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THE INFLUENCE OF SELECTED MANAGEMENT STRATEGIES ON POPULATIONS OF CEREAL LEAF BEETLE ON WHEAT IN TENNESSEE

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Lisa Covington Duke

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DEDICATION

This thesis is dedicated to my parents, Dr. and Mrs. Robert L. Duke, for the invaluable educational opportunities they have given me and for their constant support and encouragement.

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ABSTRACT

The cereal leaf beetle (CLB), Oulema melanopus L. (Coleoptera: Chrysomelidae), was introduced into North America from southern Asia (Wellso 1986). Adult beetles were first collected and identified as O. melanopus from small grain fields in Berrien County, Michigan, in 1962 (Haynes and Gage 1981). Since its identification in the United States in 1962, the CLB has expanded eastward with the prevailing winds and now occupies an area from southern Canada to North Carolina and west to Missouri (Battenfield et al. 1982).

In Tennessee, the CLB was present in low numbers as early as 1972 (Haynes and Gage 1981). However, populations of this insect pest have increased during the last 20 years throughout Tennessee, primarily in the eastern and middle areas of the state (Grant and Patrick 1988). The CLB has been reported from 81 of 95 counties in Tennessee (Grant and Patrick 1991). Fortunately, the CLB is not a serious pest in most areas of Tennessee. However, the potential for problems exists if populations of CLB continue to increase and spread across the entire wheat-growing regions of the state (Grant and Patrick 1988, 1991).

A three-year study to provide information on the distribution and seasonal incidence of CLB on wheat in Tennessee has been conducted (Grant and Patrick 1991).

However, little research, except for limited chemical efficacy studies, has been conducted on selected management strategies to control this pest. Research on other management tactics, such as the use of resistant wheat varieties, cultural control, and biological control, is necessary for the development and incorporation of appropriate management programs directed against CLB in Tennessee. Therefore, a two-year study was initiated to evaluate the influence of planting dates and varieties on populations of CLB on wheat. This study was conducted at the University of Tennessee Highland Rim Experiment Station (HRES) in middle Tennessee during 1990 and at the University of Tennessee Plant and Soil Science Field Laboratory/ Government Farm (GF) in eastern Tennessee during 1990 and 1991.

Planting date did affect CLB densities on wheat, and its influence on populations of CLB were consistent throughout this two-year study. Densities of CLB adults per five sweeps were greater in the early-planted wheat at HRES during 1990 and at GF during 1990 and 1991. Data suggest that adults were attracted to the early-planted wheat, where they mated. Adults then moved to the younger plants in the middle- and late-planted wheat. Higher densities of adults per 20 stems were found on late-planted wheat at the GF in 1990 and 1991. The density estimations of CLB on stems reflect the late-season populations of CLB or their F_1

generation on wheat. These higher densities of F_1 adults in the later-planted wheat may result from the higher densities of eggs and larvae that were present in the later-planted wheat. The low numbers of eggs per 20 stems on early-planted wheat were consistent at the GF in 1990 and 1991, while the low numbers of larvae per 20 stems on early-planted wheat were consistent at all locations during both years.

The influence of wheat varieties on populations of CLB varied among locations and years. Densities of CLB adults per five sweeps were similar at HRES in 1990 and the GF in 1991 with high numbers of adults concentrated on Pioneer 2555. Pioneer 2555 lacks leaf pubescence, which suggests that it would be more preferable to CLB adults. However, egg and larval densities were low on Pioneer 2555. Large numbers of eggs and larvae were both found on Caldwell, a variety that is also absent of leaf pubescence, at both locations during both years. A high density of F_1 adults per 20 stems were found on Caldwell at the GF during both years. This high density of F_1 adults may result from the higher number of eggs and larvae per 20 stems on Caldwell at both locations and during both years. The low number of eggs per 20 stems on Pioneer 2555 were consistent at the GF during both years. These findings are similar to the low number of larvae also found on Pioneer 2555 at the GF during both years. Low densities of larvae were found on Saluda at

HRES in 1990 and at the GF in 1991. Although information on the leaf pubescence of Saluda is not available, its effect on CLB is similar to Pioneer 2555. Because CLB populations responded differently to those varieties which lacked leaf pubescence, the lack of pubescence may not be a valid characteristic to use solely in the explanation of the impact of these varieties on CLB.

The combined use of planting date and variety may be beneficial in an integrated management program against CLB. The incorporation of these tactics into integrated pest management of CLB could improve wheat production and profitability in Tennessee by eliminating or reducing costs associated with insecticide application.

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CHAPTER I

INTRODUCTION

Wheat, Triticum aestivum L., is the world's leading crop, based on both hectarage and production (Elkins and Metcalfe 1980), and has provided more nourishment to the world's population than any other food crop. Wheat also enters into international trade more than any other food (Inglett 1974). The influence of wheat in both world and national politics allows it to play a key role in human economic and social development (Briggle 1980).

Most of the wheat is grown in the temperate zone, between 30 and 60 degrees north and 25 and 40 degrees south latitude, with the majority of hectarage grown in the northern hemisphere (Leonard and Martin 1963). Eurasia and North America contain more than 90% of this hectarage (Reitz 1967). In North America, 16 to 20% of the world wheat is produced, with about two-thirds available for export (Wilde 1981). In the United States, about 32.4 million hectares are grown annually, with about 28.3 million hectares harvested for grain (Elkins and Metcalfe 1980).

Wheat is classified into different commercial market classes, based on kernel color and texture or the geographical areas where the wheat is grown (Elkins and Metcalfe 1980). Five classes of wheat (i.e., hard red winter, hard red spring, soft red winter, white, and durum) are grown in the United States.

Fall-seeded hard red winter wheat, grown mainly in the Central Plains and Northwest, constitutes almost 50% of the total wheat hectarage in the United States. This hard-textured and high protein grain is used for bread (Elkins and Metcalfe 1980).

Hard red spring wheat is grown primarily in the northern Great Plains, where deep black soil and hot, dry summers are prevalent. Hard red spring wheat is mostly spring-seeded and constitutes about 20% of the total wheat hectarage in the United States. This grain, similar to hard red winter grain, also is used for bread.

Fall-seeded soft red winter wheat accounts for about 15% of the total wheat hectarage in the United States. This wheat type is grown exclusively east of a line from Milwaukee to Dallas, where the climate is subhumid to humid. The grain texture is soft to semihard, depending on the geographical area of production. Flour made from this grain is used for cakes, cookies, pastries, and general purposes.

White wheat, which is almost all fall-seeded, is produced in two major regions of the United States: (1) western states, primarily Washington, Oregon, and Idaho, and (2) eastern states, mainly Michigan and New York. White wheat constitutes 10% of the total wheat hectarage in the United States. Grain of white winter wheat ranges from soft to hard and usually is low in protein. The flour of this wheat type is used for pastries and general purposes.

Durum wheat, which is mainly spring-seeded, comprises about 5% of the total wheat hectarage in the United States. Durum wheat is produced mostly in the northern Great Plains, particularly North Dakota, with some of the western states growing small hectarages. The grain texture of durum is hard and brittle, and the protein content is higher than any other class of wheat. Semolina flour, used in macaroni, spaghetti, and similar products, is obtained from durum wheat (Elkins and Metcalfe 1980).

Wheats are grouped into fairly well-defined spring and winter growth-habit types in the United States. However, various intergrades exist between true spring wheat and true winter wheat on a world-wide basis (Schmidt 1974). Winter wheat is successfully produced only from fall sowing. Spring-sown winter wheat will not produce spikes or heads, and the plant will remain prostrate throughout the growing season (Briggle 1980). Germinating seeds or winter wheat seedlings must be subjected to cold or cool conditions to successfully flower, a process referred to as vernalization (Leonard and Martin 1963).

Spring wheat can be grown without being subjected to low temperatures. Fall-sown spring wheat can grow successfully only in areas with temperate winter climates. Early growth of spring wheat is erect as compared with the prostrate growth of winter wheat seedlings.

The climate in Tennessee is well suited for the production of high quality, low protein soft red winter wheat. The soft red winter wheat that is produced in Tennessee is used mainly for general milling purposes, family, pastry, and cake flours. A small percentage, approximately less than 30%, of the wheat hectarage grown in Tennessee is used as livestock feed (Reich, personal communication). By-products of the milling industry also are used as livestock feed.

Winter wheat can be successfully grown in all counties in Tennessee (Shelby 1984). In 1989, wheat was produced in 78 of the 95 counties in Tennessee, which ranked 21st among states producing winter wheat. During 1989, an estimated 6.6 hektoliters of grain valued at 69.0 million dollars were harvested from 182,250 hectares in Tennessee (Brantner and Guinn 1990).

Wheat production is affected by many factors, such as climate, soil type, fertility, variety, farming practices, and plant pests (Wilde 1981). Of the plant pests, more than 100 species of insects attack wheat, but only a few of these are important to wheat production in North America (Dahms 1967). More than 30 species of insects and mites alone attack wheat in the United States (Hatchett et al. 1987), where an estimated 6% of the wheat crop is damaged annually by insects (Elkins and Metcalfe 1980).

One important pest, the cereal leaf beetle (CLB), Oulema melanopus L. (Coleoptera: Chrysomelidae), was introduced into North America from southern Asia (Wellso 1986). The mechanism of introduction of this Eurasian pest into North America is not known (Hatchett et al. 1987). Because the natural enemies of the introduced pest species are rarely introduced with them, the pest species usually become more destructive in their new environment as compared with their native one (Hatchett et al. 1987).

Numerous adult beetles were collected from small grain fields in Berrien County, Michigan, in June 1962, and were identified as O. melanopus (Haynes and Gage 1981, Battenfield et al. 1982, Gallun et al. 1967, Hatchett et al. 1987). However, local farmers reportedly had sprayed for an undetermined leaf-feeding pest on small grains as early as 1959 (Haynes 1973). The rate of increase of populations of CLB in Michigan has been monitored since 1967 (Haynes 1973). By calculating backwards from recent peak densities, the CLB was estimated to have been introduced into the United States between 1948 and 1952 (Haynes 1973).

Since its identification in the United States in 1962, the CLB has expanded eastward with the prevailing winds and now occupies an area from southern Canada to North Carolina and west to Missouri (Battenfield et al. 1982). Approximately 25% of the small grains grown in the United States are confined within this area (Battenfield et al.

1982). The first major infestation of CLB on small grains west of the Mississippi River was reported in Morgan County, Utah, in 1984 (Hatchett et al. 1987).

Factors that control the distribution of CLB are not totally defined. The rapid movement eastward from its origin was due to the availability of food sources, sufficient environmental conditions and appropriate weather patterns that assisted its expansion (Haynes and Gage 1981). However, western and northwestern movement of CLB has been relatively slow, but continues (Haynes and Gage 1981).

Yields of the winter wheat cultivar 'Monon' in Michigan were reduced as much as 23% by both adult and larval feeding, which caused 90% damage to the flag leaf (Gallun et al. 1967). Losses in grain yield among nine spring wheat cultivars damaged by CLB ranged from 10 to 55% (Webster et al. 1972). Loss in yield results from a reduction in kernel number per head and in kernel weight caused by removal of photosynthetic tissue by CLB (Ringlund and Everson 1968).

States where the beetle is highly concentrated grow predominately winter wheat (Webster et al. 1972). The CLB has not become established in the northern Great Plains, the major spring wheat-growing area. However, the CLB does pose a potential threat to wheat production in this area.

The CLB was present in low numbers in Tennessee as early as 1972 (Haynes and Gage 1981). However, populations of this insect pest have increased during the last 20 years throughout Tennessee, primarily in the eastern and middle areas of the state (Grant and Patrick 1988). The CLB has been reported from 81 of 95 counties in Tennessee (Fig. 1) (Grant and Patrick 1991).

Some physical characteristics of adult CLB include a metallic bluish-black head and elytra and a reddish-orange prothorax and legs (Hatchett et al. 1987). Adults are about 6 mm long with the male slightly smaller than the female. Eggs are yellow, cylindrical, and about 1-2 mm in length. The eruciform larvae are yellowish with black legs and can reach a maximum length of 6 mm (Hunt and Baker 1982). They encase themselves in a globule of black fecal material which enables them to avoid dessication and provides protection against predators. Pupae are yellowish-brown and are found inside earthen cells 2 to 5 cm under the soil surface (Wilson et al. 1980).

The life cycle of CLB in Tennessee has been monitored by Grant and Patrick (1988, 1991). They reported that postdiapause adults move into small grain fields, especially winter wheat, during mid-to-late March. Host species, in order of preference, are: oats, barley, wheat, some grass spp., corn, sorghum, rye, and certain other grass spp. (Ruppel et al. 1970). The CLB rarely feeds on broad-leaved plants. After emergence from overwintering sites, adults feed, mate, and then begin to oviposit on the upper surfaces of leaves near the mid vein (Grant and Patrick 1988, 1991).

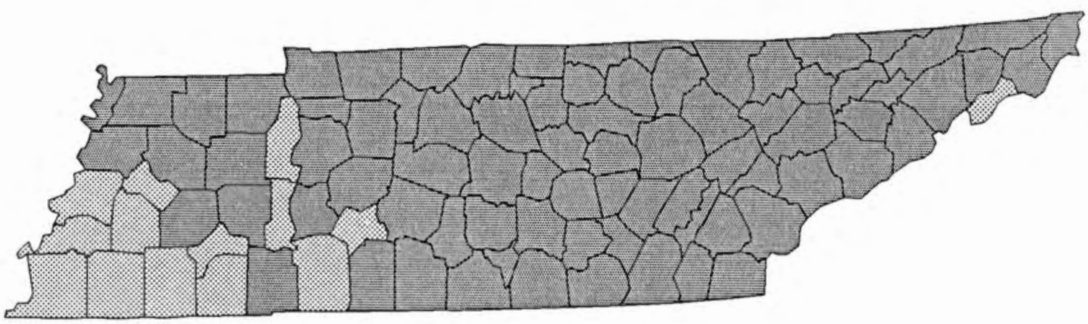

Figure 1. Distribution of cereal leaf beetle on wheat in Tennessee (dark shaded counties indicate counties in which cereal leaf beetle larvae or adults were found) (Reprinted with permission from Grant and Patrick 1991).

Eggs are present from late March to early April and usually hatch within three to four days. Prior to hatching, the eggs turn darker in color (Wilson et al. 1980). After hatching, larvae feed on the upper surfaces of the leaves from early April to late May or even early June. Larvae undergo four larval instars (Hunt and Baker 1982). Prior to pupation, larvae crawl or drop to the ground and pupate inside an earthen cell located 2 to 5 cm beneath the soil surface or underneath the debris on the surface (Wilson et al. 1980). After seven to ten days, adults emerge and feed on any suitable and available food source (e.g., corn) for about one week. Adults do not mate during this period. After feeding, adults migrate from the field and overwinter in field trash, grain stubble, along fence rows, behind sheaths of corn plants, and under loose bark of trees (Hatchett et al. 1987). Adults will return to small grain fields the following March or April. Only one generation of CLB occurs in Tennessee each year.

Both the CLB adult and larva cause damage to small grains. However, the larva is the most destructive stage because it may consume the entire upper surface of the leaf and the inner parenchymatous tissue between the veins, leaving the lower surface of the leaf intact (Gallun et al. 1967, Shade and Wilson 1967). One larva may consume one to ten times its weight each day (Hunt and Baker 1982). Because it rarely moves from one plant to another, the larva consumes a much broader area on a single plant than the adult. Thus, larval damage is much more noticeable (Hunt and Baker 1982). Severely damaged leaves are translucent, and heavily-infested fields may have an overall whitish cast or the appearance of frost damage (Hatchett et al. 1987).

Adults feed by penetrating completely through the leaves in narrow longitudinal striations that run parallel to the axis and are usually 1-2 mm wide and as long as 5 cm (Gallun et al. 1967). The adult generally restricts its feeding to the area between the leaf veins. Thus, feeding damage is linear with the veins, and the width of the opening is controlled by the adjacent veins (Wellso et al. 1975).

The immediate effect of the skeletonization of leaf surfaces by CLB is a reduction in potential photosynthetic tissue (Haynes and Gage 1981). More subtle effects also occur. For example, feeding damage causes increased water loss, sites for potential disease introduction, senescence of the leaf earlier than normal which further reduces potential photosynthesis, the reduction of tillering, and increased stem mortality (Haynes and Gage 1981).

Plants in heavily-infested winter wheat fields, where the majority of leaf surface is consumed, may be mature enough to tolerate the damage, but yield may be reduced (Gallun et al. 1967). However, heavily-infested spring oats and barley are usually small and cannot tolerate severe feeding damage, and entire fields may have to be abandoned (Gallun et al. 1967). Fall-sown grains sometimes avoid serious damage because they often have achieved extensive spring vegetative growth when the overwintering CLB adults become active (Webster and Smith 1983, Hatchett et al. 1987). Seedling plants or new growth on older plants are much more preferable than older vegetative growth to adults and larvae (Ruppel et al. 1970).

Since the discovery of this exotic pest in 1962, much time and effort have been spent to conduct research on its life cycle. These basic biological studies were necessary to develop effective management strategies for CLB control. The first studies were aimed at quarantining and eradicating CLB before it could spread beyond the point of introduction (Haynes 1973). Chemical control methods were developed and made available to government agencies which then attempted large-scale pesticide applications for eradication of CLB. This broad aerial control program using two insecticides, malathion and carbaryl, was initiated in Michigan, Indiana, and Illinois in 1963 (Wellso 1986).

At the height of this program, the effectiveness of different insecticides and applications on all stages of CLB development also was under investigation. One study evaluated the effect of five insecticidal compounds on CLB in spring-infested small grains (Ruppel and Wilson 1964). In 1966, researchers concluded that the CLB could not be eradicated or contained either by quarantine procedures or chemical control methods (Haynes 1973).

Approaches other than chemical insecticides also were evaluated for use in control of CLB. Breeding for resistance to CLB in small grains resulted in the development of wheat varieties with the highest levels of resistance, barley with intermediate levels, and oats with low levels (Steidl et al. 1979). The high resistance to the CLB shown in wheat was associated with leaf surface pubescence (Gallun et al. 1966, Schillinger and Gallun 1968, Ringlund and Everson 1968, Hatchett et al. 1987). The deterrent effect of leaf pubescence on CLB oviposition and larval survival was believed to be a result of both density and length of trichomes (Gallun et al. 1966, Schillinger and Gallun 1968, Hoxie et al. 1975, Webster et al. 1975, Hatchett et al. 1987).

The resistance in wheat involves the classical resistance components of non-preference and antibiosis (Painter 1958). Reduced oviposition on pubescent lines was an expression of non-preference while reductions in egg hatch, larval weight gain, and larval survival on pubescent lines were an expression of antibiosis (Steidl et al. 1979). Trichome densities of about 17 trichomes per mm^2 and trichome lengths exceeding 250 μm were probably sufficient to deter oviposition when populations of CLB were low (Webster et al. 1975 in Hatchett et al. 1987). But when CLB populations were high and few alternate hosts were available, trichomes at a higher density (> 35 trichomes per mm^2) and longer in length (> 250 μm) may be tolerable (Webster et al. 1975 in Hatchett et al. 1987). Leaf pubescence has been shown to be influenced by the environment and varies among plants, within plants, and even within single leaves on the same plant (Wellso and Hoxie 1982).

Several highly pubescent wheat lines were evaluated under field conditions and were found to reduce ovipostion of CLB by 94% (Gallun et al. 1973, Haynes and Gage 1981). Resistant and susceptible lines combined in ratios of 9:1, 1:1, and 1:9 reduced seasonal densities of CLB larvae by 74, 47, and 1%, respectively (Casagrande and Haynes 1976, Haynes and Gage 1981). 'CI 9321', a spring wheat introduced from the Soviet Union, has been the major breeding source of pubescence (Hatchett et al. 1987). The density of pubescence was quantitatively inherited, and gene action was mainly additive with partial dominance for dense pubescence (Ringlund and Everson 1968, Hatchett et al. 1987).

Another approach to CLB management, biological control, was initiated in 1963, when a field survey for CLB parasitoids was conducted in Europe through the United States Department of Agriculture European Parasite Laboratory (Haynes and Gage 1981). Between 1964 and 1967, five parasitoid species were introduced and released into the area were CLB originated in the United States. By 1973, four of these species were reported to be established: _Tetrastichus julis_ Walker (Hymenoptera: Eulophidae), a larval parasitoid (Stehr 1970), _Anaphes flavipes_ Foerster (Hymenoptera: Mymaridae), an egg parasitoid (Maltby et al. 1971), _Diaparsis carinifer_ Thomson (Hymenoptera: Ichneumonidae), a larval parasitoid (Stehr and Haynes 1972), and _Lemophagus curtus_ Townes (Hymenoptera: Ichneumonidae), another larval parasitoid (Stehr et al. 1974).

