



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

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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.

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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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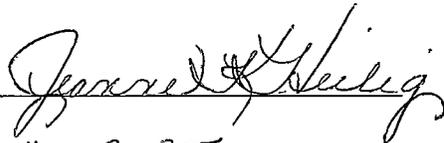
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ABSTRACT

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.

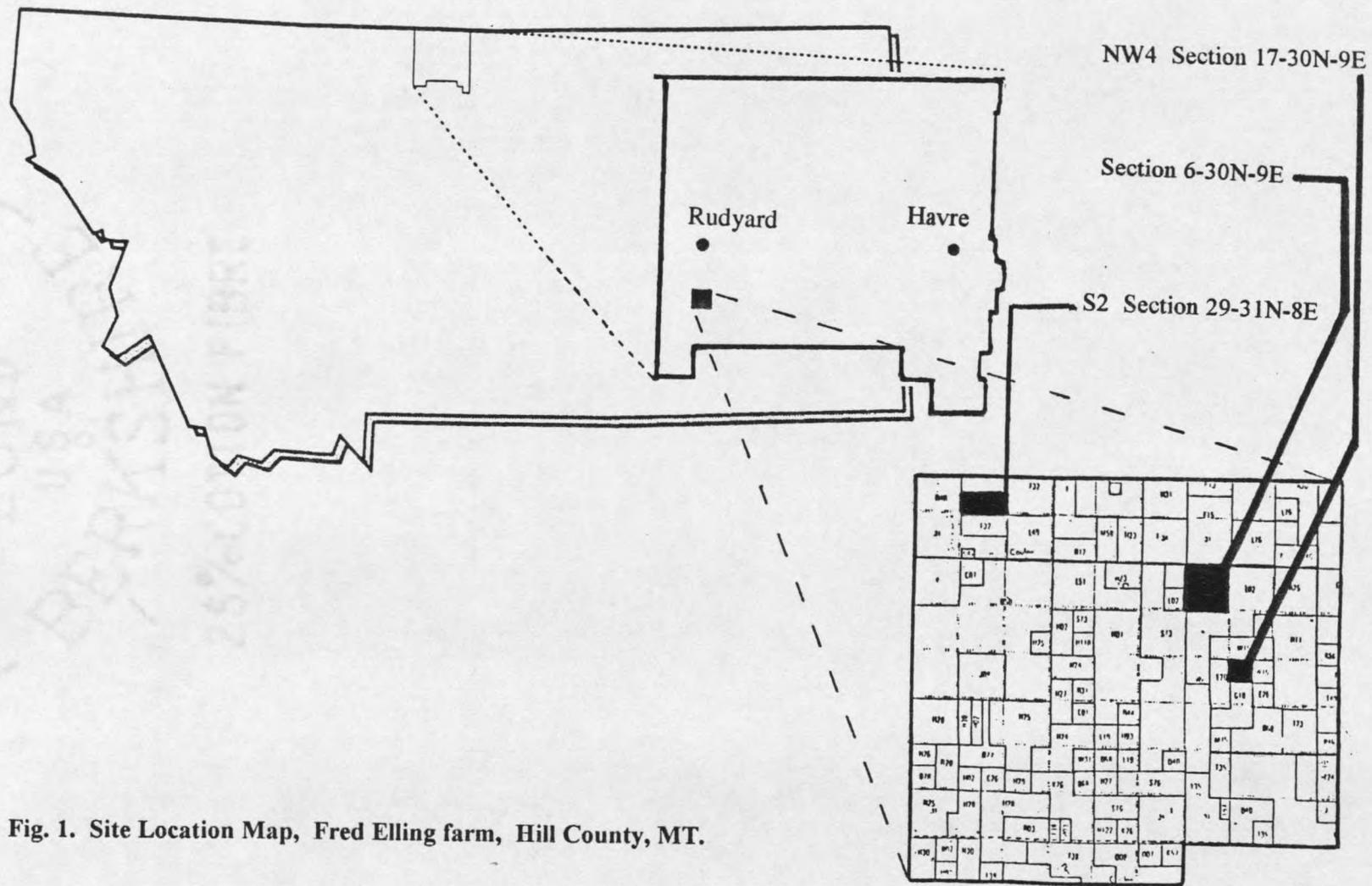


Fig. 1. Site Location Map, Fred Elling farm, Hill County, MT.

