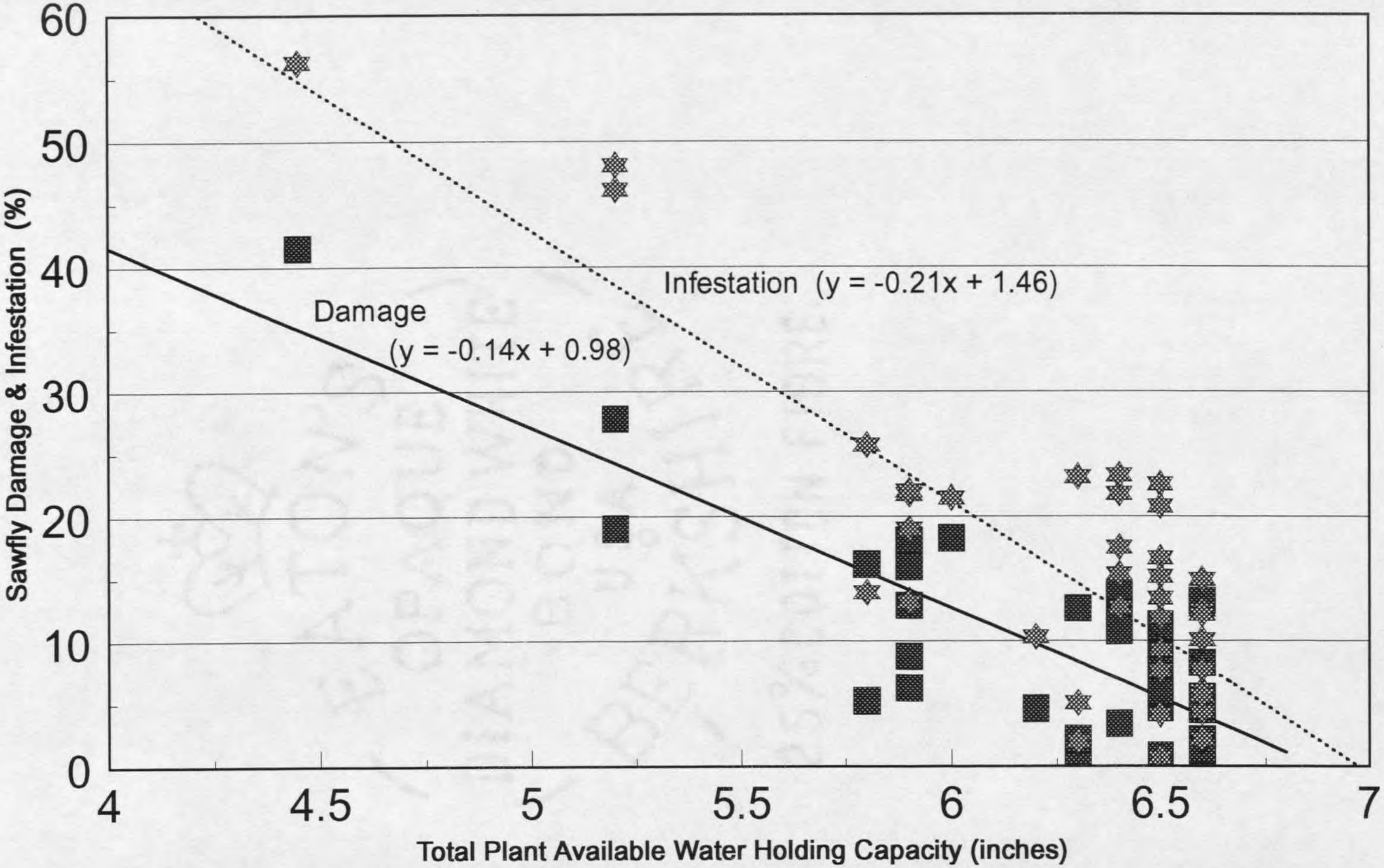

Fig. 6. Comparison of total plant available water holding capacity (PAWHC) to sawfly damage and infestation for all fields sampled: ■ = Damage, ✶ = Infestation .