Cultural control provides another type of approach to CLB management. This approach includes the use of production practices that make the environment less favorable for the survival and reproduction of arthropod pests (Hatchett et al. 1987). One cultural practice currently used for reduction of CLB populations is the use of deep plowing. This method reduces both Hessian fly, _Mayetiola destructor_ Say (Diptera: Cecidomyidae), and CLB by preventing their emergence in the fall and spring, respectively, but this method also destroys CLB parasitoids which overwinter in the soil and may enhance erosion (Wilde 1981). Another method is the use of favorable planting dates. Fall wheat should be planted immediately after the Hessian fly-free date (Hunt and Baker 1982). Small grains planted this early will be more advanced in growth the following spring; thus, they may be less attractive and more tolerant to CLB than late-planted small grains.

Alternately, small grains planted later than optimal times (e.g., after December 1 in the southeast) may have thin stands, less than 37 heads/m^2 (Herbert 1990). Fields with thin stands are typically infested with CLB.

Fortunately, the CLB is not a serious pest in most areas of Tennessee. However, the potential for problems exists if populations of CLB continue to increase and spread across the entire wheat-growing regions of the state (Grant and Patrick 1988, 1991) A three-year study to provide information on the distribution and seasonal incidence of CLB on wheat in Tennessee has been conducted (Grant and Patrick 1991). In Tennessee, the CLB also feeds on other small grains, especially oats, and it is important to understand its seasonal phenology, population dynamics and host relationships.

Because the CLB is a relatively new threat to wheat production in Tennessee, little research, except for limited chemical efficacy studies, has been conducted on selected management strategies to control this pest. Research on other management tactics, such as the use of resistant wheat varieties, cultural control, and biological control, is necessary for the development and incorporation of appropriate management programs directed against CLB in Tennessee.

Due to the lack of information on the influence of selected management strategies on populations of CLB in Tennessee, a two-year study was initiated. The objectives of this research were to: 1) evaluate the influence of planting date on populations of CLB on wheat, and 2) evaluate the influence of wheat varieties on populations of CLB.

CHAPTER II

MATERIALS AND METHODS

Wheat plots were located at two sites, one in eastern Tennessee [the University of Tennessee Plant and Soil Science Field Laboratory/Government Farm (GF), Knoxville, Knox County] and one in middle Tennessee [the University of Tennessee Highland Rim Experiment Station (HRES), Springfield, Robertson County] during 1989/1990 (Fig. 2). Populations of CLB are relatively high at both of these locations. During 1990/1991, wheat was grown only at the GF. Wheat was grown at both locations using standard agronomic practices as recommended by the University of Tennessee Agricultural Extension Service. No insecticide or fungicide treatments were applied.

Wheat was sown at the rate of 100.8 kilograms per hectare on three different dates at each location (Table 1). In 1989, planting dates at HRES were: (1) 26 October, (2) 30 October, and (3) 20 November. The 26 October and 30 October planting dates were close because adverse environmental conditions prevented planting on the planned dates. At the GF in 1989, planting dates were: (1) 30 October, (2) 20 November, and (3) 7 December. At the GF in 1990, the planting dates were: (1) 2 November, (2) 16 November, and (3) 30 November. In each case, the first, second, or third planting date will be referred to throughout this thesis as

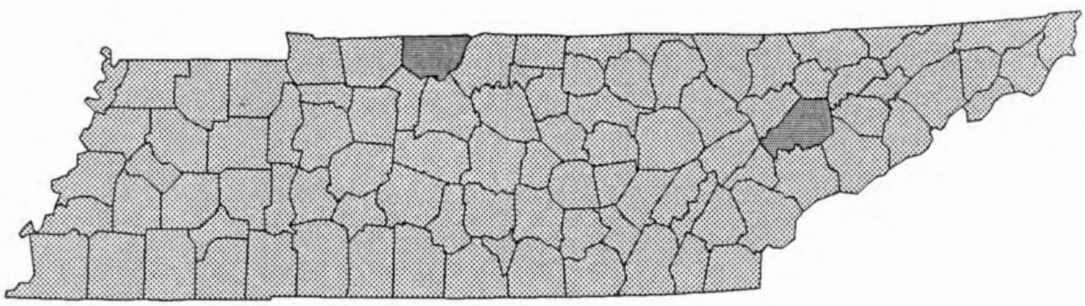

Figure 2. Location of sampling sites in eastern and middle Tennessee (represented by the dark shaded counties).

Table 1. Dates of planting of wheat at the Government Farm (GF) and Highland Rim Experiment Station (HRES).

DURATION OF STUDY	LOCATION	DATE OF PLANTING
1989-1990	Knoxville (GF)[a]	30 October 1989
		20 November 1989
		7 December 1989
	Springfield (HRES)[b]	26 October 1989
		30 October 1989
		20 November 1989
1990-1991	Knoxville (GF)[c]	2 November 1990
		16 November 1990
		30 November 1990

[a] Decatur silt loam (2 to 5% slopes).
[b] Dickson silt loam (2 to 5% slopes).
[c] Decatur silty clay loam (2 to 5% slopes, severely eroded).

the early planting, middle planting, or late planting, respectively.

Three varieties (Caldwell, Pioneer 2555, and Saluda) of soft red winter wheat were evaluated in this study (Table 2). These varieties were selected because they are commonly grown in Tennessee and seeds were readily available.

'Caldwell' (Reg. no. 660, CI 17897) was developed at the Purdue University Agricultural Experiment Station in cooperation with ARS-USDA and was released in 1981 (Patterson et al. 1982). Caldwell, a semidwarf, is moderately winter hardy, is an early maturing cultivar, and averages 91 cm in height. At maturity, the stems are glabrous, strong, erect, hollow, and characteristically lack a waxy bloom. The flag leaf is recurved, but not twisted. The leaf sheath has a light waxy bloom and is hairless on the first sheath. The head is 9 cm in length, tapered, lax, and awnleted at maturation. This variety is susceptible to CLB and to races C and D of the Hessian fly. However, it is resistant to races GP, A, and B of the Hessian fly.

Pioneer '2555' (Reg. no. CV-759, PI 532914) was developed by Pioneer Hi-Bred International, Inc., and was released in 1986 (Iwig et al. 1991). Pioneer 2555, a semidwarf, is susceptible to winter injury and drought stress, but has good resistance to lodging. It matures mid-early in the season and is 101 cm in height. Stems of Pioneer 2555 have hollow internodes and a light waxy bloom

Table 2. Varieties of wheat planted at the Government Farm and Highland Rim Experiment Station.

BRAND	VARIETY	C.I. or P.I. NO.[a]	LEAF PUBESCENCE[b]
Indiana	Caldwell	C.I. 17897	Absent
Pioneer	2555	P.I. 532914	Absent
Virginia	Saluda	P.I. 480474	N/A[c]

[a] C.I. is the cereal identification number and P.I. is the plant introduction number.
[b] Relative to the first leaf sheath.
[c] Information not available.

at maturity. The flag leaf, like Caldwell, is recurved, but not twisted, with a light waxy bloom on the sheath. Hairs are absent from the first leaf sheath. The head is 8 cm in length, tapered, lax, and awned at maturation. The awns are 2 to 6 cm in length. This variety has not been tested for CLB, but has demonstrated excellent field resistance to the prevalent biotypes of Hessian fly in the Southeast.

'Saluda' (Reg. no. 705, PI 480474) was developed by the Virginia Agricultural Experiment Station and was released in 1983 (Starling et al. 1986). Saluda, a semidwarf, is moderately winter hardy, matures in midseason, and is fairly short at 90 cm in height. At maturation, the stems of Saluda are moderately stiff with hollow internodes and a waxy bloom. The flag leaf is recurved and is generally not twisted, but can be occasionally. The leaf sheath also has a waxy bloom. The head is tapered, lax, and is usually apically awnleted, but can be awnleted on occasion. The tip awns range from 1 to 3.6 cm in length and average ≈2 cm. This variety is susceptible to CLB and to races B and D of the Hessian fly.

Plots located at Knoxville and Springfield were arranged in a 3 x 3 factorial, randomized complete block design with four replications at each location. A replication consisted of nine six-row drill plots (13.72 m long in 1990 and 8.51 m long in 1991) at the GF and nine plots (7.62 m x 15.24 m) at HRES. Rows were spaced 17.8 cm apart at GF and 16.5 cm apart at HRES.

Each plot was sampled twice weekly at the GF and once per week at the HRES beginning in mid-March when the first CLB adults were observed in the plots. Sampling ended in early to mid-June, when the F_1 adults had left the field to overwinter and the wheat was mature. On each sampling date, 20 tillers were randomly selected and examined in each plot. The number of CLB eggs, larvae, and adults on each tiller were counted, and number of the leaf (1-5 from top to bottom) where the CLB was found was recorded. Larval size also was estimated (i.e., small ≈1-2 mm, medium ≈2-4 mm, and large ≈4-6 mm) and recorded. To provide further information relative to adult CLB, five sweep-samples using a standard sweep-net (37.5 cm diam) were randomly taken on each sampling date. Sweep-net sampling was terminated when larvae were first collected because of the difficulty in using this sampling method without destroying the larvae. Additional information taken on selected dates during the sampling period included weekly determination of stage of plant development using Feekes scale (Large 1954) and plant height. Prior to harvest, plant density was determined by selecting and delineating two or three areas 1 meter in length per plot. The number of tillers in these areas were counted and recorded. Plants were counted from 2 areas/plot at HRES in 1990 and 3 areas/plot at the GF in 1990 and 1991. Prior to harvest, CLB damage also was rated (0 = no damage thru 10 = 90-100% damage). Yield was measured at harvest, and one hundred-seed weight was recorded after harvest.

Data were subjected to an analysis of variance procedure to evaluate influence of planting dates and varieties on populations of CLB on wheat (SAS Institute 1985). When significant (p=0.05) differences were observed, Duncan's (1955) multiple range test was used to determine significant (p=0.05) differences among the means.

CHAPTER III

RESULTS AND DISCUSSION

PLANTING DATE 1990. Adult CLBs were first observed on wheat during the middle of March, when wheat averaged three to five leaves per plant (growth stages 2 and 3)(Fig. 3 and 4). Density of adult CLBs peaked at both locations on 1 April when wheat plants were between stages 5 and 9.

The mean number of CLB adults per five sweeps averaged across each sampling date from mid-March to mid-April were significantly different among planting dates at the GF (Table 3). At this location, significantly greater numbers (ca. 2.5X) of adults were found in the early-planted wheat compared with middle- and late-planted wheat (Table 3, Fig. 3). Although no significant differences were found among planting dates at HRES, the trend was similar with greater densities of CLB adults in the early-planted wheat (Table 3, Fig. 4). These findings are consistent with preliminary data reported by Grant and Patrick (1991).

The reason for greater numbers of adults in early-planted wheat is unclear. Data suggest that adults move into early-planted wheat and mate. However, conditions within the early-planted wheat stand may not be conducive to ovipostion, and adults may move to middle- and late-planted wheat where they may oviposit. The later- planted wheat has younger growth and/or less fully matured leaf pubescence and

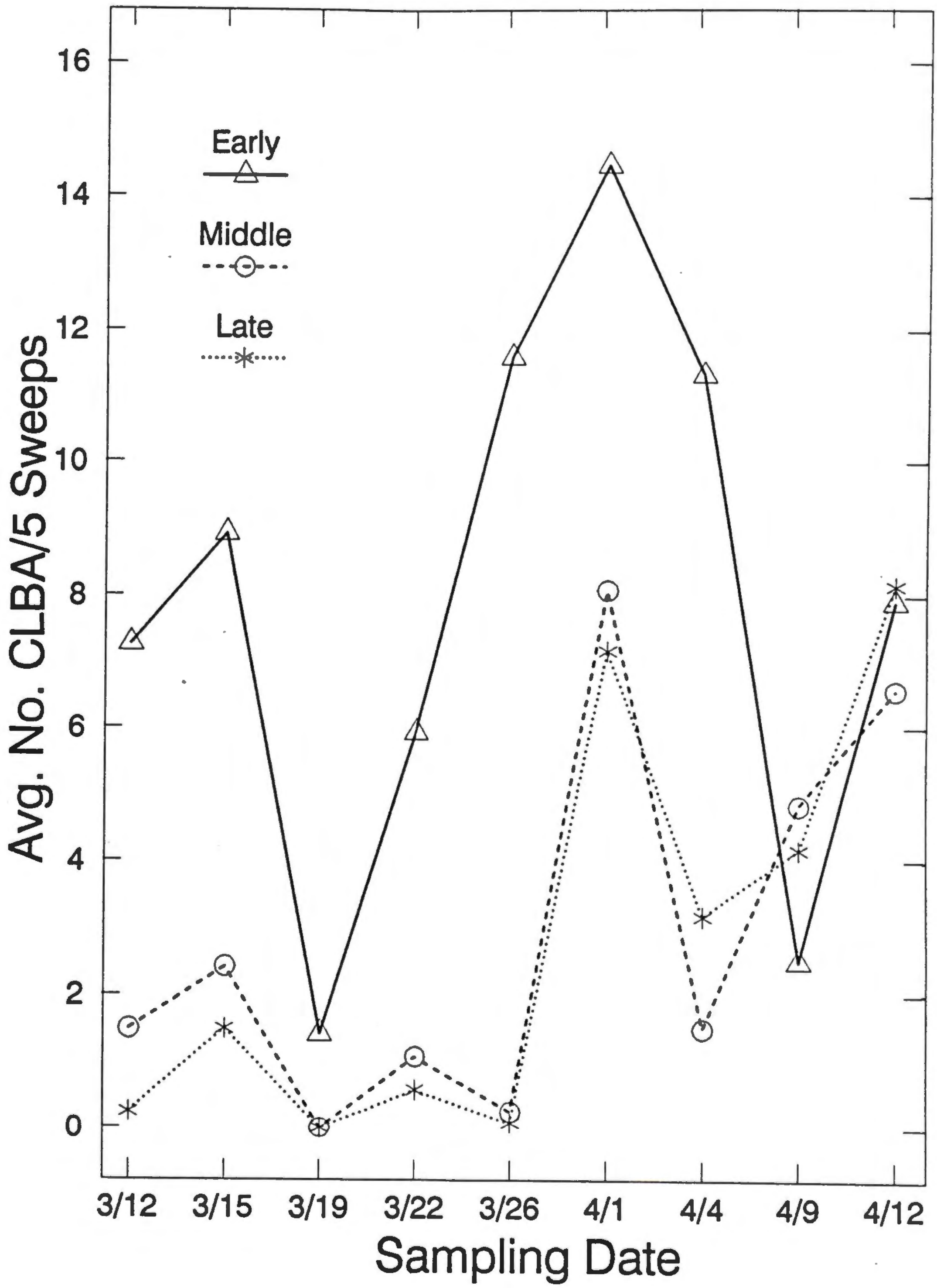

Figure 3. The average number of cereal leaf beetle adults (CLBA) per five sweeps among planting dates during the first month of the sampling period, Government Farm, 1990.

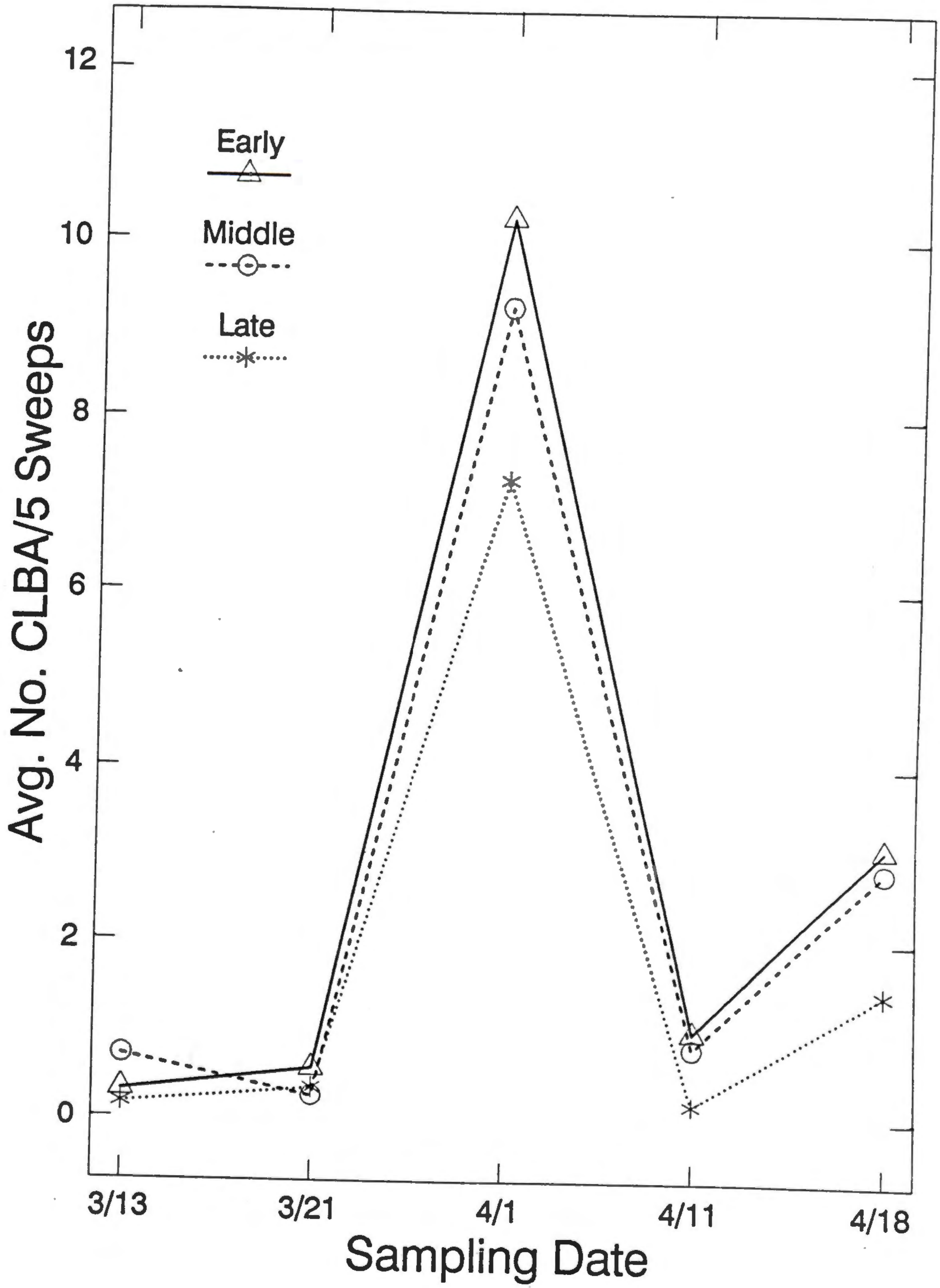

Figure 4. The average number of cereal leaf beetle adults (CLBA) per five sweeps among planting dates during the first month of the sampling period, Highland Rim Experiment Station, 1990.

Table 3. The influence of planting date on the mean number of cereal leaf beetle (CLB) adults per five sweeps at two locations, 1990.

PLANTING DATE[a]	$\bar{X}$ NO. (± SD) CLB ADULTS/ 5 SWEEPS[b]	
	KNOXVILLE (GF)	SPRINGFIELD (HRES)
Early	7.87 ± 6.68a[c]	3.05 ± 5.32a
Middle	2.92 ± 4.07b	2.62 ± 3.93a
Late	2.79 ± 3.77b	1.77 ± 3.23a

[a] Early, middle, and late planting dates were 30 October, 20 November, and 7 December 1989, respectively, at GF, and 26 October, 30 October, and 20 November 1989, respectively, at HRES.
[b] Averaged across each sampling date from mid-March to mid-April.
[c] Values within columns followed by the same letter are not significantly different at the 0.05 level (Duncan's multiple range test).

may be more preferable to CLB. The plant stands also may be thinner (i.e., less than 37 heads/m^2) in late-planted wheat (Herbert 1990). A thinner stand may not have a high number of predators or other insects to compete with CLB eggs or young larvae. The close planting dates (within 4 days) for the early- and middle-planted wheat at HRES may be responsible for the lack of statistical significance among adults per five sweeps at that location.

The mean number of CLB adults per 20 stems averaged across each sampling date from mid-March to early June were not significantly different among planting dates at both locations (Table 4). No significant differences were observed among any of the three planting dates on any sampling date at the GF until 1 June, when densities were greater in the late-planted wheat (Fig. 5). At the HRES, no significant differences were observed on any sampling date among the three planting dates during the entire sampling period (Fig. 6). Adult CLBs drop to lower leaves or to the ground when disturbed or when randomly sampled tillers are touched or shaken (personal observation). This behavior may explain the low numbers of adults observed per 20 stems at both locations. Sweep-net sampling is a better method for sampling CLB adults; however, the use of the sweep net is impractical when larvae are present.