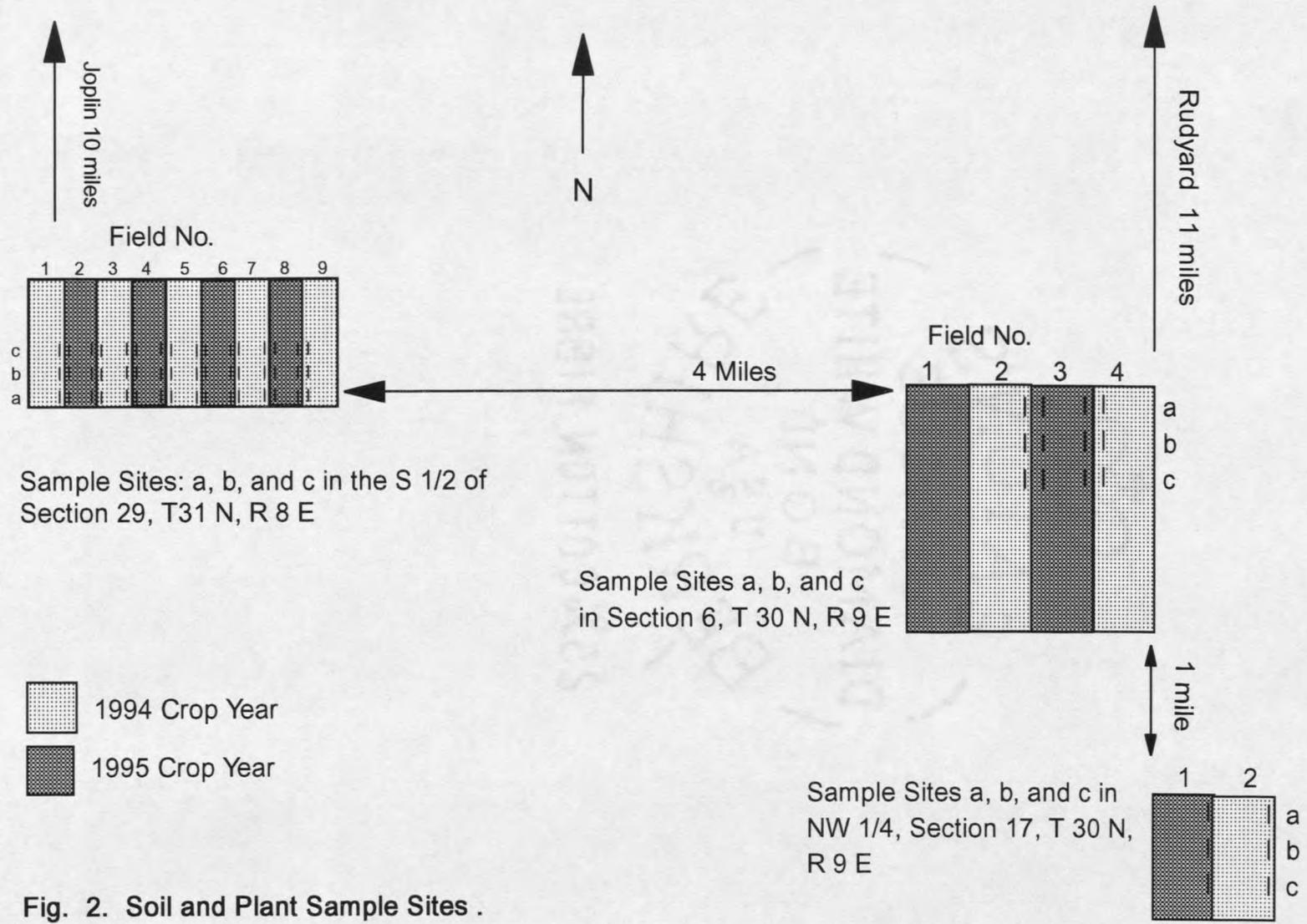


Fig. 2. Soil and Plant Sample Sites .

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 Baldrige, 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.

Site	0 - 12 inches			12 - 24 inches			24 - 36 inches			0 - 36 in	Depth to CaCO3	Mean Damage	Mean Infestation
	Soil texture ++	Clay content	PAWHC	Soil texture ++	Clay content	PAWHC	Soil texture ++	Clay content	PAWHC	Total PAWHC			
		%	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.

Site	0 - 12 inches			12 - 24 inches			24 - 36 inches			0 - 36 in	Depth to CaCO ₃	Mean Damage	Mean Infestation
	Soil texture ++	Clay content	PAWHC	Soil texture ++	Clay content	PAWHC	Soil texture ++	Clay content	PAWHC	Total PAWHC			
		%	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.

Site	0 - 12 inches			12 - 24 inches			24 - 36 inches			0 - 36 in	Depth to CaCO3	Mean Damage	Mean Infestation
	Soil texture ++	Clay content	PAWHC	Soil texture ++	Clay content	PAWHC	Soil texture ++	Clay content	PAWHC	Total PAWHC			
		%	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.

Site	0 - 12 inches			12 - 24 inches			24 - 36 inches			0 - 36 in	Depth to CaCO3	Mean Damage	Mean Infestation
	Soil texture ++	Clay content	PAWHC	Soil texture ++	Clay content	PAWHC	Soil texture ++	Clay content	PAWHC	Total PAWHC			
		%	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