Table 3. The relationship between sawfly larval infestation and actual cutting damage

	Section 29	Section 6	Section 17	All Sections
	Sawfly Larval Infestation			
Cutting Damage	0.91**	0.91**	0.86*	0.93**
Sample Size	24	12	6	42

* Significant at the 0.05 probability level

** Significant at the 0.01 probability level

Table 4. Relationship between sawfly cutting damage and total infestation to total plant available water holding capacity (PAWHC) at various soil depths for all sampled sites (n = 42).

Site Correlation	R
PAWHC 0-12 inches to cutting damage	-0.70**
PAWHC 0-24 inches to cutting damage	-0.72**
PAWHC 0-36 inches to cutting damage	-0.81**
PAWHC 0-12 inches to total infestation	-0.68**
PAWHC 0-24 inches to total infestation	-0.77**
PAWHC 0-36 inches to total infestation	-0.81**

** Significant at the 0.01 probability level

TABLE 5. Relationship between sawfly cutting damage and total infestation to profile depth to calcium carbonate (CaCO3) and clay content in the 0 - 12 inches of the soil profile for all sample sites (n = 42).

	Depth to CaCO3	Clay content 0-12 inches
Cutting damage	-0.29 ns	-0.26 ns
Infestation	-0.37**	-0.35**

** Significant at the 0.01 probability level
ns Not Significant

DISCUSSION

Water-related soil properties analyzed in the present study were the percentage of clay in the upper 12 inches of the soil profile, depth to $CaCO_3$, soil textural class, and estimated PAWHC throughout the soil profile (Table 1). Estimated total PAWHC of the rooting depth of wheat was the soil physical property showing the strongest negative relationship to sawfly cutting damage and infestion ($r = -0.81$, $P < 0.01$). A high positive relationship existed between wheat stem sawfly larval infestation and actual cutting damage ($r = 0.93$, $P < 0.01$) across all sites, indicating that actual cutting damage is influenced by infestion of the stems (Table 3). Regardless of site location, soil textural class, or total PAWHC of the soil, there was a high degree of linear association between the number of stems cut by the sawfly larvae and the total number of infested stems. Consequently, there was also a high negative relationship between the actual stem cutting damage and the estimated PAWHC of the soil profile (Table 2).

Plant available water holding capacity in the top 12 inches of the soil profile was negatively correlated with sawfly larval infestation ($r = -0.68$, $P < 0.01$). Adding the PAWHC from a depth of 12 to 24 inches of the soil profile resulted in a stronger correlation ($r = -0.72$, $P < 0.01$), and when the total PAWHC of the entire 36 inch soil profile was calculated, the correlation between total PAWHC and sawfly infestation strengthened even more ($r = -0.81$, $P < 0.01$). Higher correlations were also obtained between PAWHC and actual cutting damage as PAWHC was accumulated to 36 inches in the soil profile (Table 4).

The actual number of cut stems differed each year, but some fields consistently showed more cutting damage than others, regardless of the year. The total number of cut stems and loss due to lodging was greater during 1994 when growing season precipitation was low. During 1995 when growing season precipitation was high, fewer stems were actually cut by the sawfly larvae, but relative damage between fields remained consistent (Appendix).

During the 1994 winter wheat crop year (Sept. 1993 - July 1994), the study site received 5.03 inches of precipitation, but 12.44 inches of precipitation were received during the 1995 spring wheat crop year (April 1995 - Aug. 1995) (NOAA, 1995). These precipitation estimates were based on data recorded at the Joplin, MT. NOAA Station #4512. The Joplin NOAA station is located approximately ten miles north of the Section 29 sampling sites. Regardless of annual precipitation amounts, sawfly cutting damage was heavy both years on Section 17 and much less on Section 6. Varying degrees of sawfly cutting damage were observed on Section 29 during the 1995 crop year. These observations were consistent with the farmer's observations of cutting damage on these fields (F. Elling, 1993, personal communication).

There was a weak negative correlation between the total PAWHC and actual stem cutting damage when Section 29 ($r = -0.54$, $P < 0.01$) was considered separately (Table 2). Limited variability existed in the estimated total PAWHCs for the soils in Section 29. Hail destroyed the winter wheat crop in the fields on Section 29 in 1994, so no data were available for that year. Annual precipitation in 1995 was above average and occurred regularly throughout the summer, simulating irrigated conditions. A combination of these factors was most likely responsible for the weaker relationship between total PAWHC and cutting damage that resulted in this section during the 1995 crop year (Table 2).