Eggs of CLB were first recorded in mid-March when the wheat was in stages 2 and 3 (Fig. 7 and 8). The peak

Table 4. The influence of planting date on the mean number of cereal leaf beetle (CLB) adults per 20 stems at two locations, 1990.

PLANTING DATE[a]	$\bar{X}$ NO. (± SD) CLB ADULTS/ 20 STEMS[b]	
	KNOXVILLE (GF)	SPRINGFIELD (HRES)
Early	0.24 ± 0.63a[c]	0.69 ± 1.54a
Middle	0.37 ± 1.15a	0.57 ± 1.31a
Late	0.36 ± 1.38a	0.56 ± 1.27a

[a] Early, middle, and late planting dates were 30 October, 20 November, and 7 December 1989, respectively, at GF, and 26 October, 30 October, and 20 November 1989, respectively, at HRES.
[b] Averaged across each sampling date from mid-March to early June.
[c] Values within columns followed by the same letter are not significantly different at the 0.05 level (Duncan's multiple range test).

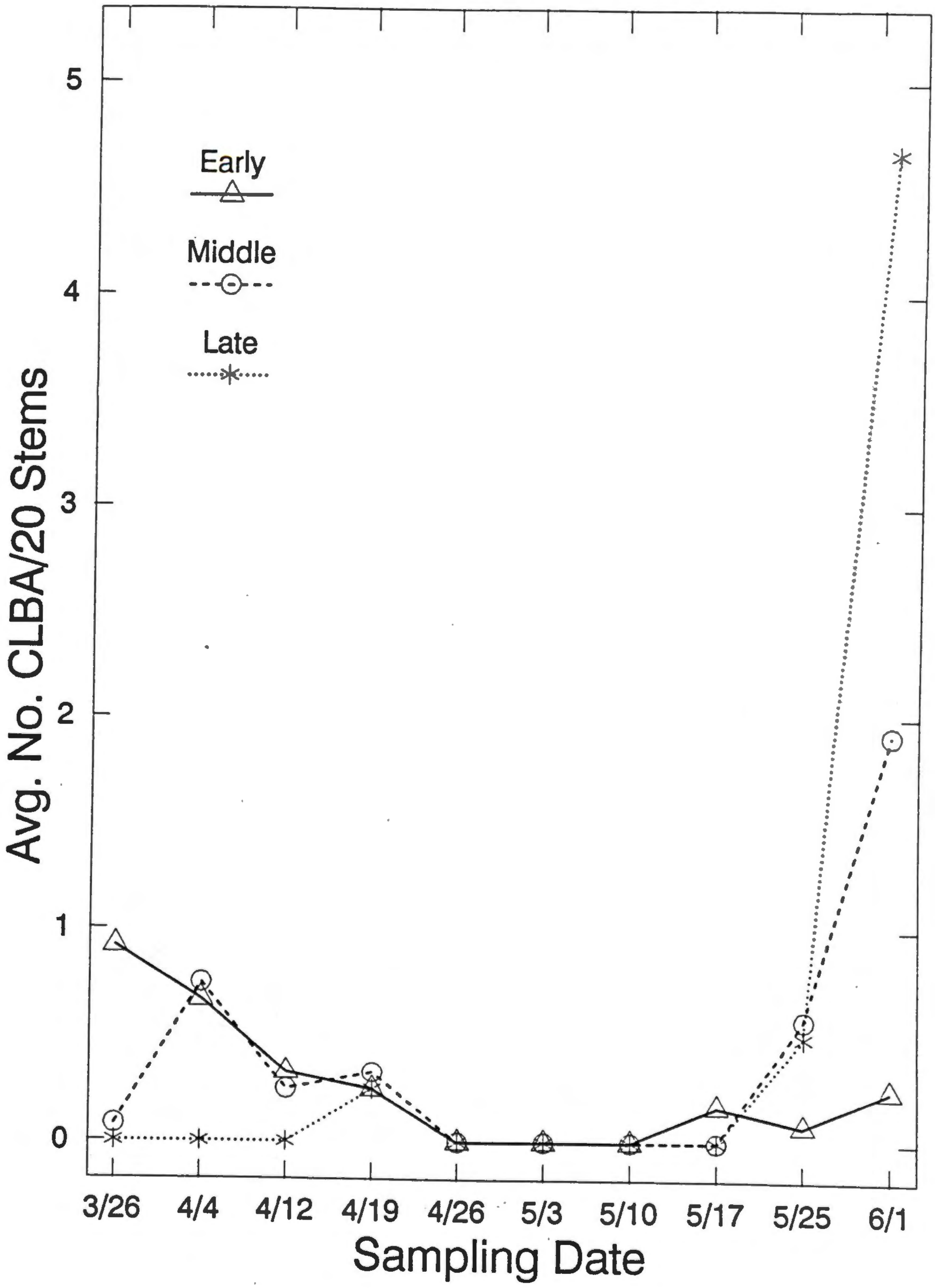

Figure 5. The average number of cereal leaf beetle adults (CLBA) per 20 stems among planting dates from mid-March to early June, Government Farm, 1990.

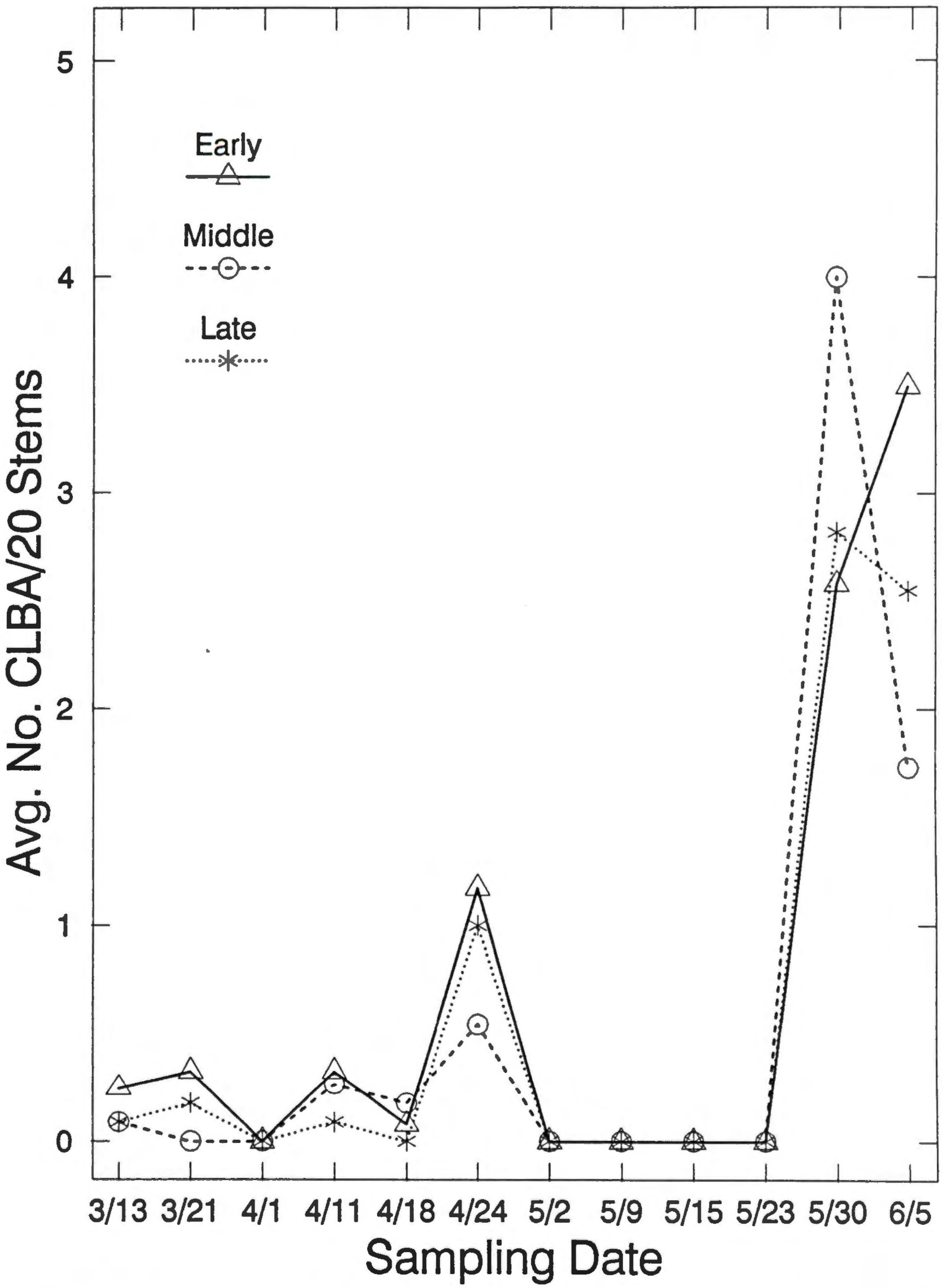

Figure 6. The average number of cereal leaf beetle adults (CLBA) per 20 stems among planting dates from mid-March to early June, Highland Rim Experiment Station, 1990.

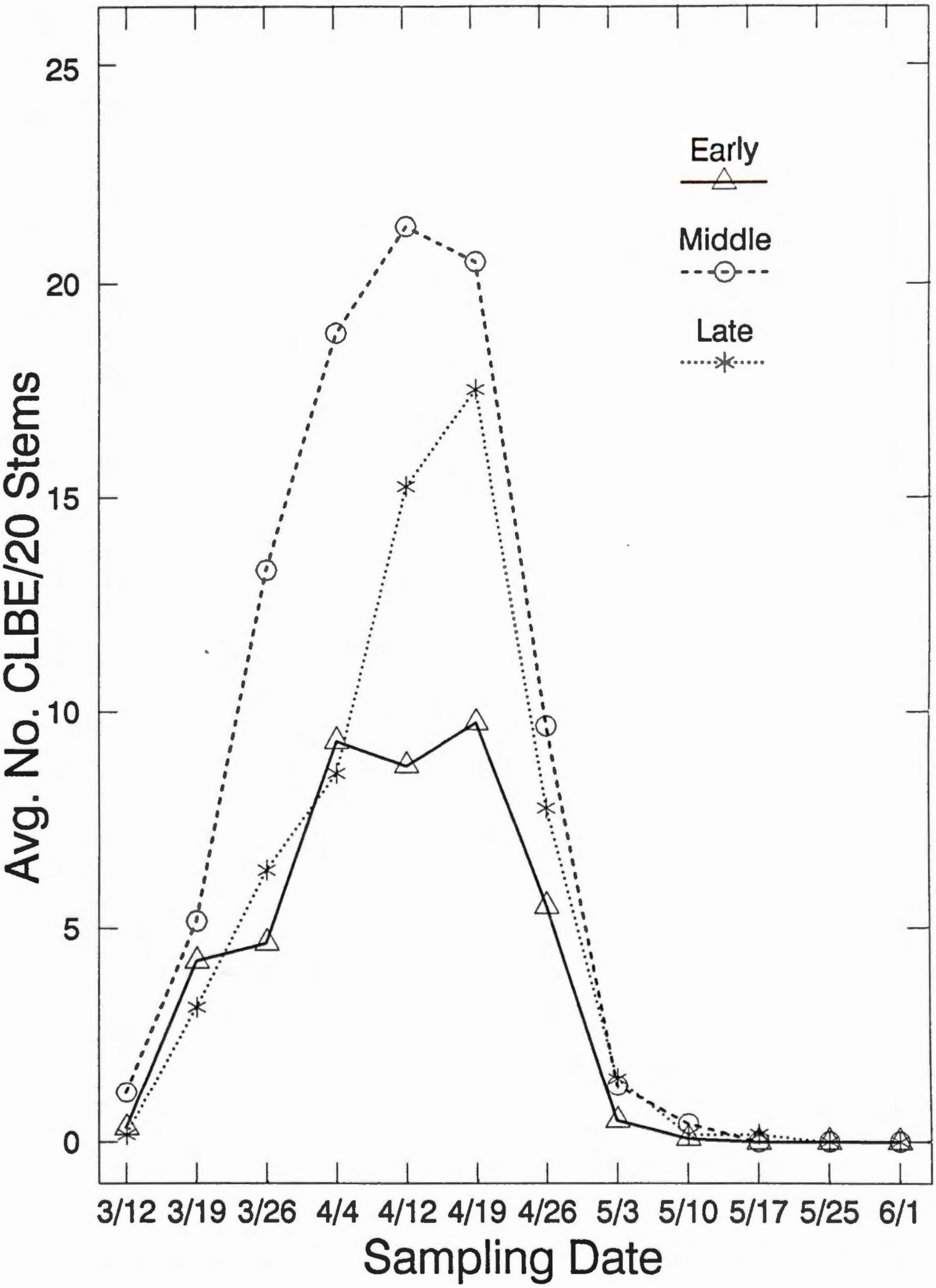

Figure 7. The average number of cereal leaf beetle eggs (CLBE) per 20 stems among planting dates from mid-March to early June, Government Farm, 1990.

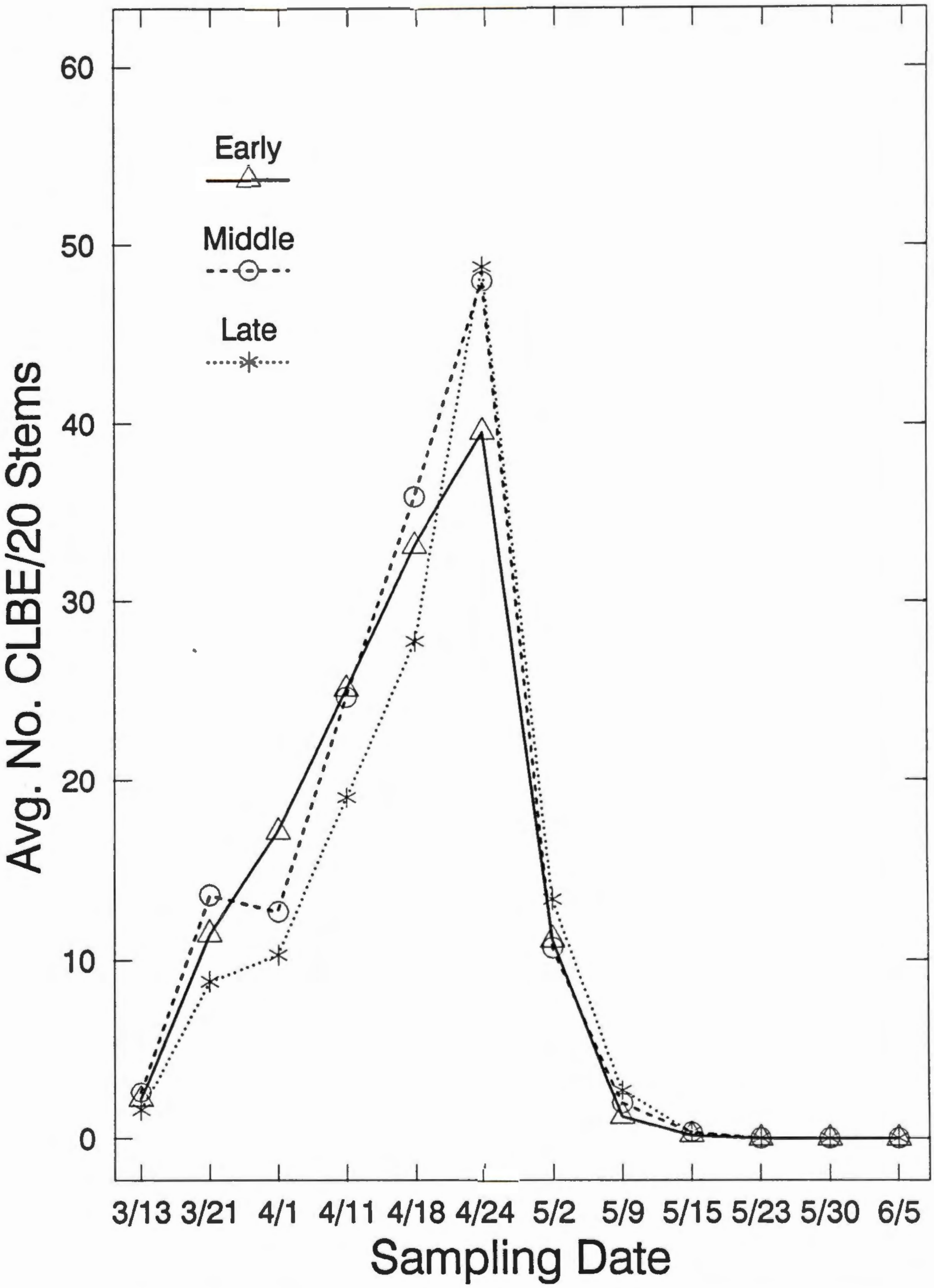

Figure 8. The average number of cereal leaf beetle eggs (CLBE) per 20 stems among planting dates from mid-March to early June, Highland Rim Experiment Station, 1990.

density of CLB eggs was recorded on 12 April at the GF and on 24 April at HRES. On these dates, the stage of wheat growth ranged from 6 to 10 at the GF and 6 to 8 at HRES. No eggs were found in the field after 10 May at either location.

The mean number of CLB eggs per 20 stems averaged across each sampling date from mid-March to early June were significantly different among planting dates at the GF (Table 5). At this location, significantly fewer eggs were found in the early-planted wheat compared with the middle- and late-planted wheat (Table 5, Fig. 7). However, no significant differences in CLB egg densities were observed among the three planting dates at HRES (Table 5, Fig. 8). This lack of statistical significance may be attributed to the close planting dates for the early- and middle-planted wheat. Greater numbers of eggs were found on middle-planted wheat than on early-or late-planted wheat at both locations (Table 5, Fig. 7 and 8).

The lower number of eggs per 20 stems in the early-planted wheat at the GF may be attributed to advanced leaf pubescence of the more mature early-planted wheat which may have deterred ovipositing adults. More eggs were found on middle- or late-planted wheat which had younger growth and possibly less mature leaf pubescence. Leaf pubescence can be influenced by the environment and varies among plants, within plants, and even within single leaves on the same

Table 5. The influence of planting date on the mean number of cereal leaf beetle (CLB) eggs per 20 stems at two locations, 1990.

PLANTING DATE[a]	$\bar{X}$ NO. (± SD) CLB EGGS/ 20 STEMS[b] KNOXVILLE (GF)	SPRINGFIELD (HRES)
Early	3.78 ± 5.23c[c]	11.74 ± 15.05a
Middle	8.19 ± 10.37a	12.44 ± 16.67a
Late	5.44 ± 7.03b	10.99 ± 15.34a

[a] Early, middle, and late planting dates were 30 October, 20 November, and 7 December 1989, respectively, at GF, and 26 October, 30 October, and 20 November 1989, respectively, at HRES.
[b] Averaged across each sampling date from mid-March to early June.
[c] Values within columns followed by the same letter are not significantly different at the 0.05 level (Duncan's multiple range test).

plant (Wellso and Hoxie 1982). The differences in pubescence of the three varieties used will be discussed later in Variety 1990. The lower number of eggs per 20 stems in the early-planted wheat also may be attributed to a denser stand which could harbor more predators and/or parasitoids that could devour or parasitize CLB eggs.

The CLB larvae were first observed in late March at the GF and in early April at HRES when the wheat was between stages 3 to 5 at the GF and 5 to 9 at HRES (Fig. 9 and 10). The larval peak was recorded between 26 April and 3 May at the GF and on 2 May at HRES. At this time, the wheat was between stages 8 and 10.5. Larvae were not found in the field after 25 May at either location.

The mean number of CLB larvae per 20 stems averaged across each sampling date from mid-March to early June were significantly different among planting dates at both locations (Table 6). At the GF, significantly fewer larvae were concentrated in the early-planted wheat when compared with the middle- and late-planted wheat (Table 6, Fig. 9). This trend also was evident at HRES where significantly fewer larvae were found in early-planted wheat as compared to the middle- and late-planted wheat (Table 6, Fig. 10).

Densities of both eggs (at GF) and larvae (at GF and HRES) per 20 stems were significantly lower in the early-planted wheat. These low numbers of eggs and larvae per 20 stems may be due to nonpreference of adult CLB to oviposit

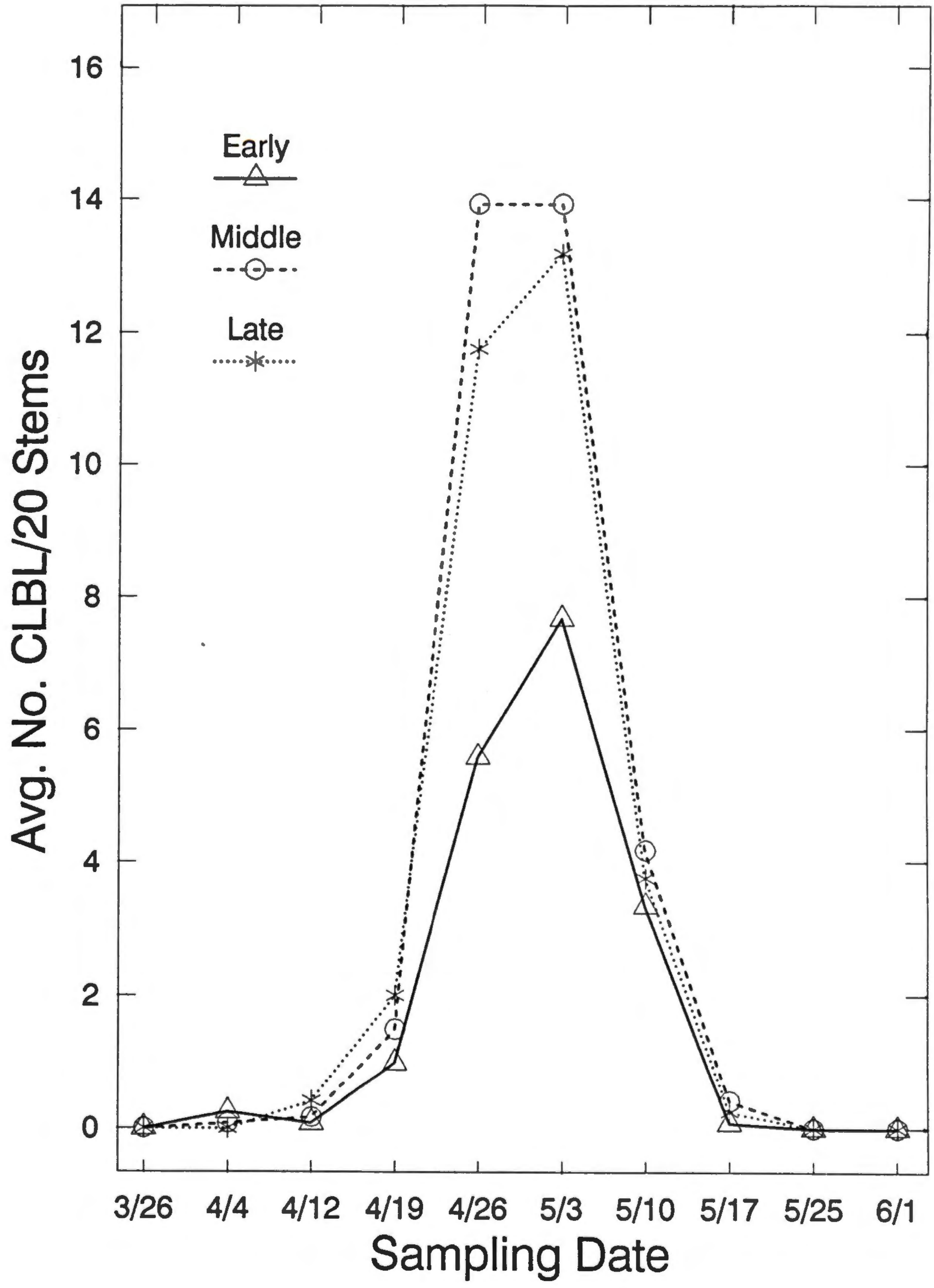

Figure 9. The average number of cereal leaf beetle larvae (CLBL) per 20 stems among planting dates from mid-March to early June, Government Farm, 1990.

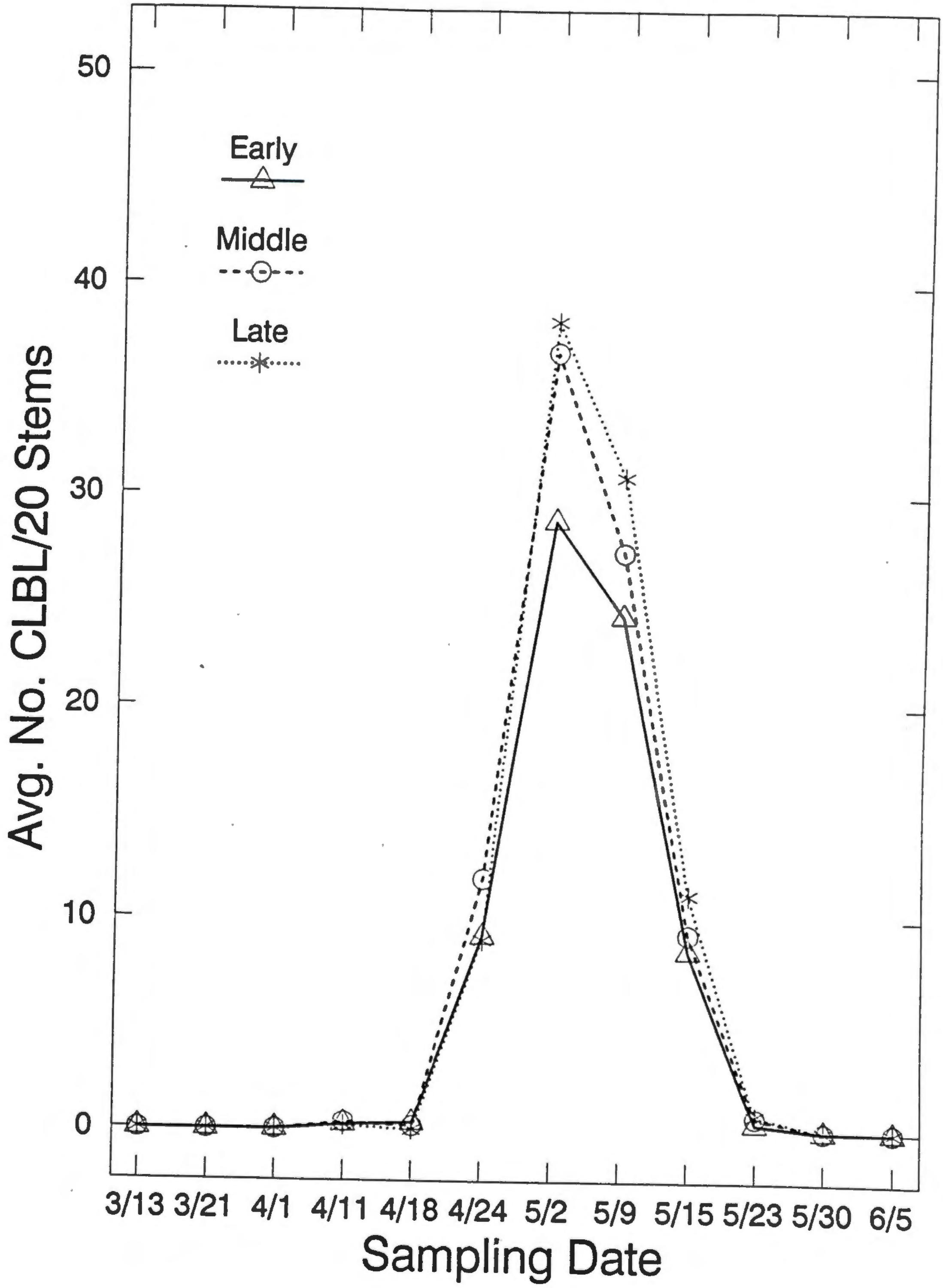

Figure 10. The average number of cereal leaf beetle larvae (CLBL) per 20 stems among planting dates from mid-March to early June, Highland Rim Experiment Station, 1990.

Table 6. The influence of planting date on the mean number of cereal leaf beetle (CLB) larvae per 20 stems at two locations, 1990.

PLANTING	$\bar{X}$ NO. (± SD) CLB LARVAE/ 20 STEMS[b]	
DATE[a]	KNOXVILLE (GF)	SPRINGFIELD (HRES)
Early	1.45 ± 2.61b[c]	5.97 ± 10.72b
Middle	2.75 ± 5.34a	7.03 ± 12.32a
Late	2.74 ± 5.22a	7.38 ± 13.44a

[a] Early, middle, and late planting dates were 30 October, 20 November, and 7 December 1989, respectively, at GF, and 26 October, 30 October, and 20 November 1989, respectively, at HRES.
[b] Averaged across each sampling date from mid-March to early June.
[c] Values within columns followed by the same letter are not significantly different at the 0.05 level (Duncan's multiple range test).

on early-planted wheat which is more established in growth. The middle- or late-planted wheat which has younger and more tender growth may be more preferable to adults for egg laying and for feeding by the newly-hatched larvae. Another explanation for these lower number of eggs and larvae could be that a large number of predators were concentrated in the dense, early-planted stand. These predators may have fed on eggs and/or young larvae, thereby reducing CLB densities.

Yield and stand density analysis for all studies is provided in Appendix. ANOVA tables for hundred-seed weight, yield, moisture, test weight and stand density also are provided in Appendix.

PLANTING DATE 1991. This study was conducted only at the GF. Adult CLBs were first observed on wheat during the middle of March, when wheat averaged three to five leaves per plant (growth stages 2 and 3) (Fig. 11). Density of adult CLBs peaked on 7 April when wheat plants were between stages 3.5 and 7.

The mean number of CLB adults per five sweeps averaged across each sampling date from mid-March to mid-April were significantly different among planting dates (Table 7). Significantly greater numbers of adults (ca. 33% more) were found in the early- and middle-planted wheat compared with the late-planted wheat (Table 7, Fig. 11). These results were similar to the 1990 data (Table 3, Fig. 3 and 4).

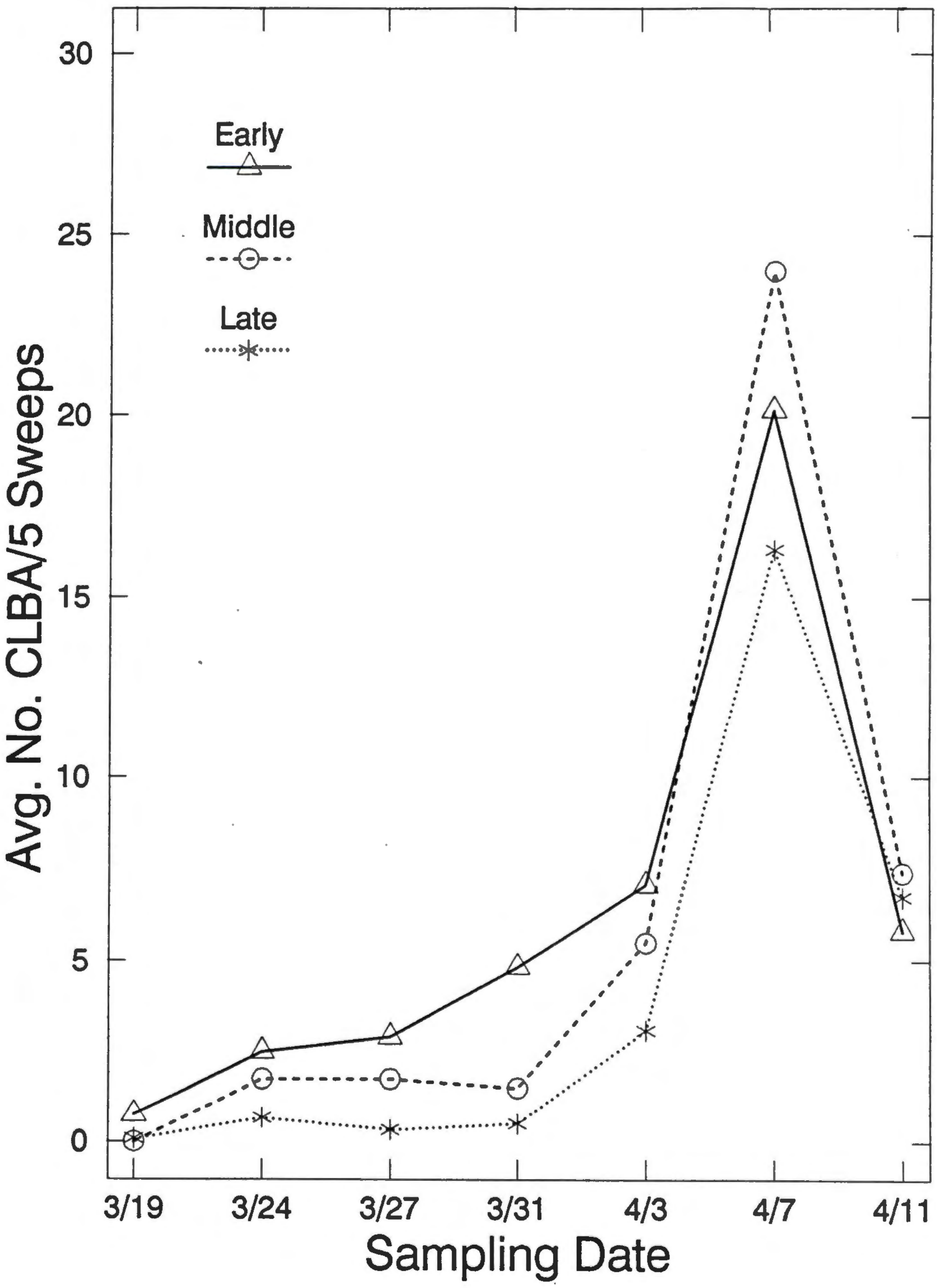

Figure 11. The average number of cereal leaf beetle adults (CLBA) per five sweeps among planting dates during the first month of the sampling period, Government Farm, 1991.

Table 7. The influence of planting date on the mean number of cereal leaf beetle (CLB) adults per five sweeps, Government Farm, 1991.

PLANTING DATE[a]	$\bar{X}$ NO. (± SD) CLB ADULTS/ 5 SWEEPS[b]
Early	6.29 ± 7.35a[c]
Middle	5.98 ± 8.43a
Late	3.96 ± 6.34b

[a] Early, middle, and late planting dates were 2 November, 16 November, and 30 November 1990, respectively.
[b] Averaged across each sampling date from mid-March to mid-April.
[c] Values within columns followed by the same letter are not significantly different at the 0.05 level (Duncan's multiple range test).

As discussed earlier, the reason for greater numbers of adults in early-planted wheat is unclear. However, adults may prefer the early-planted wheat for mating sites and then move into the middle- and late-planted wheat to oviposit. The later-planted wheat which has younger growth also may not yet have mature leaf pubescence and may have a thinner stand.

The mean number of CLB adults per 20 stems averaged across each sampling date from mid-March to early June were significantly different among planting dates (Table 8). During this period, significantly greater numbers of CLB adults were found in the late-planted wheat. Weekly densities of CLB were consistent among planting dates until 25 May, when densities were greater (ca. 1.5 to 2.0X) in the late-planted wheat (Fig. 12). This trend was also similar to the high numbers of CLB adults concentrated in the late-planted wheat at the GF in 1990 (Fig. 5). Late-season adults represented the F_1 generation.The skiddish behavior of CLB adults, as described earlier, may explain the low numbers observed per 20 stems at HRES in 1990 and the GF in 1990 and 1991 (Table 4 and 8).

Eggs of CLB were first recorded in mid-March when wheat was in stages 2 and 3 (Fig. 13). The peak density of CLB eggs was recorded on 11 April, when the wheat was between stages 5.5 and 10. No eggs were found in the field after 7 May.

Table 8. The influence of planting date on the mean number of cereal leaf beetle (CLB) adults per 20 stems, Government Farm, 1991.

PLANTING DATE[a]	$\bar{X}$ NO. (± SD) CLB ADULTS/ 20 STEMS[b]
Early	0.10 ± 0.42b[c]
Middle	0.19 ± 0.57ab
Late	0.24 ± 0.87a

[a] Early, middle, and late planting dates were 2 November, 16 November, and 30 November 1990, respectively.
[b] Averaged across each sampling date from mid-March to early June.
[c] Values within columns followed by the same letter are not significantly different at the 0.05 level (Duncan's multiple range test).

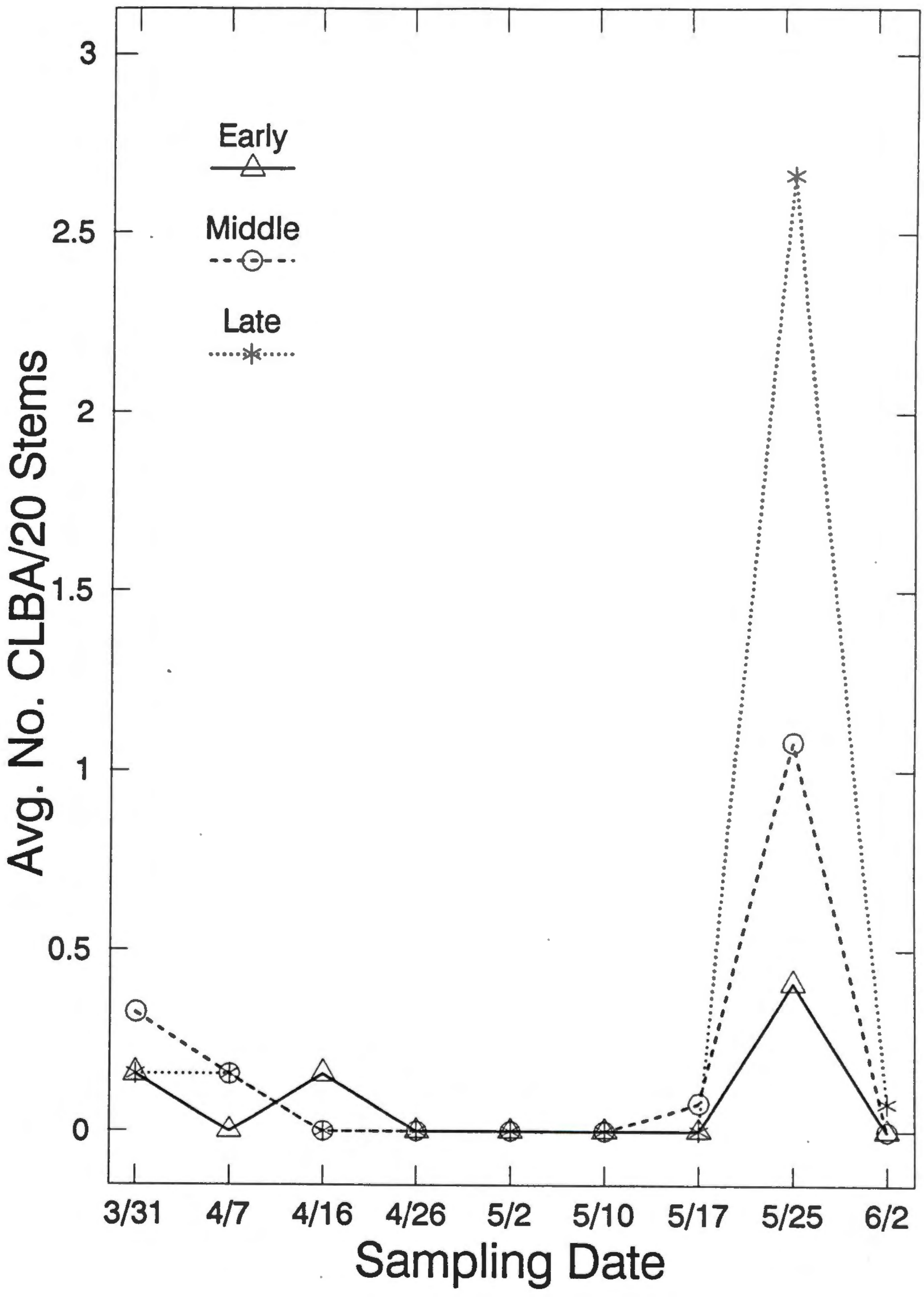

Figure 12. The average number of cereal leaf beetle adults (CLBA) per 20 stems among planting dates from late March to early June, Government Farm, 1991.