Lack of variability in soil texture and PAWHC of the soils in Section 6 made it difficult to obtain an association between wheat stem sawfly cutting damage and total PAWHC (Table 2). The soils sampled in this section were predominantly clay loams and loams with relatively high clay content. The estimated PAWHCs of these soils were high, and ranged from 6.2 inches to 6.6 inches (Table 1). Visible cutting damage in the fields on Section 6 was evident only along the field edges within the first six drill rows. No stem cutting damage had occurred beyond about eight feet from the field borders.

The soils in Section 17 varied from sandy loams with low PAWHC to clay loams with high PAWHC (Table 1). Larval infestation and sawfly cutting damage were also variable, and the relationship between estimated total PAWHC and cutting damage was high ($r = -0.93, P < 0.01$).

The sampling sites were chosen to reflect a range of observed sawfly damage, so in order to analyze the data and determine the existence of any possible relationships, the data from all of the sites were combined and analyzed. Each sampling site was a unique location, and the need for a wide range of soil variability to obtain a realistic analysis necessitated combining the data for all three sections from both the 1994 and 1995 crop years (Table 2).

An attempt to find a possible strong relationship between sawfly cutting damage and the percentage of clay in the top 12 inches of the soil profile was unsuccessful, r = -0.26 (Table 5). It appears that the physical water holding capacity of the soil surrounding the basal area of the wheat plant is only partially responsible for the variability in actual cutting damage by the sawfly larvae. Depth to $CaCO_3$ in the soil profile was also not strongly related to sawfly larval infestation, r = -0.37 (Table 5). The depth to $CaCO_3$ in the soil profile is generally an indication of precipitation and water percolation over a long period of time.

The results of this preliminary study suggest that management decisions can be made by the farm operator to minimize yield loss resulting from sawfly cutting and stem lodging. Sawfly larval infestation and the subsequent stem cutting of the wheat are higher in soils with low estimated PAWHCs. The soil textural class may be an important factor to consider when choosing a hollow-stemmed cultivar or a solid-stemmed, sawfly-resistant cultivar to plant in areas where sawflies are a problem. Currently, farmers operating in areas where extensive sawfly damage occurs will plant a solid-stemmed wheat across the entire farmed acreage. Ideally, fields with soils having high total PAWHC within the wheat rooting depth would be planted to hollow-stemmed cultivars that generally yield better and have higher protein quality than solid-stemmed cultivars. Conversely, those fields with soils having low total PAWHC and high levels of sawfly infestation and cutting damage would likely provide a greater economic return if planted to a solid-stemmed, sawfly-resistant cultivar. The solid-stemmed cultivars would then be limited to acreages with low total PAWHC soils rather than the entire farm.

When deciding to plant a hollow-stemmed or a solid-stemmed cultivar, the farm operator could determine the proportion of fine textured to coarse textured soils within each field or groups of fields. Based on soil textures, the total PAWHC of the predominant soil textural class would help to determine whether the farmer should plant a hollow-stemmed cultivar, or whether a solid-stemmed, sawfly-resistant cultivar would be the better choice. Ultimately, the farm operator could utilize site or soil-specific farming practices. Where areas of contrasting soils are large enough, hollow-stemmed cultivars could be planted on the fine textured soils with high total PAWHC, and solid-stemmed, sawfly-resistant cultivars could be planted on the coarse textured soils with lower total PAWHC.

Although not a part of this study, further research is needed to determine why the sawfly adult females prefer to oviposit in wheat stems growing in soils with low total PAWHC. Why is there a greater difference between total larval infestation and cutting damage of wheat grown on soils with low total PAWHC, and less when total PAWHC of the soils are higher? An evaluation is also needed to determine an economic threshold to indicate when the advantages of planting a sawfly resistant cultivar outweigh the yield and quality reductions. Using site-specific farming practices to minimize loss from sawflies requires more intensive management, but could be an effective management strategy for optimizing crop yield and economic return.

CONCLUSIONS

The results of this study indicate that as the total PAWHC of the soil profile decreases, the sawfly larval infestation in the stems increases. The total PAWHC of the soil profile refers to the PAWHC of the soils within 36 inches from the soil surface. There is a very strong positive linear relationship between sawfly larval infestation and the actual cutting damage that results in stem lodging. Consequently, as the total PAWHC of the soil decreases, actual stem cutting damage to the wheat also increases.