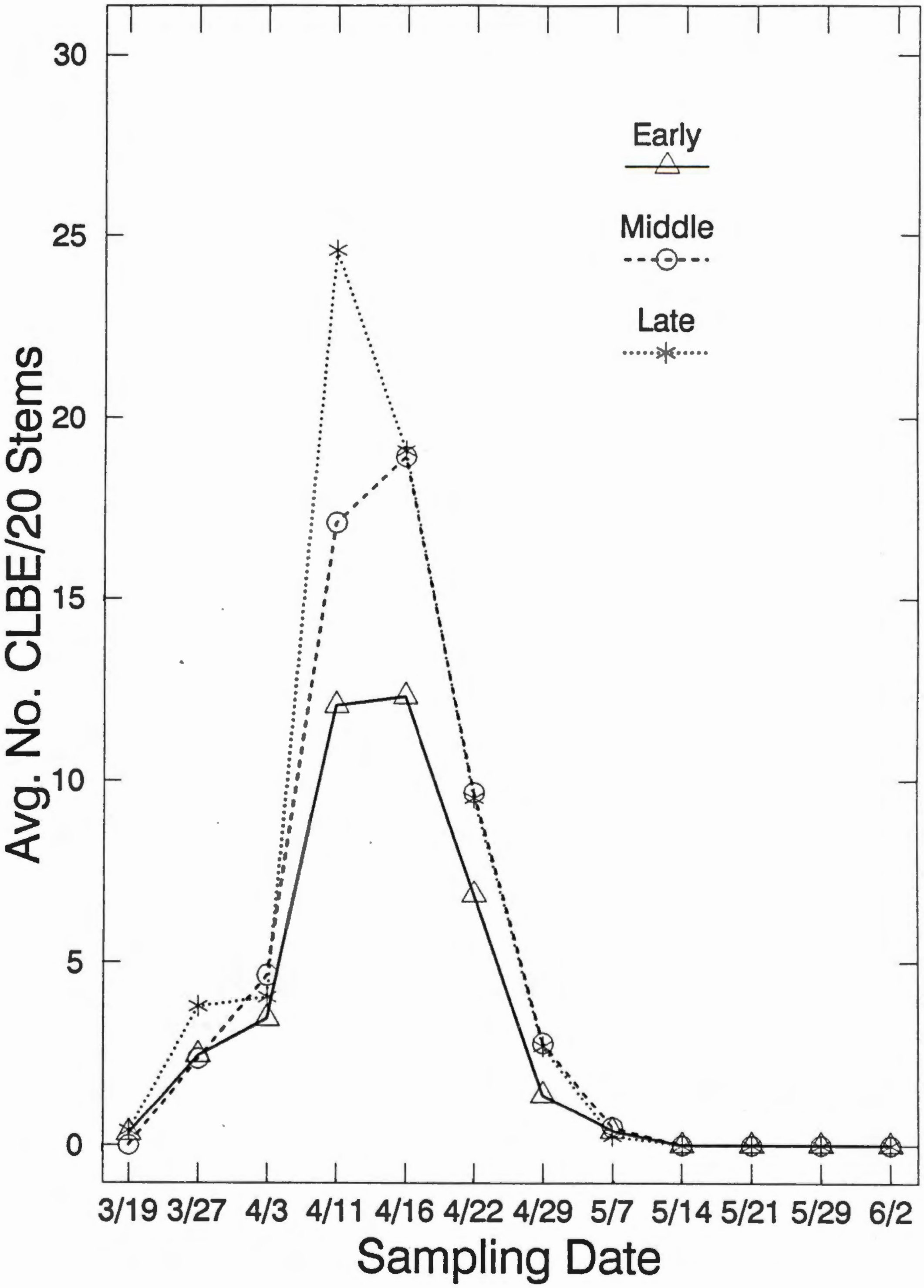

Figure 13. The average number of cereal leaf beetle eggs (CLBE) per 20 stems among planting dates from mid-March to early June, Government Farm, 1991.

The mean number of CLB eggs per 20 stems averaged across each sampling date from mid-March to early June were significantly different among planting dates (Table 9). Significantly fewer eggs were found in the early-planted wheat compared with the middle- and late-planted wheat (Table 9, Fig. 13). This trend also was observed at the GF in 1990 (Table 5, Fig. 7). Greater numbers of eggs were found on late-planted wheat than on early- or middle-planted wheat (Table 9, Fig. 13), which is consistent with observations by Grant and Patrick (1991).

The low number of eggs per 20 stems in the early-planted wheat may again support the explanation that advanced leaf pubescence deters ovipositing adults. More eggs were found in the later-planted wheat which has younger growth and possibly less pubescent leaves. As discussed earlier, the lower number of eggs per 20 stems in the early-planted wheat and the greater number of eggs per 20 stems in the late-planted wheat also may relate to stand density as well as to predation. Although no significant differences were found among planting dates, the thinnest plant stand was found in the late-planted wheat. As described earlier, thin wheat stands have higher infestations of CLB.

The CLB larvae were first observed in early April when wheat was between stages 3.5 and 7 (Fig. 14). The larval peak was recorded on 2 May, when wheat was between stages 9 and 10.5. Larvae were not found in the field after 25 May.

Table 9. The influence of planting date on the mean number of cereal leaf beetle (CLB) eggs per 20 stems, Government Farm, 1991.

PLANTING DATE[a]	$\bar{X}$ NO. (± SD) CLB EGGS/ 20 STEMS[b]
Early	2.88 ± 4.70b[c]
Middle	4.22 ± 7.18a
Late	4.60 ± 7.89a

[a] Early, middle, and late planting dates were 2 November, 16 November, and 30 November 1990, respectively.
[b] Averaged across each sampling date from mid-March to early June.
[c] Values within columns followed by the same letter are not significantly different at the 0.05 level (Duncan's multiple range test).

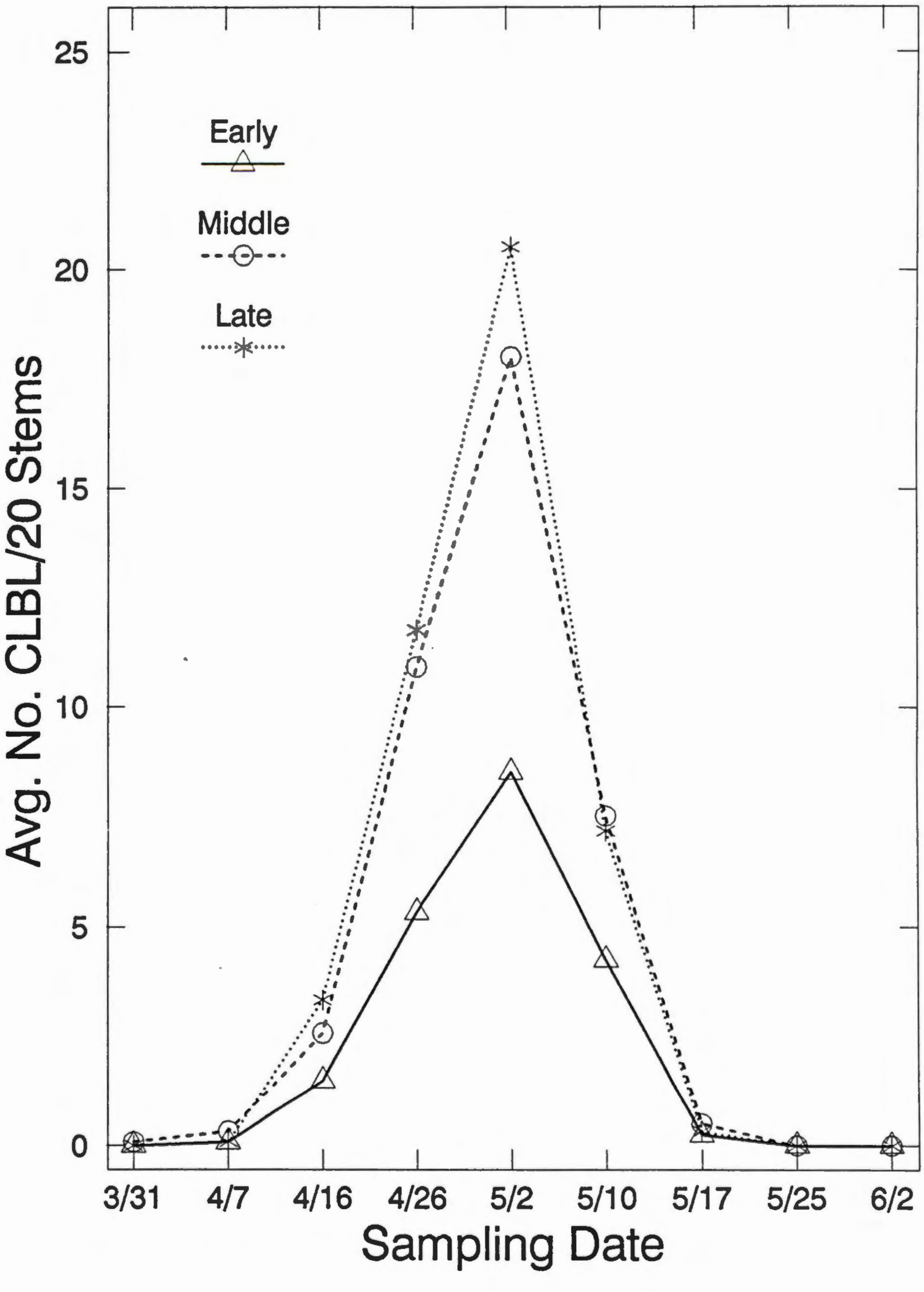

Figure 14. The average number of cereal leaf beetle larvae (CLBL) per 20 stems among planting dates from late March to early June, Government Farm, 1991.

The appearance, peak, and disappearance of CLB larvae were similar to that observed at HRES in 1990 (Fig. 10).

The mean number of CLB larvae per 20 stems averaged across each sampling date from mid-March to early June were significantly different among planting dates (Table 10). Significantly fewer larvae were concentrated in the early-planted wheat when compared with the middle- and late-planted wheat (Table 10, Fig. 14). This trend also was evident at both the GF and HRES in 1990 where significantly fewer larvae were found in early-planted wheat as compared to the middle- and late-planted wheat (Table 6, Fig. 10).

Data obtained from both locations in 1990 were consistent with those obtained at the GF in 1991. Densities of both eggs and larvae per 20 stems were significantly lower in the early-planted wheat. Low numbers of eggs and larvae per 20 stems in early-planted wheat may again be due to nonpreference of adult CLBs to oviposit on the more mature early-planted wheat. Leaf pubescence, predation and/or stand density may also deter ovipositing adults.

VARIETY 1990. Populations of CLB adults, eggs, and larvae first appeared, peaked, and disappeared as discussed in Planting Date 1990 (Fig. 3, 4, 5, 6, 7, 8, 9, and 10).

The mean number of CLB adults per five sweeps averaged across each sampling date from mid-March to mid-April were significantly different among varieties at each location (Table 11). However, CLB adults responded differently to

Table 10. The influence of planting date on the mean number of cereal leaf beetle (CLB) larvae per 20 stems, Government Farm, 1991.

PLANTING DATE[a]	$\bar{X}$ NO. (± SD) CLB LARVAE/ 20 STEMS[b]
Early	2.10 ± 3.84b[c]
Middle	3.55 ± 6.05a
Late	4.11 ± 7.13a

[a] Early, middle, and late planting dates were 2 November, 16 November, and 30 November 1990, respectively.
[b] Averaged across each sampling date from mid-March to early June.
[c] Values within columns followed by the same letter are not significantly different at the 0.05 level (Duncan's multiple range test).

Table 11. The influence of variety on the mean number of cereal leaf beetle (CLB) adults per five sweeps at two locations, 1990.

	$\bar{X}$ NO. (± SD) CLB ADULTS/ 5 SWEEPS[a]	
VARIETIES	KNOXVILLE (GF)	SPRINGFIELD (HRES)
Saluda	5.31 ± 5.60a[b]	1.98 ± 3.12b
Pioneer 2555	4.16 ± 5.62ab	3.93 ± 6.07a
Caldwell	4.03 ± 5.28b	1.75 ± 2.54b

[a] Averaged across each sampling date from mid-March to mid-April.

[b] Values within columns followed by the same letter are not significantly different at the 0.05 level (Duncan's multiple range test).

these varieties at each location. At the GF, significantly more adults were concentrated on Saluda than on Caldwell. However, weekly densities of adults on Saluda were closely consistent with those on Pioneer 2555 and Caldwell (Fig. 15). Whereas at HRES, significantly more adults were concentrated on Pioneer 2555 than on the other two varieties (Table 11, Fig. 16). Densities of CLB adults were lowest on Caldwell at both locations.

The reason for different responses of CLB adults to the varieties at each location is unclear. However, these varieties may respond differently because of geographical and environmental differences at each location. These varying conditions may have affected the attractiveness and suitability of these varieties to populations of CLB.

The mean number of CLB adults per 20 stems averaged across each sampling date from mid-March to early June were significantly different among varieties at the GF; however, no significant differences were observed among varieties at the HRES (Table 12). CLB adults responded differently to these varieties at each location. At the GF, significantly more adults were found on Caldwell than on Saluda (Table 12). Weekly densities of CLB adults were consistent among varieties at the GF until 25 May (Fig. 17) and at the HRES throughout the sampling period (Fig. 18). The higher number of adults per 20 stems on Caldwell at the GF may be due to lack of pubescent leaves on this variety. However, all

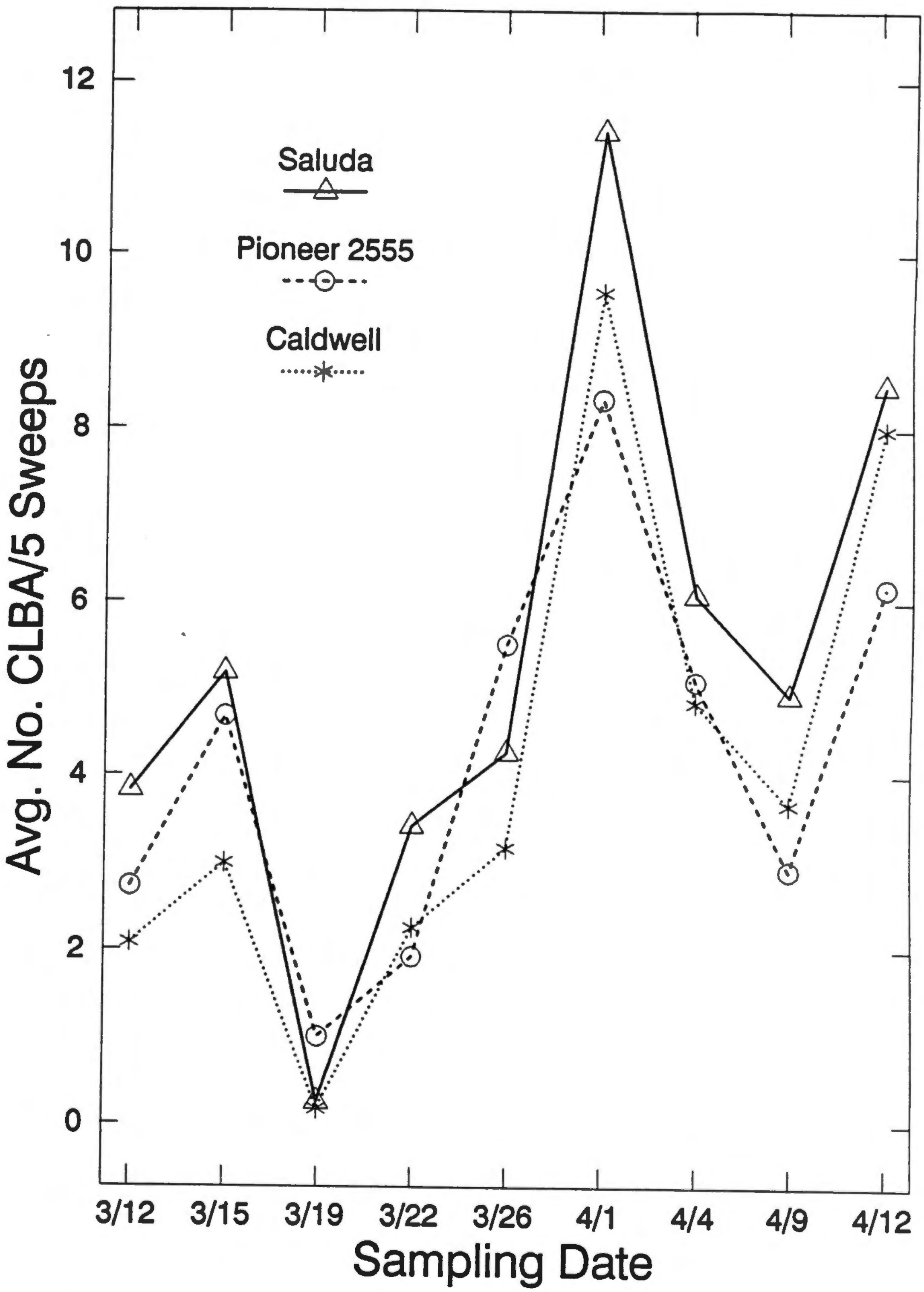

Figure 15. The average number of cereal leaf beetle adults (CLBA) per five sweeps among varieties during the first month of the sampling period, Government Farm, 1990.

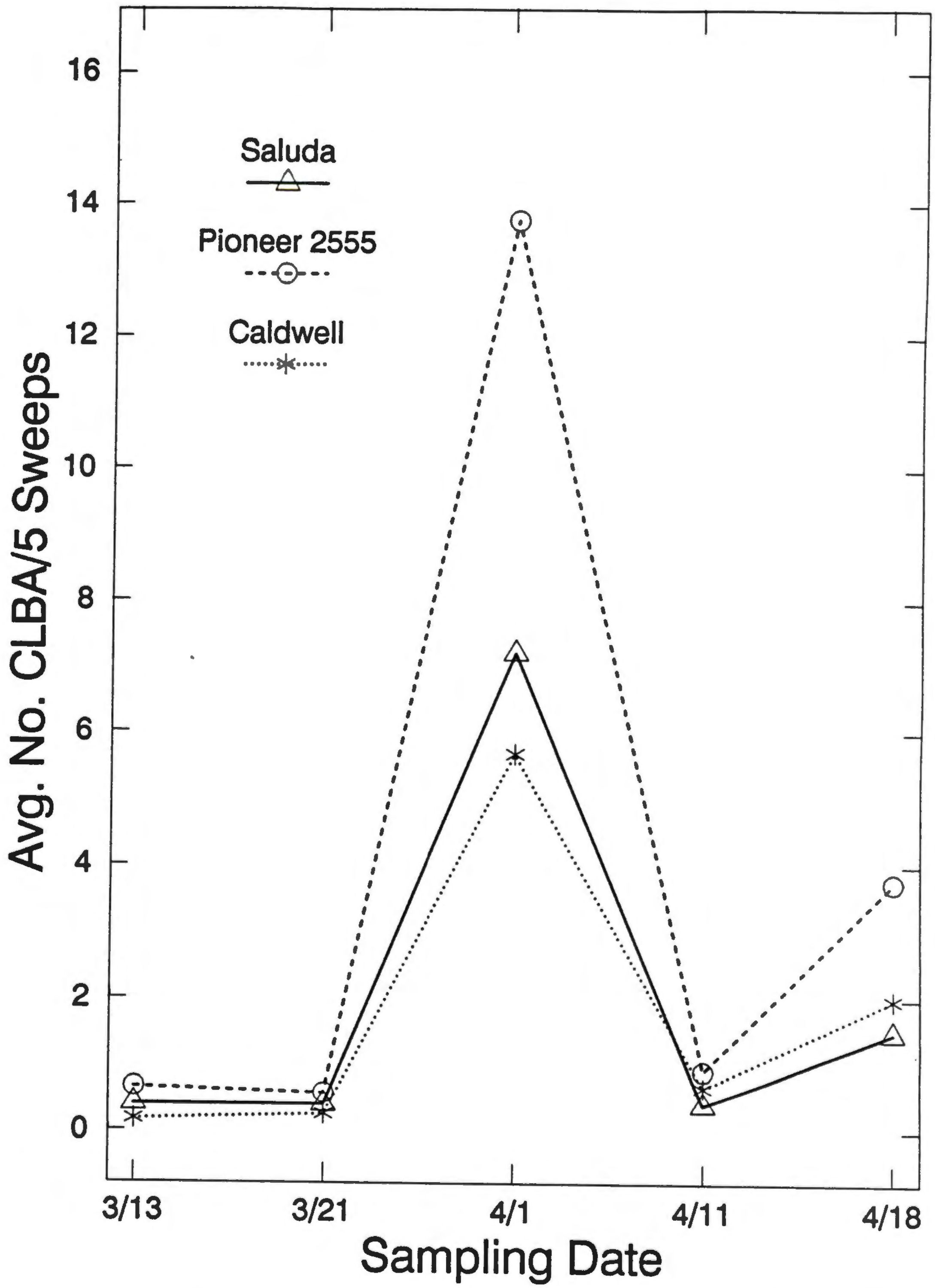

Figure 16. The average number of cereal leaf beetle adults (CLBA) per five sweeps among varieties during the first month of the sampling period, Highland Rim Experiment Station, 1990.

Table 12. The influence of variety on the mean number of cereal leaf beetle (CLB) adults per 20 stems at two locations, 1990.

	$\bar{X}$ NO. (± SD) CLB ADULTS/ 20 STEMS[a]	
VARIETIES	KNOXVILLE (GF)	SPRINGFIELD (HRES)
Saluda	0.25 ± 0.70b[b]	0.64 ± 1.54a
Pioneer 2555	0.30 ± 0.85ab	0.66 ± 1.42a
Caldwell	0.43 ± 1.55a	0.53 ± 1.23a

[a] Averaged across each sampling date from mid-March to early June..
[b] Values within columns followed by the same letter are not significantly different at the 0.05 level (Duncan's multiple range test).

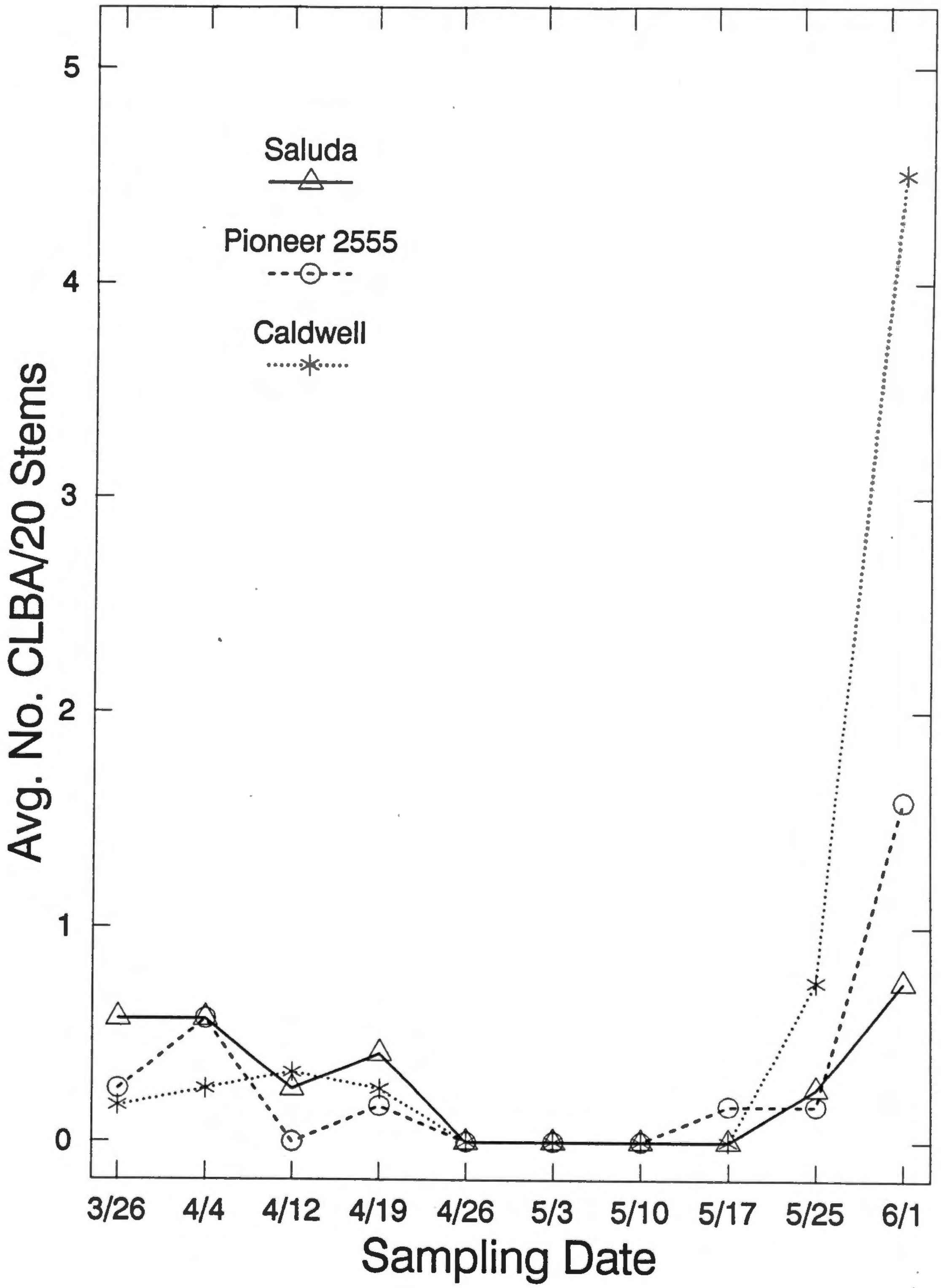

Figure 17. The average number of cereal leaf beetle adults (CLBA) per 20 stems among varieties from mid-March to early June, Government Farm, 1990.

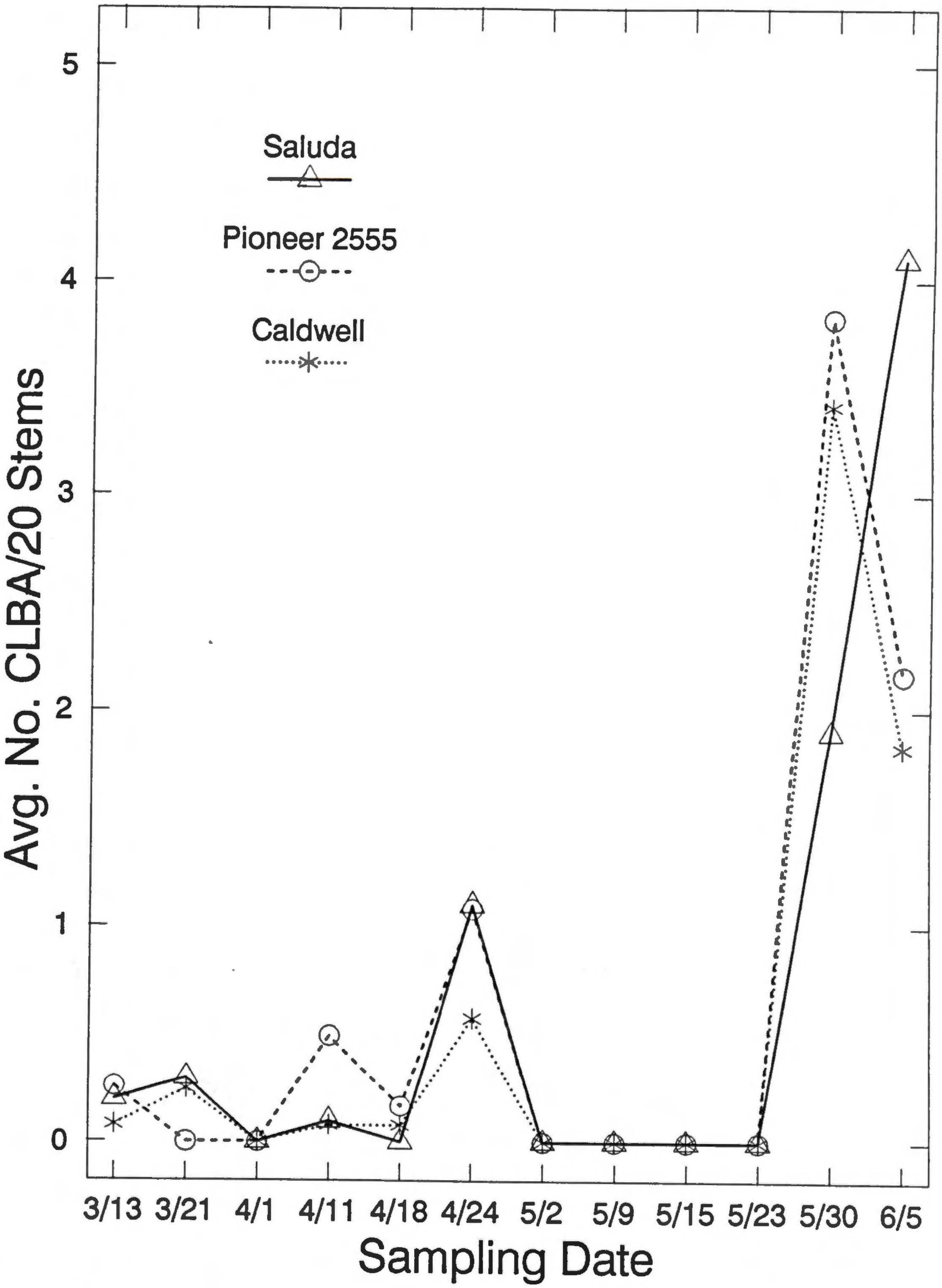

Figure 18. The average number of cereal leaf beetle adults (CLBA) per 20 stems among varieties from mid-March to early June, Highland Rim Experiment Station, 1990.

varieties in this study appear similar in pubescence. Most of these adults occurred later in the season and were believed to be the F_1 generation. Natural mortality of CLB may be reduced on Caldwell, as this variety may harbor a smaller population of egg and larval predators or parasitoids, resulting in greater survivability of CLB to adulthood. In addition, plant stands were significantly different among varieties at the GF in 1990. Plant stands of caldwell were significantly thinner than those of Saluda, and thin stands are reported to have a higher infestation of CLB.

The mean number of CLB eggs per 20 stems averaged across each sampling date from mid-March to early June were significantly different among varieties at the GF (Table 13). However, densities of CLB eggs were inconsistent among varieties at each location. At the GF, significantly fewer eggs were concentrated on Pioneer 2555 when compared to the other two varieties, and a higher number of eggs, although not significantly different from Caldwell, were found on Saluda (Table 13, Fig. 19). Whereas at HRES, no significant differences were detected among varieties although a greater number of eggs were found on Caldwell (Table 13, Fig. 20).

The influence of variety on the density of CLB eggs per 20 stems differed at each location. The low density of eggs concentrated on Pioneer 2555 at the GF may be due to the presence of a large number of egg predators or parasitoids.

Table 13. The influence of variety on the mean number of cereal leaf beetle (CLB) eggs per 20 stems at two locations, 1990.

VARIETIES	$\bar{X}$ NO. (± SD) CLB EGGS/ 20 STEMS[a]	
	KNOXVILLE (GF)	SPRINGFIELD (HRES)
Saluda	6.48 ± 9.20a[b]	11.39 ± 14.74a
Pioneer 2555	4.74 ± 6.65b	11.35 ± 15.01a
Caldwell	6.19 ± 7.97a	12.50 ± 17.46a

[a] Averaged across each sampling date from mid-March to early June..

[b] Values within columns followed by the same letter are not significantly different at the 0.05 level (Duncan's multiple range test).

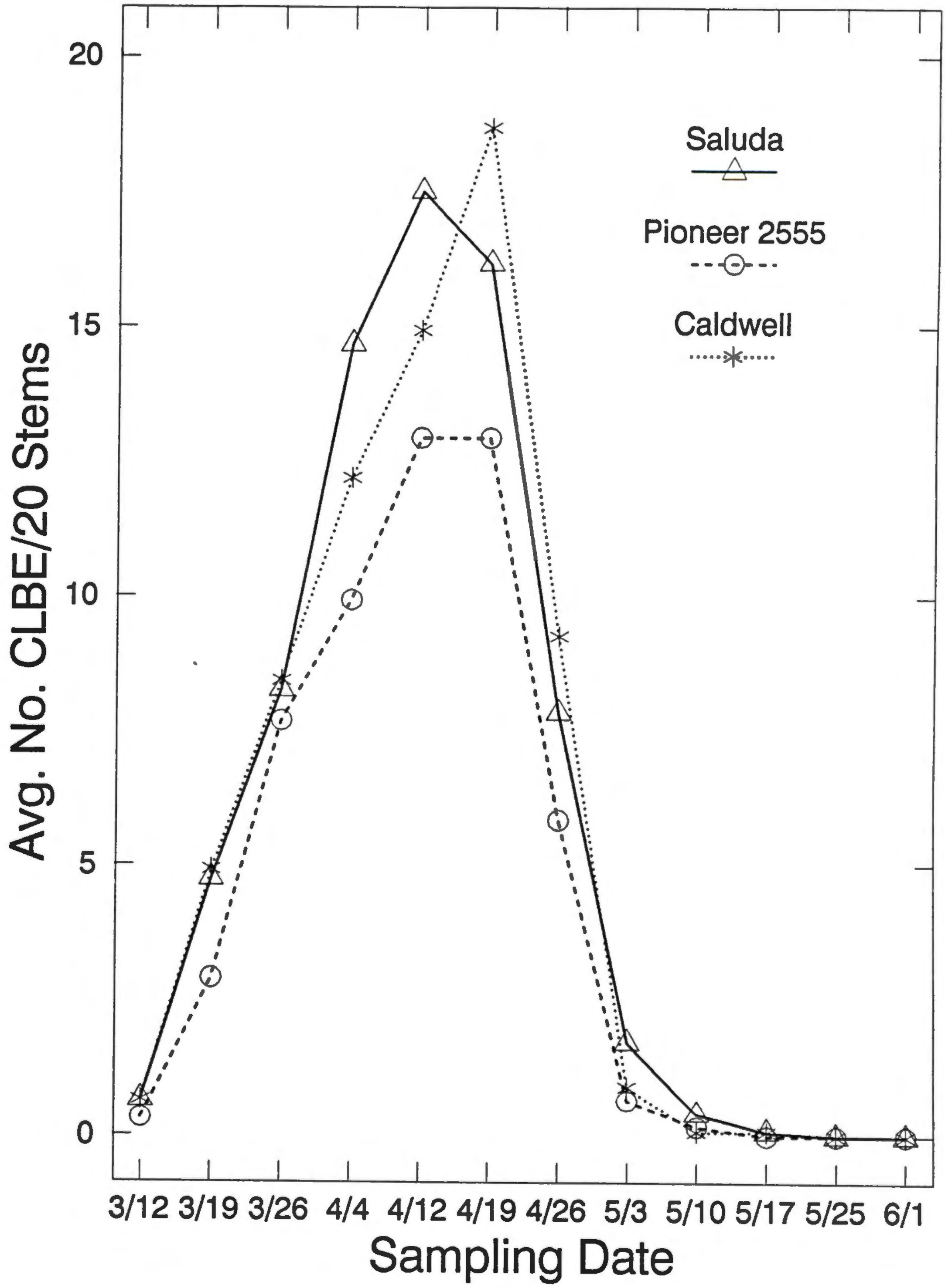

Figure 19. The average number of cereal leaf beetle eggs (CLBE) per 20 stems among varieties from mid-March to early June, Government Farm, 1990.

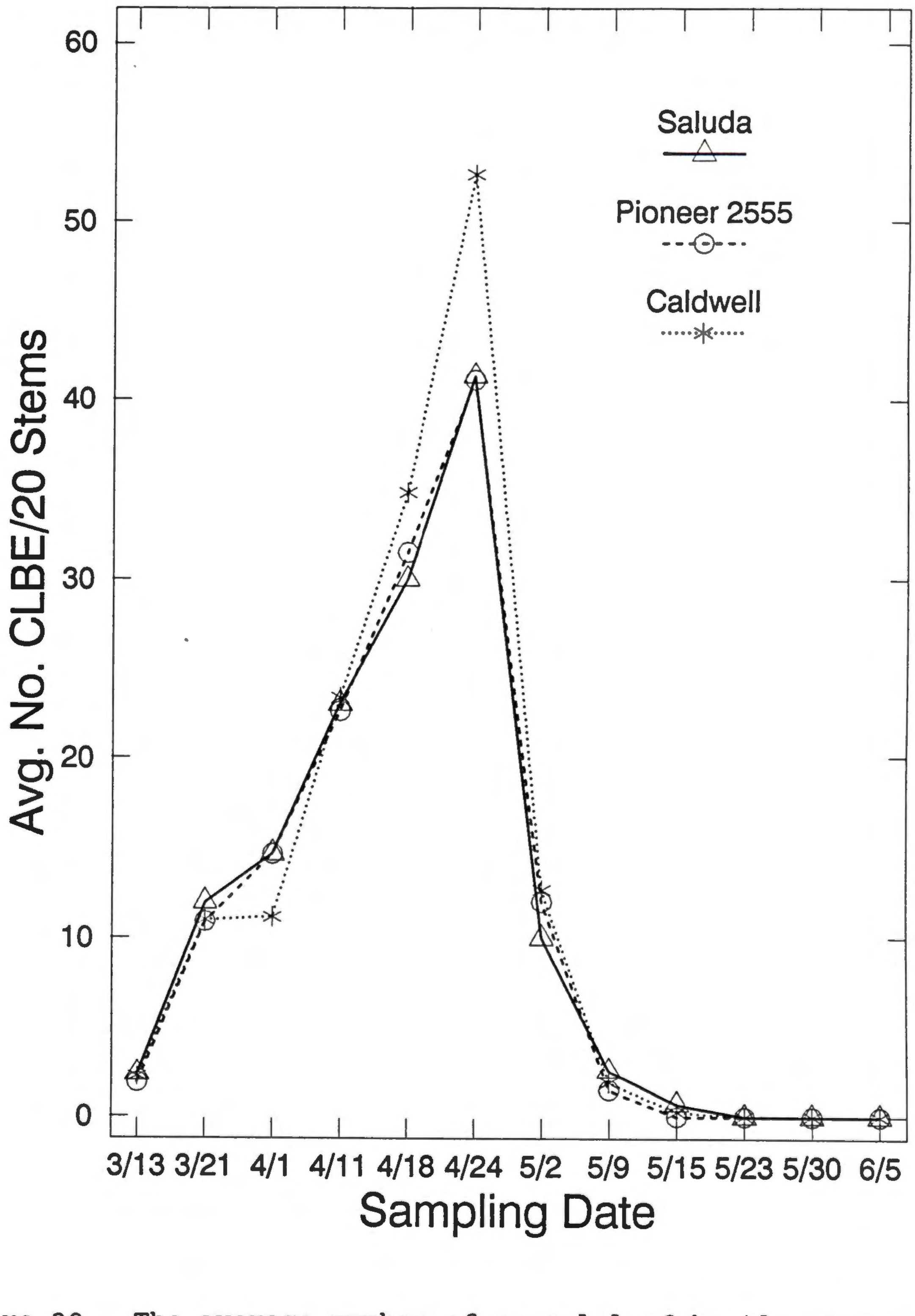

Figure 20. The average number of cereal leaf beetle eggs (CLBE) per 20 stems among varieties from mid-March to early June, Highland Rim Experiment Station, 1990.

Also, a high level of an antibiosis component may be associated with this variety. This mortality may help to explain the low numbers of eggs. However, the low number of eggs do not correlate with the reported preference of ovipositing adults to varieties that lack leaf pubescence. Again, no significant differences were found among varieties at HRES. A higher number of eggs were concentrated on Caldwell and Saluda at both locations. Since Caldwell is absent in pubescence, but this information is lacking for Saluda, these data support the possibility that ovipositing adults may prefer non-pubescent leaves and thin stands. Saluda may have a similar effect as Caldwell.

The mean number of CLB larvae per 20 stems averaged across each sampling date from mid-March to early June were significantly different among varieties at each location (Table 14). However, CLB larvae responded differently to these varieties at each location. At the GF, significantly fewer larvae were concentrated on Pioneer 2555, which also had the lower number of eggs per 20 stems, when compared with the other two varieties (Table 13, Fig. 21). Although not significantly different from Saluda, more larvae were found on Caldwell, which also had the higher number of eggs per 20 stems. At HRES, significantly fewer larvae were concentrated on Saluda than on Caldwell (Table 14, Fig. 22).

The CLB larvae per 20 stems responded differently to the varieties at each location. The low density of larvae

Table 14. The influence of variety on the mean number of cereal leaf beetle (CLB) larvae per 20 stems at two locations, 1990.

	$\bar{X}$ NO. (± SD) CLB LARVAE/ 20 STEMS[a]	
VARIETIES	KNOXVILLE (GF)	SPRINGFIELD (HRES)
Saluda	2.34 ± 4.71a[b]	5.90 ± 10.54b
Pioneer 2555	1.92 ± 3.82b	6.72 ± 11.76ab
Caldwell	2.68 ± 5.15a	7.80 ± 14.20a

[a] Averaged across each sampling date from mid-March to early June.

[b] Values within columns followed by the same letter are not significantly different at the 0.05 level (Duncan's multiple range test).