If further research supports the results of this preliminary study, then management decisions that help minimize crop yield losses associated with sawfly cutting damage can be made based on soil textural classes. The total PAWHC of the soils in each field could become an important factor to consider when deciding whether a higher yielding hollow-stemmed cultivar or a sawfly-resistant, solid-stemmed cultivar would be the best choice to optimize wheat production and economic return from each field.

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APPENDIX

DATA TABLES

Table 6. Sawfly cut, infested, and non-infested winter wheat stems in the 1993 stubble.

Site	Cut stems	Uncut stems with larva	Stems with no larva	Total stems	Damage	Infestation
					——— %	———
Section 29						
2w - a	9	3	56	68	13.2	17.6
2w - b	0	1	50	51	0.0	2.0
2w - c	3	1	61	65	4.6	6.2
2e - a	0	1	49	50	0.0	2.0
2e - b	4	4	52	60	6.7	13.3
2e - c	6	7	61	74	8.1	17.6
4w - a	0	0	50	50	0.0	0.0
4w - b	2	6	41	49	4.1	16.3
4w - c	1	0	45	46	2.2	2.2
4e - a	1	0	39	40	2.5	2.5
4e - b	0	0	53	53	0.0	0.0
4e - c	0	0	61	61	0.0	0.0
6w - a	2	3	34	39	5.1	12.8
6w - b	1	4	53	58	1.7	8.6
6w - c	2	2	57	61	3.3	6.6
6e - a	2	0	39	41	4.9	4.9
6e - b	2	1	46	49	4.1	6.1
6e - c	1	1	44	46	2.2	4.3
8w - a	6	8	41	55	10.9	25.5

Table 6. Sawfly cut, infested, and non-infested winter wheat stems in the 1993 stubble.

Site	Cut stems	Uncut stems with larva	Stems with no larva	Total stems	Damage	Infestation
					%	%
Continued:						
8w - b	6	4	31	41	14.6	24.4
8w - c	4	1	54	59	6.8	8.5
8e - a	0	0	46	46	0.0	0.0
8e - b	1	0	39	40	2.5	2.5
8e - c	0	0	47	47	0.0	0.0
Section 6						
3w - a	0	4	32	36	0.0	11.1
3w - b	5	5	34	44	11.4	22.7
3w - c	0	0	45	45	0.0	0.0
3e - a	5	1	24	30	16.7	20.0
3e - b	5	0	39	44	11.4	11.4
3e - c	1	2	42	45	2.2	6.7

Table 7. Sawfly cut, infested, and non-infested winter wheat stems at 1994 harvest.

Site	Cut stems	Uncut stems with larva	Stems with no larva	Total stems	Damage	Infestation	Dge:Inf. Ratio
						%	
Section 6							
2e - a - 1	1	0	38	39	0.7	0.7	100.0
2e - a - 2	0	0	54	54			
2e - a - 3	0	0	50	50			
2e - b - 1	0	7	44	51	1.4	12.2	11.1
2e - b - 2	0	6	47	53			
2e - b - 3	2	3	39	44			
2e - c - 1	2	2	62	66	4.5	7.7	58.3
2e - c - 2	3	2	38	43			
2e - c - 3	2	1	43	46			
4w - a - 1	4	2	38	44	10.8	15.4	70.0
4w - a - 2	8	3	38	49			
4w - a - 3	2	1	34	37			
4w - b - 1	2	2	40	44	6.0	13.4	44.4
4w - b - 2	3	5	34	42			
4w - b - 3	3	3	42	48			
4w - c - 1	2	5	36	43	5.5	15.0	36.8
4w - c - 2	1	5	33	39			
4w - c - 3	4	2	39	45			
Section 17							
2e - a - 1	15	7	31	53	27.8	48.1	57.8
2e - a - 2	25	19	40	84			
2e - a - 3	19	17	39	75			
2e - b - 1	10	20	43	70	19.0	46.2	41.2
2e - b - 2	19	35	61	115			
2e - b - 3	18	12	32	62			
2e - c - 1	34	14	36	84	41.5	56.3	73.8
2e - c - 2	45	12	37	94			
2e - c - 3	14	7	25	46			

Table 8. Sawfly cut, infested, and non-infested spring wheat stems at 1995 harvest.

Site	Cut stems	Uncut stems with larva	Stems with no larva	Total stems	Damage	Infestation	Dge:Inf. Ratio
						%	
Section 29							
2w - a - 1	4	0	41	45	4.7	6.1	77.8
2w - a - 2	1	0	47	48			
2w - a - 3	2	2	51	55			
2w - b - 1	1	8	36	45	1.8	12.5	14.3
2w - b - 2	0	3	37	40			
2w - b - 3	1	1	25	27			
2w - c - 1	2	1	33	36	4.7	9.3	50.0
2w - c - 2	3	3	47	53			
2w - c - 3	1	2	37	40			
2e - a - 1	1	0	47	48	3.4	4.1	83.3
2e - a - 2	3	0	47	50			
2e - a - 3	1	1	45	47			
2e - b - 1	0	1	50	51	0.0	2.0	0.0
2e - b - 2	0	2	61	63			
2e - b - 3	0	0	39	39			
2e - c - 1	1	2	29	32	2.0	6.0	33.3
2e - c - 2	0	2	37	39			
2e - c - 3	1	0	28	29			
4w - a - 1	0	0	34	34	0.8	7.6	11.1
4w - a - 2	1	5	31	37			
4w - a - 3	0	3	44	47			
4w - b - 1	0	0	42	42	2.2	5.1	42.9
4w - b - 2	3	4	43	50			
4w - b - 3	0	0	46	46			
4w - c - 1	2	1	36	39	6.3	13.3	47.1
4w - c - 2	3	7	46	56			
4w - c - 3	3	1	29	33			
4e - a - 1	0	1	29	30	2.2	4.3	50.0
4e - a - 2	2	1	24	27			
4e - a - 3	0	0	36	36			

Table 8. Sawfly cut, infested, and non-infested spring wheat stems at 1995 harvest.

Site	Cut stems	Uncut stems with larva	Stems with no larva	Total stems	Damage	Infestation	Dge:Inf. Ratio
						%	
Continued:							
4e - b - 1	1	0	25	26	4.5	5.7	80.0
4e - b - 2	2	1	28	31			
4e - b - 3	1	0	30	31			
4e - c - 1	0	0	30	30	1.0	2.1	50.0
4e - c - 2	1	1	42	44			
4e - c - 3	0	0	22	22			
6w - a - 1	5	5	30	40	13.2	21.7	60.9
6w - a - 2	6	2	28	36			
6w - a - 3	3	2	25	30			
6w - b - 1	10	5	31	46	16.2	25.7	63.0
6w - b - 2	2	0	27	29			
6w - b - 3	5	5	20	30			
6w - c - 1	4	5	24	33	9.4	16.7	56.3
6w - c - 2	4	2	23	29			
6w - c - 3	1	0	33	34			
6e - a - 1	0	1	37	38	0.9	5.7	16.7
6e - a - 2	0	4	32	36			
6e - a - 3	1	0	31	32			
6e - b - 1	6	1	27	34	16.0	19.0	84.2
6e - b - 2	7	1	22	30			
6e - b - 3	3	1	32	36			
6e - c - 1	1	4	33	38	3.4	12.7	26.7
6e - c - 2	2	0	42	44			
6e - c - 3	1	7	28	36			
8w - a - 1	3	3	29	35	8.8	13.2	66.7
8w - a - 2	0	0	40	40			
8w - a - 3	7	2	30	39			
8w - b - 1	3	2	27	32	5.2	13.9	37.5
8w - b - 2	1	2	42	45			
8w - b - 3	2	6	30	38			

Table 8. Sawfly cut, infested, and non-infested spring wheat stems at 1995 harvest.