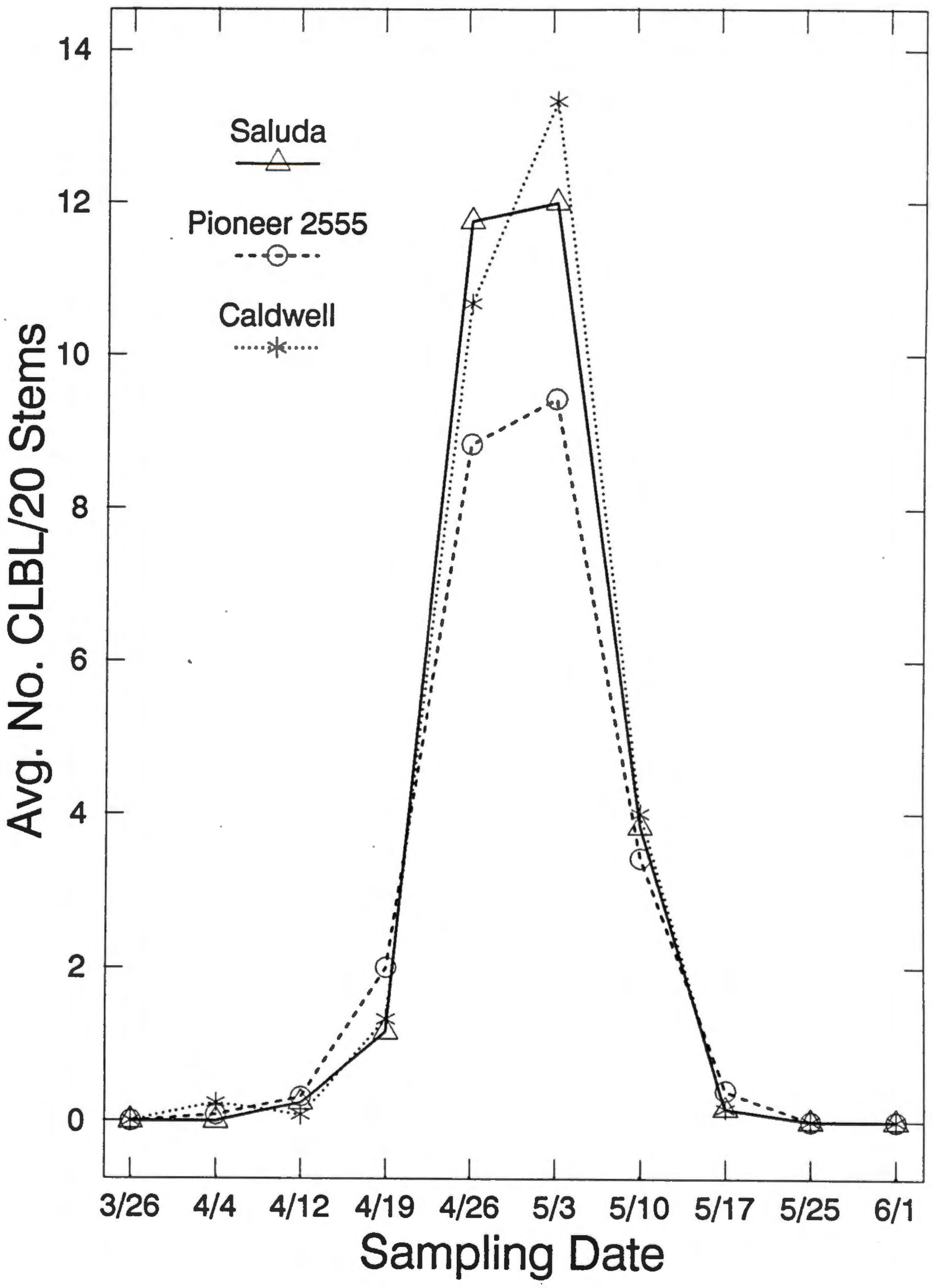

Figure 21. The average number of cereal leaf beetle larvae (CLBL) per 20 stems among varieties from mid-March to early June, Government Farm, 1990.

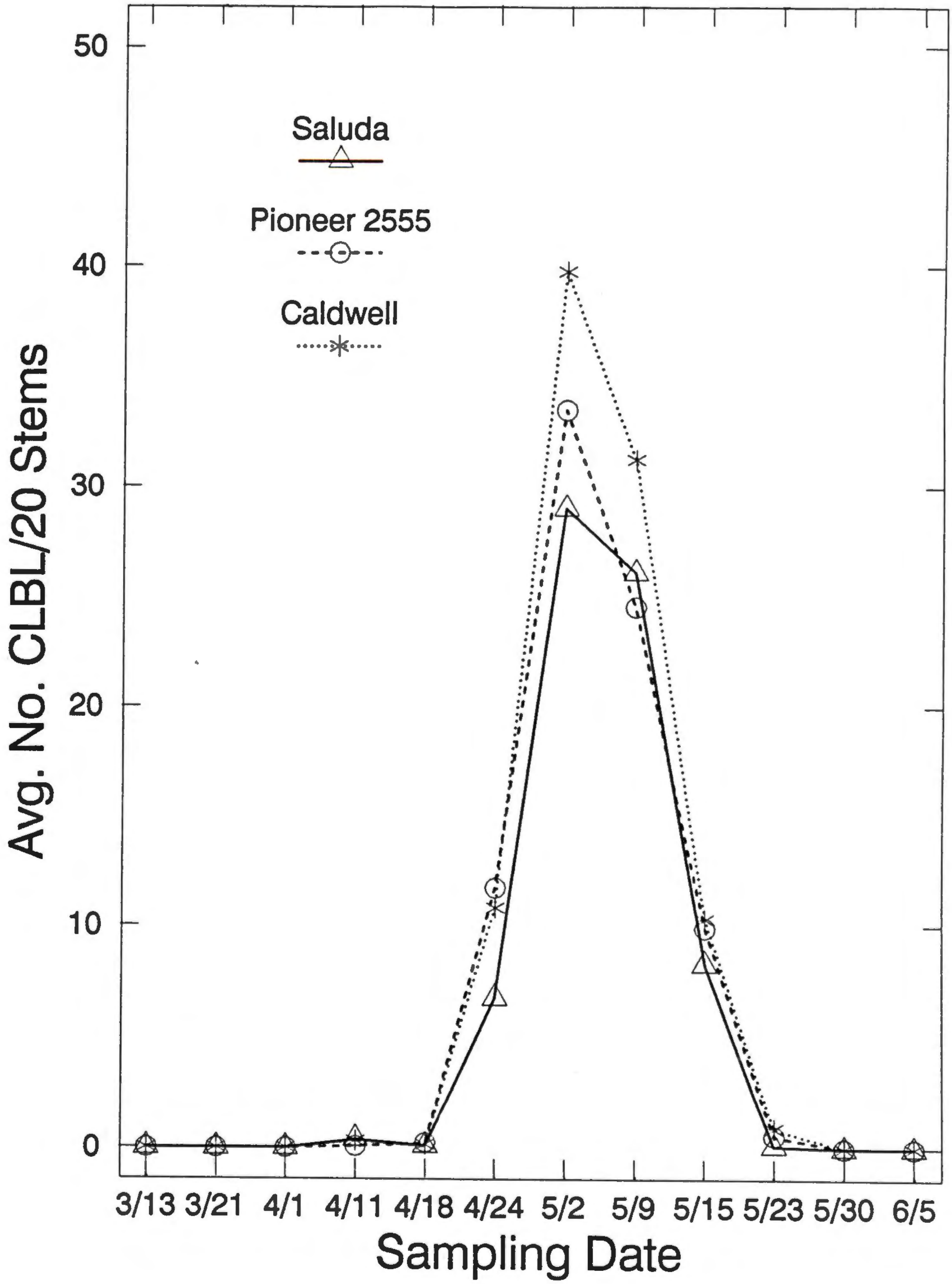

Figure 22. The average number of cereal leaf beetle larvae (CLBL) per 20 stems among varieties from mid-March to early June, Highland Rim Experiment Station, 1990.

concentrated on Pioneer 2555 at the GF may be due to a large population of egg and/or larval predators or parasitoids in this variety. This explanation may account for the low numbers of larvae, but again it does not correlate with the lack of pubescent leaves on this variety, which should make it preferable to ovipositing adults. Reduced egg hatch and/or larval survival could be due to antibiosis components of this variety. At HRES, a low number of larvae were found on Saluda and again it could be due to leaf pubescence, but the pubescence of Saluda is not available. CLB larvae responded similarly to the varieties at each location, where a high number of larvae were concentrated on Caldwell, suggesting that adults may prefer to oviposit on leaves that are non-pubescent and on a variety with a thinner density stand.

VARIETY 1991. This study was conducted only at the GF. Populations of CLB adults, eggs, and larvae first appeared, peaked, and disappeared as discussed in Planting Date 1991 (Fig. 11, 12, 13, and 14).

The mean number of CLB adults per five sweeps averaged across each sampling date from mid-March to mid-April were signficantly different among varieties (Table 15). Significantly more adults were concentrated on Pioneer 2555 and Saluda than on Caldwell. Weekly densities of adults on Pioneer 2555 were closely consistent with those on Saluda (Fig. 23). The greater density of adults per five sweeps on

Table 15. The influence of variety on the mean number of cereal leaf beetle (CLB) adults per five sweeps, Government Farm, 1991.

VARIETIES	$\bar{X}$ NO. (± SD) CLB ADULTS/ 5 SWEEPS[a]
Saluda	5.84 ± 7.78a[b]
Pioneer 2555	6.29 ± 7.92a
Caldwell	4.10 ± 6.51b

[a] Averaged across each sampling date from mid-March to mid-April.
[b] Values within columns followed by the same letter are not significantly different at the 0.05 level (Duncan's multiple range test).

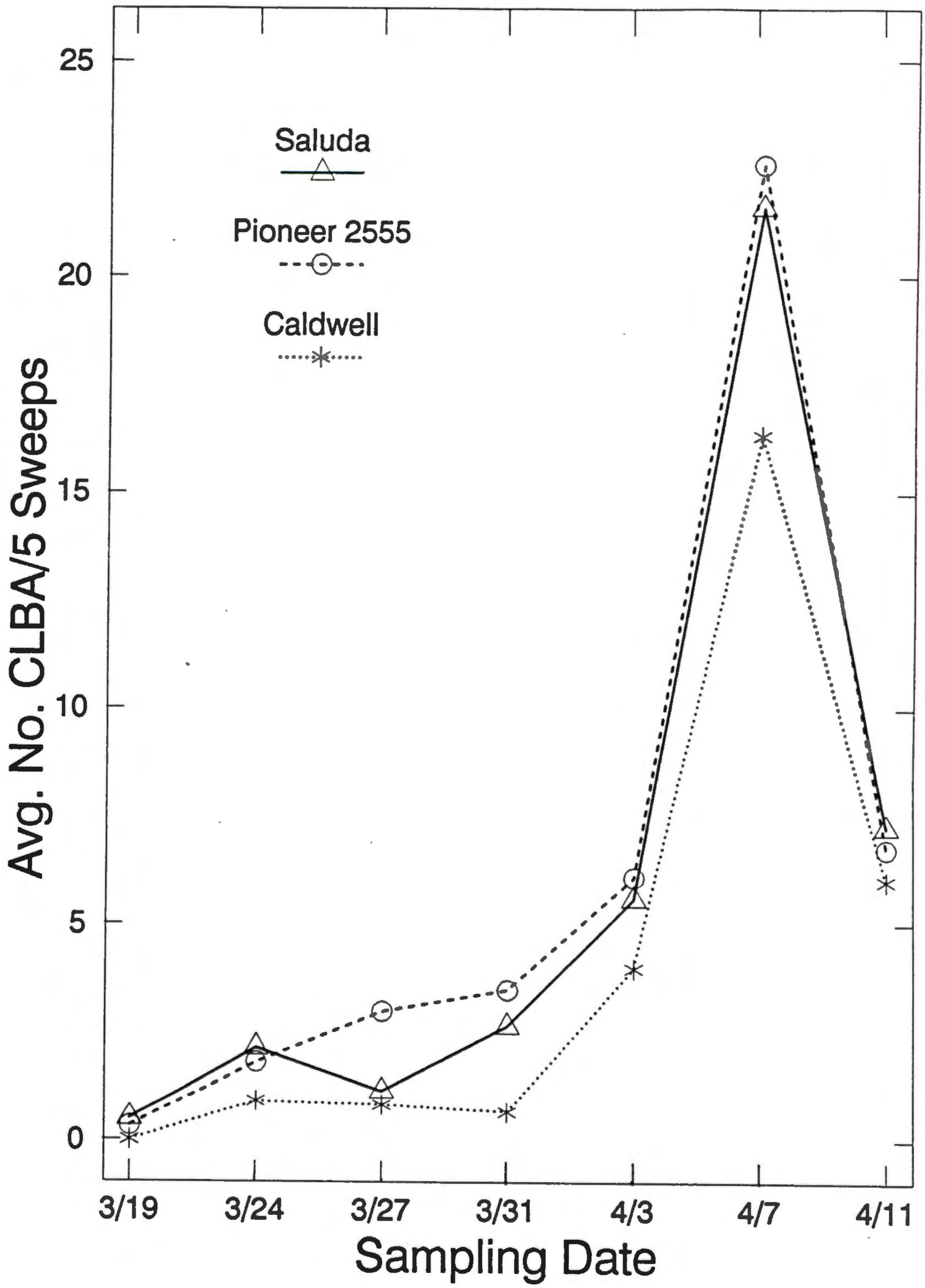

Figure 23. The average number of cereal leaf beetle adults (CLBA) per five sweeps among varieties during the first month of the sampling period, Government Farm, 1991.

Pioneer 2555 is similar to that observed at HRES in 1990 (Fig. 16).

The mean number of CLB adults per 20 stems averaged across each sampling date from mid-March to early June were not significantly different among varieties (Table 16). Weekly densities of CLB adults were consistent among varieties throughout the sampling period (Fig. 24). This similarity also was observed at HRES in 1990 (Fig. 18).

The mean number of CLB eggs per 20 stems averaged across each sampling date from mid-March to early June were significantly different among varieties (Table 17). Significantly fewer eggs were concentrated on Pioneer 2555 when compared to the other two varieties (Table 17, Fig. 25). The low density of eggs concentrated on Pioneer 2555 is similar to that observed at the GF in 1990 (Table 13, Fig. 19). The higher number of eggs concentrated on both Saluda and Caldwell could be due to the possibility that Saluda may be absent of pubescent leaves similar to Caldwell. However, specific information related to leaf pubescence of Saluda is not available.

The mean number of CLB larvae per 20 stems averaged across each sampling date from mid-March to early June were significantly different among varieties (Table 18). Significantly more larvae were found on Caldwell when compared to the other two varieties (Table 18, Fig. 26).

Table 16. The influence of variety on the mean number of cereal leaf beetle (CLB) adults per 20 stems, Government Farm, 1991.

VARIETIES	$\bar{X}$ NO. (± SD) CLB ADULTS/ 20 STEMS[a]
Saluda	0.16 ± 0.60a[b]
Pioneer 2555	0.19 ± 0.61a
Caldwell	0.19 ± 0.73a

[a] Averaged across each sampling date from mid-March to early June.
[b] Values within columns followed by the same letter are not significantly different at the 0.05 level (Duncan's multiple range test).

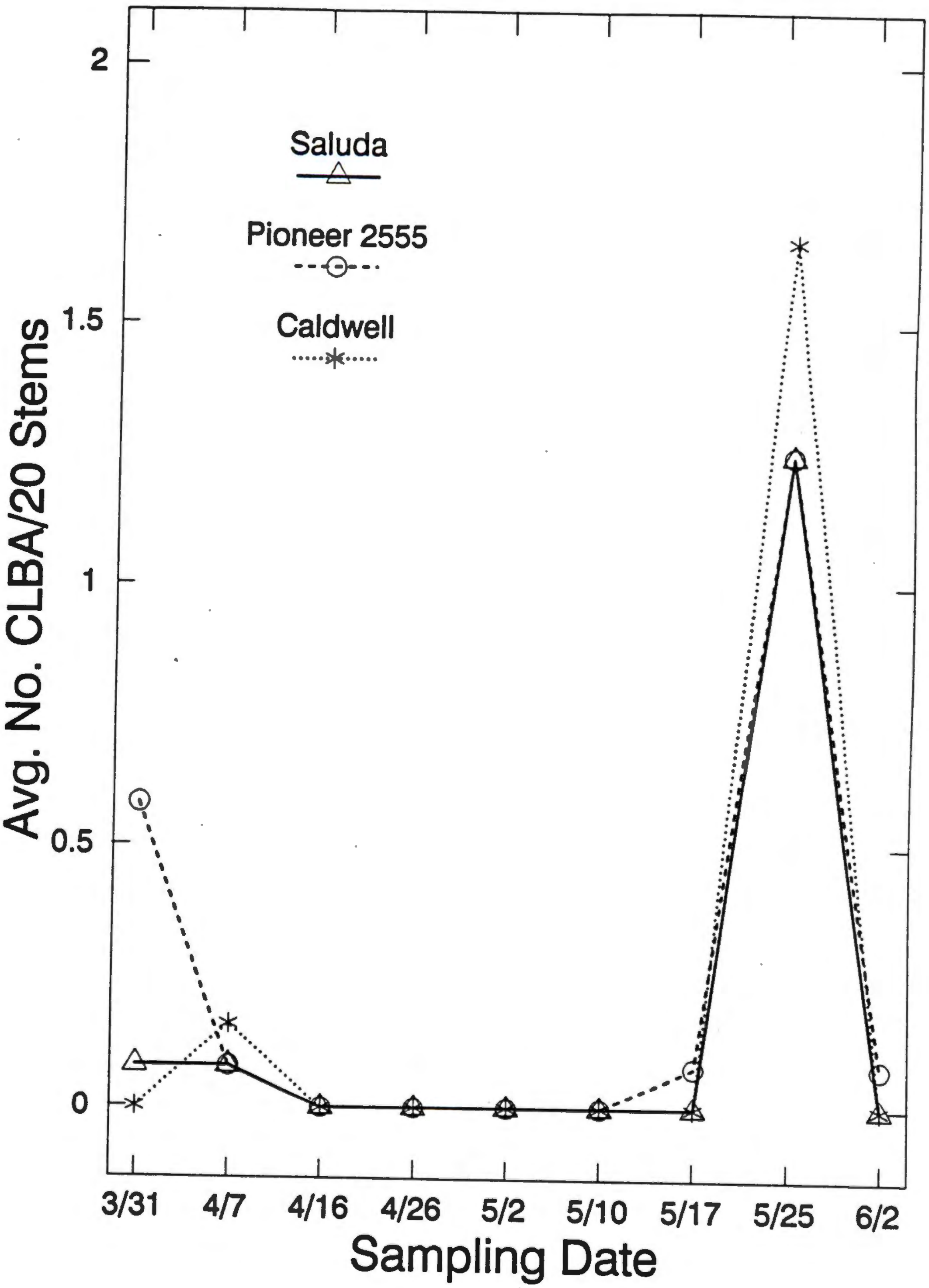

Figure 24. The average number of cereal leaf beetle adults (CLBA) per 20 stems among varieties from late March to early June, Government Farm, 1991.

Table 17. The influence of variety on the mean number of cereal leaf beetle (CLB) eggs per 20 stems, Government Farm, 1991.

VARIETIES	$\bar{X}$ NO. (± SD) CLB EGGS/ 20 STEMS[a]
Saluda	4.34 ± 7.63a[b]
Pioneer 2555	3.08 ± 5.15b
Caldwell	4.28 ± 7.20a

[a] Averaged across each sampling date from mid-March to early June.
[b] Values within columns followed by the same letter are not significantly different at the 0.05 level (Duncan's multiple range test).