Site	Cut stems	Uncut stems with larva	Stems with no larva	Total stems	Damage	Infestation	Dge:Inf. Ratio
						%	
Continued:							
8w - c - 1	4	3	34	41	6.8	11.9	57.1
8w - c - 2	2	2	39	43			
8w - c - 3	2	1	31	34			
8e - a - 1	4	4	25	33	12.9	21.8	59.1
8e - a - 2	6	0	27	33			
8e - a - 3	3	5	27	35			
8e - b - 1	7	4	23	34	12.4	17.5	70.6
8e - b - 2	2	0	33	35			
8e - b - 3	3	1	24	28			
8e - c - 1	1	1	24	26	12.6	23.2	54.5
8e - c - 2	5	4	26	35			
8e - c - 3	6	5	23	34			
Section 6							
3w - a - 1	10	4	31	45	11.3	22.6	50.0
3w - a - 2	1	6	39	46			
3w - a - 3	4	5	33	42			
3w - b - 1	6	2	40	48	11.8	21.8	54.2
3w - b - 2	2	4	22	28			
3w - b - 3	5	5	24	34			
3w - c - 1	8	4	23	35	13.8	23.3	59.3
3w - c - 2	4	0	36	40			
3w - c - 3	4	7	30	41			
3e - a - 1	6	2	24	32	7.6	15.2	50.0
3e - a - 2	1	1	23	25			
3e - a - 3	0	4	31	35			
3e - b - 1	0	1	17	18	11.1	20.8	53.3
3e - b - 2	2	4	16	22			
3e - b - 3	6	2	24	32			

Table 8. Sawfly cut, infested, and non-infested spring wheat stems at 1995 harvest.

Site	Cut stems	Uncut stems with larva	Stems with no larva	Total stems	Damage	Infestation	Dge:Inf. Ratio
					%		
Continued:							
3e - c - 1	4	3	30	37	4.6	10.3	44.4
3e - c - 2	0	2	24	26			
3e - c - 3	0	0	24	24			
Section 17							
1e - a - 1	1	1	26	28	8.2	10.3	80.0
1e - a - 2	3	1	32	36			
1e - a - 3	4	0	29	33			
1e - b - 1	4	0	20	24	18.3	21.5	85.0
1e - b - 2	5	0	25	30			
1e - b - 3	8	3	28	39			
1e - c - 1	4	2	34	40	18.1	22.0	82.1
1e - c - 2	10	2	35	47			
1e - c - 3	9	1	30	40			

Table 9. Relationship between sawfly damage : infestation ratio and total PAWHC for each sampled site. (n = 42, r = -0.19, p < 0.01)

Section	Site	Total PAWHC	Damage : Infestation Ratio
		in/ft	%
Section 29	2w - a	6.6	77.8
	2w - b	6.6	14.3
	2w - c	6.5	50.0
	2e - a	6.5	83.3
	2e - b	6.3	0.0
	2e - c	6.6	33.3
	4w - a	6.5	11.1
	4w - b	6.3	42.9
	4w - c	5.9	47.1
	4e - a	6.6	50.0
	4e - b	6.6	80.0
	4e - c	6.6	50.0
	6w - a	6.6	60.9
	6w - b	5.8	63.0
	6w - c	6.5	56.3
	6e - a	6.6	16.7
	6e - b	5.9	84.2
	6e - c	6.4	26.7
	8w - a	5.9	66.7
	8w - b	5.8	37.5
	8w - c	6.5	57.1
	8e - a	5.9	59.1
	8e - b	6.4	70.6
	8e - c	6.3	54.6
Section 6	2e - a	6.5	100.0
	2e - b	6.6	11.1
	2e - c	6.6	58.3
	3w - a	6.5	50.0
	3w - b	6.4	54.2
	3w - c	6.4	59.3
	3e - a	6.5	50.0
	3e - b	6.5	53.3
	3e - c	6.2	44.4
	4w - a	6.4	70.0
	4w - b	6.5	44.4
	4w - c	6.6	36.8
Section 17	1e - a	6.6	80.0
	1e - b	6.0	85.0
	1e - c	5.9	82.1
	2e - a	5.2	57.8
	2e - b	5.2	41.2
	2e - c	4.5	73.8

Table 10. Plant available water capacities (PAWC) for soil textural classes in Montana

	Soil Texture Group	Soil Textural Class	Estimated Average Plant Available Water Capacities (in/ft)
Sandy soils	Coarse Texture	Sands	0.5
		Loamy Sands	1.0
		Loamy fine sands Loamy v. fine sands Fine sands V. fine sands	1.25
Loamy soils	Moderate coarse texture	Sandy loam Fine sandy loam	1.50
	Medium texture	V. fine sandy loam Loam Silt loam Silt	2.00
	Moderately fine texture	Clay loam Sandy clay loam Silty clay loam	2.20
Clayey soils	Fine texture	Sandy clay Silty clay Clay	2.00