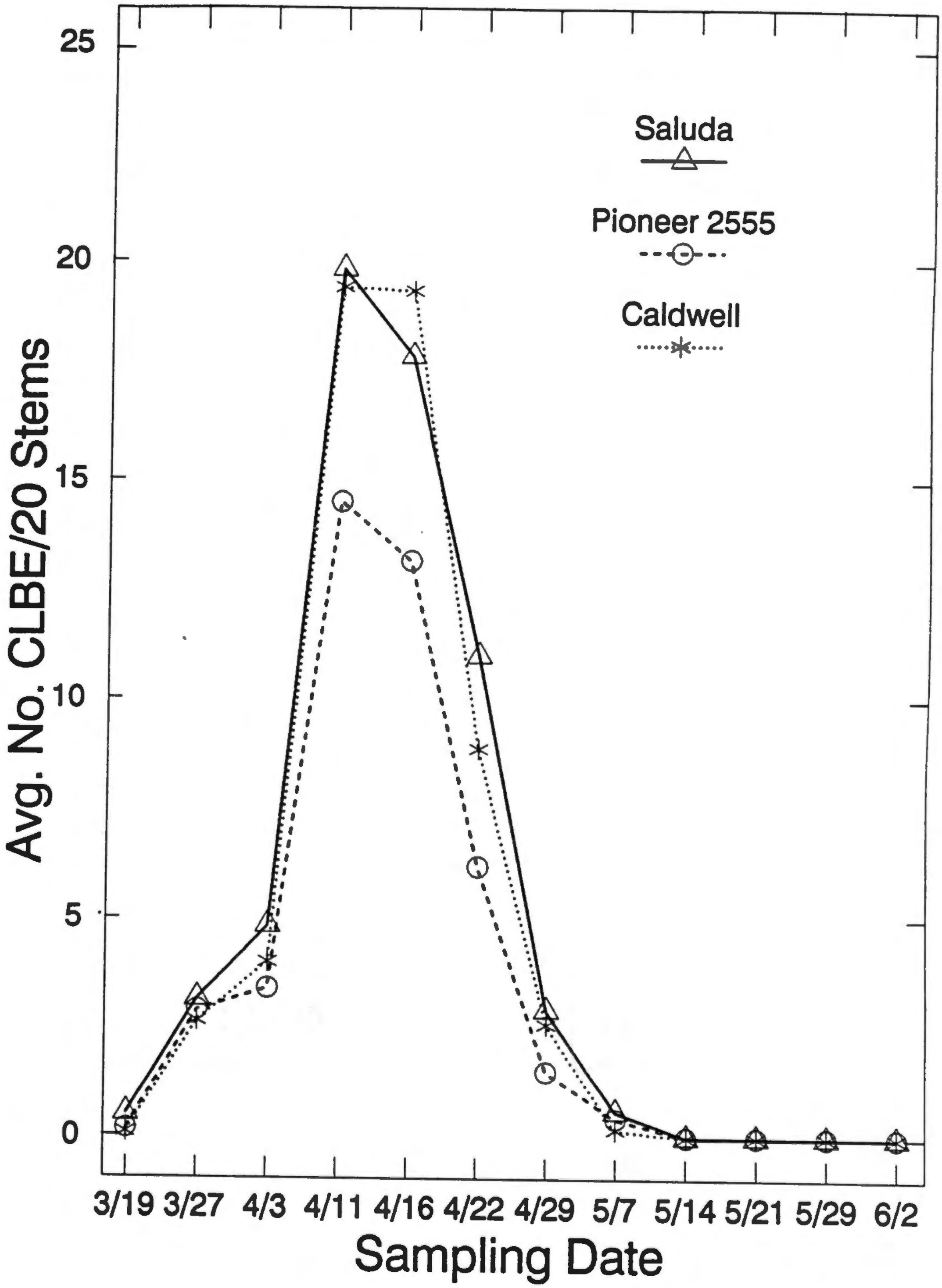

Figure 25. The average number of cereal leaf beetle eggs (CLBE) per 20 stems among varieties from mid-March to early June, Government Farm, 1991.

Table 18. The influence of variety on the mean number of cereal leaf beetle (CLB) larvae per 20 stems, Government Farm, 1991.

VARIETIES	$\bar{X}$ NO. (± SD) CLB LARVAE/ 20 STEMS[a]
Saluda	3.20 ± 5.59b[b]
Pioneer 2555	2.72 ± 4.78b
Caldwell	3.84 ± 7.04a

[a] Averaged across each sampling date from mid-March to early June.
[b] Values within columns followed by the same letter are not significantly different at the 0.05 level (Duncan's multiple range test).

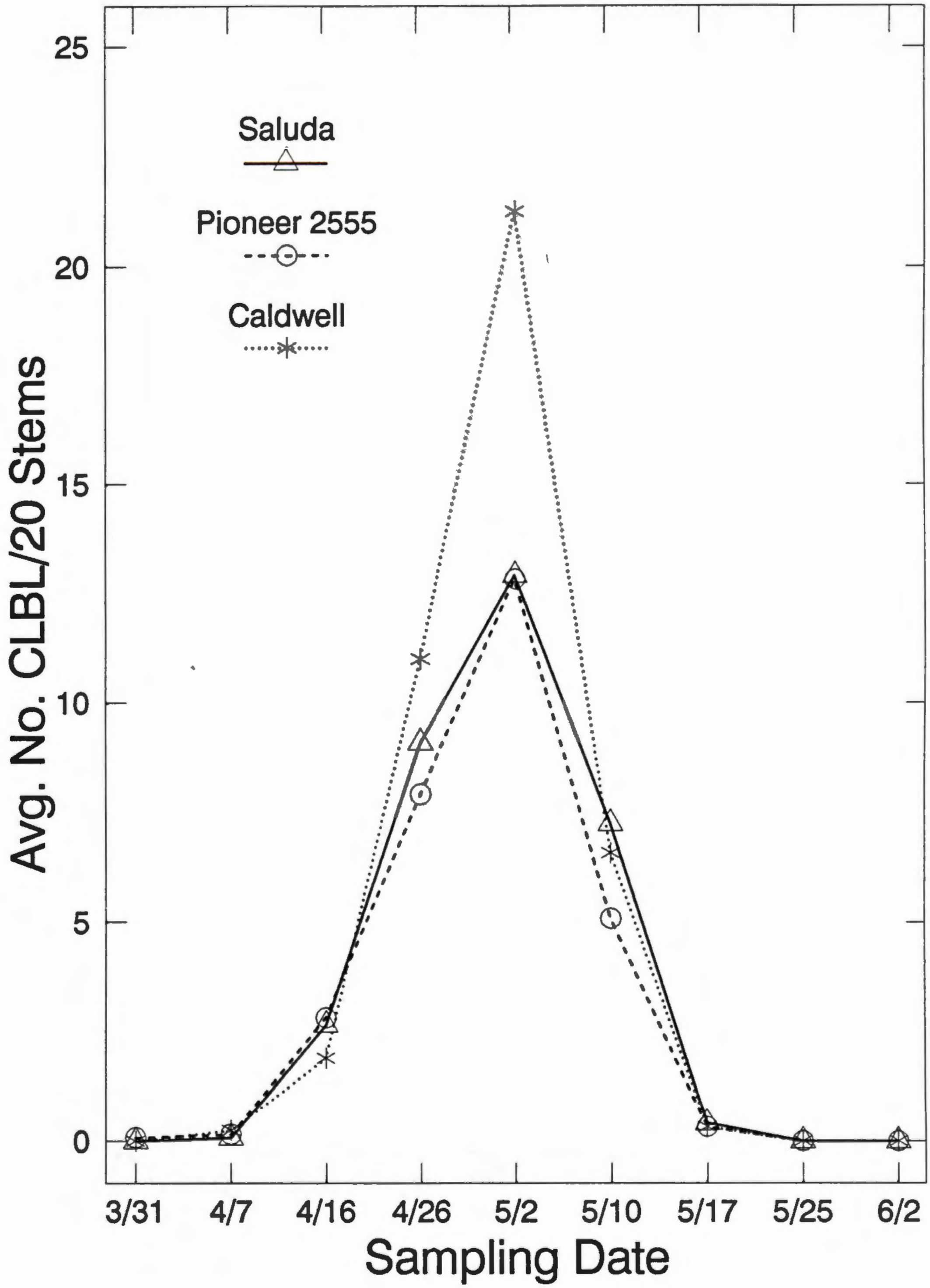

Figure 26. The average number of cereal leaf beetle larvae (CLBL) per 20 stems among varieties from late March to early June, Government Farm, 1991.

The lower numbers of larvae concentrated on both Pioneer 2555 and Saluda could be due to the possibility that these varieties harbor a large population of egg or larval predators or parasitoids and/or possess an antibiosis component. This explanation may account for the low numbers of larvae, but again they do not correlate with the lack of pubescent leaves on these varieties, although, this information for Saluda is not available. The low density of larvae per 20 stems on these two varieties and the high number of larvae on Caldwell also are similar in trend with that observed at both the GF and HRES in 1990 (Table 14, Fig. 21 and 22). Once again, these data suggest that adults probably prefer to oviposit on non-pubescent leaves and in stands that have a thin plant density.

CHAPTER IV

CONCLUSIONS

The cereal leaf beetle (CLB), *Oulema melanopus* L. (Coleoptera: Chrysomelidae), was introduced into North America from southern Asia (Wellso 1986). Adult beetles were first collected and identified as *O. melanopus* from small grain fields in Berrien County, Michigan, in 1962 (Haynes and Gage 1981). Since its identification in the United States in 1962, the CLB has expanded eastward with the prevailing winds and now occupies an area from southern Canada to North Carolina and west to Missouri (Battenfield et al. 1982).

In Tennessee, the CLB was present in low numbers as early as 1972 (Haynes and Gage 1981). However, populations of this insect pest have increased during the last 20 years throughout Tennessee, primarily in the eastern and middle areas of the state (Grant and Patrick 1988). The CLB has been reported from 81 of 95 counties in Tennessee (Grant and Patrick 1991). Fortunately, the CLB is not a serious pest in most areas of Tennessee. However, the potential for problems exists if populations of CLB continue to increase and spread across the entire wheat-growing regions of the state (Grant and Patrick 1988, 1991).

A three-year study to provide information on the distribution and seasonal incidence of CLB on wheat in Tennessee has been conducted (Grant and Patrick 1991). In Tennessee, the CLB also feeds on other small grains, especially oats, and it is important to understand its seasonal phenology, population dynamics and host relationships. However, little research, except for limited chemical efficacy studies, has been conducted on selected management strategies to control this pest. Research on other management tactics, such as the use of resistant wheat varieties, cultural control, and biological control, is necessary for the development and incorporation of appropriate management programs directed against CLB in Tennessee. Therefore, a two-year study was initiated to evaluate the influence of planting dates and varieties on populations of CLB on wheat. This study was conducted at the University of Tennessee Highland Rim Experiment Station (HRES) in middle Tennessee during 1990 and at the University of Tennessee Plant and Soil Science Field Laboratory/ Government Farm (GF) in eastern Tennessee during 1990 and 1991.

Populations of CLB were influenced by planting date and variety at both locations. Densities of CLB eggs, larvae and adults varied widely among treatments at each location during this two-year study.

Densities of CLB adults per five sweeps were greater in the early-planted wheat at HRES during 1990 and at GF during 1990 and 1991. The exact reason for this difference is unclear. Sweep-sampling data reflect the early-season movement of CLB into, and their incidence on, wheat plots. Sweep sampling was terminated once larvae appeared in the field because of the destructive damage of sweeping to larvae. Data suggest that adults were attracted to the early-planted wheat, where they mated. Adults then moved to the younger plants in the middle- and late-planted wheat. The later-planted wheat has younger plant growth and also may have less mature leaf pubescence which may be more preferable to CLB adults for feeding and ovipositing, respectively. Later-planted wheat also may have a thinner stand due to increased plant mortality during the winter. A thinner stand is believed to be more preferable to ovipositing CLB adults.

The density estimations of CLB on stems reflect the late-season populations of CLB or their F_1 generation on wheat. Higher densities of adults per 20 stems were found on late-planted wheat at the GF in 1990 and 1991. These data appear to contradict the results of the sweep-net sampling of adult populations. However, sweep-net sampling estimated the overwintering population of CLB while stem count sampling estimated primarily the F_1 generation. Using stem count sampling, most adults were observed on stems during late May to early June. These higher densities of F_1 adults in the later-planted wheat may result from the higher densities of eggs and larvae found in the later-planted wheat.

The low numbers of eggs per 20 stems on early-planted wheat were consistent at the GF in 1990 and 1991, while the low numbers of larvae per 20 stems on early-planted wheat were consistent at all locations during both years. These data suggest that leaf pubescence or possibly another plant characteristic may deter oviposition, the ability of the eggs to adhere to the leaf, or may increase larval mortality. These dense, early stands of wheat also may have a larger predator population. The higher densities of eggs on middle- and late-planted wheat may be attributed to younger plant growth, less mature leaf pubescence, and/or a thinner plant density.

Planting date did affect CLB densities on wheat, and its influence on populations of CLB were consistent throughout this two-year study. Although densities of CLB adults were initially higher on early-planted wheat, adults tended to move to later-planted wheat where egg and larval densities were greater. These findings suggest the expanded use of this cultural practice in wheat and other small grains that are threatened by CLB.

The influence of wheat varieties on populations of CLB varied among locations and years. This variability may be partially attributed to leaf pubescence and other plant characteristics which can be influenced by the environment and may vary among plants, within plants, and even within single leaves of the same plant (Wellso and Hoxie 1982). Densities of CLB adults per five sweeps were similar at the HRES in 1990 and the GF in 1991 with high numbers of adults concentrated on Pioneer 2555. Pioneer 2555 lacks leaf pubescence, which suggests that it would be more preferable to CLB adults. However, large numbers of eggs and larvae were both found on Caldwell, a variety that is also absent of leaf pubescence, at both locations during both years. These data suggest that factors other than, or combined with, leaf pubescence may be important in attractability and suitability of a variety to CLB. Higher densities of adults per 20 stems were found on Caldwell at the GF during both years. As discussed earlier, adult stem count densities reflect the F_1 generation of CLB. This higher number of F_1 adults per 20 stems may result from the higher number of eggs and larvae per 20 stems on Caldwell at both locations and during both years.

The low number of eggs per 20 stems on Pioneer 2555 were consistent at the GF during both years. However, this variety lacks pubescent leaves, which suggests that it should be preferable to CLB adults for oviposition. These findings are similar to the low number of larvae also found on Pioneer 2555 at the GF during both years. Low densities of larvae were found on Saluda at HRES in 1990 and at the GF in 1991. Although information on the leaf pubescence of Saluda is not available, its effect on CLB is similar to Pioneer 2555.

Because CLB populations responded differently to those varieties which lacked leaf pubescence, the lack of pubescence may not be a valid characteristic to use solely in the explanation of the impact of these varieties on CLB. Other plant characteristics may cause non-preference of oviposition, reduction in egg hatch, and reduction in larval survival. Beneficial organisms, such as lady beetles or spiders, may be attracted to these varieties which, in turn, could have an effect on CLB populations. Further research is necessary to characterize the impact of beneficials on CLB.

The combined use of planting date and variety may be beneficial in an integrated management program against CLB. The incorporation of these tactics into integrated pest management of CLB could improve wheat production and profitability in Tennessee by eliminating or reducing costs associated with insecticide application.

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APPENDIX

Table A1. ANOVA table illustrating significance among effects in model, Government Farm, 1990.

Effects	df	Hundred-seed Weight	Yield	Moisture	Test Weight	Stand Density
Model	35	*[a]	*	*	NS[b]	*
Rep	3	NS	*	NS	-	NS
Planting Date (pld)	2	*	*	*	-	*
Variety (var)	2	*	NS	*	-	*
Rep * pld	6	NS	NS	NS	-	NS
Rep * var	6	NS	NS	*	-	NS
Pld * var	4	*	*	*	-	NS

[a] * = significant ($p < 0.05$).
[b] non-significant ($p > 0.05$).

Table A2. ANOVA table illustrating significance among effects in model, Government Farm, 1991.

Effects	df	Hundred-seed Weight	Yield	Moisture	Test Weight	Stand Density
Model	35	*[a]	*	*	*	*
Rep	3	NS[b]	*	NS	*	*
Planting Date (pld)	2	*	*	*	*	NS
Variety (var)	2	*	*	*	*	*
Rep * pld	6	NS	NS	NS	NS	NS
Rep * var	6	NS	NS	NS	NS	*
Pld * var	4	NS	NS	NS	NS	NS

[a] * = significant ($p < 0.05$).
[b] non-significant ($p > 0.05$).

Table A3. Influence of planting date and variety on yield of wheat, Government Farm, 1990.

Treatment	Hundred-seed Weight (gm)	Yield (kg/14.60 m^2)	Moisture (%)	Test Weight (kg/35.24 l)	Stand Density (/row-m)
Planting Date					
Early planted	3.13 ± 0.60 a[a]	7.36 ± 0.65 a	13.78 ± 0.50 a	25.56 ± 1.99 a	88.00 ± 18.65 a
Middle planted	2.60 ± 0.42 b	4.59 ± 0.48 b	13.22 ± 0.23 b	23.58 ± 2.18 a	68.54 ± 11.44 b
Late planted	2.57 ± 0.44 b	4.80 ± 0.54 b	13.77 ± 0.45 a	23.29 ± 2.05 a	71.46 ± 10.76 b
Variety					
Caldwell	2.32 ± 0.18 c	5.42 ± 1.08 b	13.70 ± 0.54 a	24.28 ± 2.06 a	74.75 ± 13.70 b
Pion 2555	3.30 ± 0.42 a	5.58 ± 1.35 ab	13.42 ± 0.32 b	24.08 ± 2.70 a	66.75 ± 9.97 b
Saluda	2.68 ± 0.45 b	5.76 ± 1.76 a	13.65 ± 0.53 a	24.08 ± 2.17 a	86.50 ± 18.22 a

[a] Values within a column among respective treatments followed by the same letter are not significantly different ($P > 0.05$; Duncan's multiple range test).

Table A4. Influence of planting date and variety on yield of wheat, Government Farm, 1991.

Treatment	Hundred-seed Weight (gm)	Yield (kg/9.04 m^2)	Moisture (%)	Test Weight (kg/35.24 l)	Stand Density (/row-m)
Planting Date					
Early planted	2.40 ± 0.62 a[a]	2.78 ± 0.78 a	12.54 ± 0.40 a	26.55 ± 2.23 a	97.44 ± 16.27 a
Middle planted	2.01 ± 0.55 b	2.02 ± 0.73 b	12.26 ± 0.36 b	25.73 ± 2.86 ab	98.50 ± 15.15 a
Late planted	1.84 ± 0.39 b	1.59 ± 0.55 c	12.23 ± 0.30 b	25.11 ± 1.75 b	93.86 ± 13.27 a
Variety					
Caldwell	1.49 ± 0.21 c	1.35 ± 0.54 b	12.01 ± 0.22 c	23.94 ± 2.36 b	97.28 ± 11.10 b
Pion 2555	2.58 ± 0.46 a	2.62 ± 0.71 a	12.34 ± 0.27 b	26.45 ± 2.04 a	84.25 ± 7.81 c
Saluda	2.20 ± 0.30 b	2.41 ± 0.65 a	12.68 ± 0.30 a	26.65 ± 1.92 a	108.28 ± 13.53 a

[a] Values within a column among respective treatments followed by the same letter are not significantly different ($P > 0.05$; Duncan's multiple range test).

Table A5. Yield of wheat varieties among planting dates, Government Farm, 1990.

Planting Date	Variety	Hundred-seed Weight (gm)	Yield ($kg/14.60\ m^2$)	Moisture (%)	Test Weight (kg/35.24 l)	Stand Density (/row-m)
Early planted	Caldwell	2.39 ± 0.10	6.80 ± 0.31	13.48 ± 0.49	24.28 ± 2.83	88.63 ± 12.20
	Pion 2555	3.76 ± 0.19	7.25 ± 0.54	13.55 ± 0.25	26.06 ± 0.96	72.13 ± 9.03
	Saluda	3.24 ± 0.15	8.04 ± 0.35	14.30 ± 0.22	26.35 ± 1.48	103.25 ± 19.95
Middle planted	Caldwell	2.22 ± 0.13	4.70 ± 0.22	13.38 ± 0.26	24.58 ± 2.46	64.75 ± 5.84
	Pion 2555	3.05 ± 0.40	4.74 ± 0.74	13.10 ± 0.25	23.69 ± 2.57	63.75 ± 11.44
	Saluda	2.45 ± 0.21	4.32 ± 0.33	13.18 ± 0.05	22.50 ± 1.39	77.13 ± 12.91
Late planted	Caldwell	2.34 ± 0.27	4.74 ± 0.54	14.23 ± 0.44	23.98 ± 1.15	70.88 ± 9.76
	Pion 2555	3.10 ± 0.15	4.74 ± 0.48	13.60 ± 0.22	22.51 ± 3.22	64.38 ± 9.71
	Saluda	2.35 ± 0.21	4.92 ± 0.73	13.48 ± 0.24	23.39 ± 1.51	79.13 ± 9.44

Table A6. Yield of wheat varieties among planting dates, Government Farm, 1991.

Planting Date	Variety	Hundred-seed Weight (gm)	Yield ($kg/9.04\ m^2$)	Moisture (%)	Test Weight (kg/35.24 l)	Stand Density (/row-m)
Early planted	Caldwell	1.69 ± 0.10	1.92 ± 0.48	12.08 ± 0.15	24.27 ± 2.07	98.25 ± 11.11
	Pion 2555	3.03 ± 0.35	3.31 ± 0.63	12.63 ± 0.19	27.83 ± 1.53	80.50 ± 5.53
	Saluda	2.50 ± 0.20	3.11 ± 0.32	12.93 ± 0.21	27.54 ± 1.13	113.58 ± 9.25
Middle planted	Caldwell	1.39 ± 0.23	1.16 ± 0.35	11.93 ± 0.28	22.49 ± 3.15	97.92 ± 14.20
	Pion 2555	2.58 ± 0.22	2.57 ± 0.41	12.23 ± 0.10	26.65 ± 1.18	85.75 ± 4.12
	Saluda	2.07 ± 0.28	2.33 ± 0.36	12.63 ± 0.26	27.24 ± 2.16	111.83 ± 12.98
Late planted	Caldwell	1.38 ± 0.16	0.98 ± 0.21	12.03 ± 0.25	25.47 ± 0.84	95.67 ± 11.03
	Pion 2555	2.13 ± 0.23	1.99 ± 0.29	12.18 ± 0.24	24.87 ± 2.38	86.50 ± 12.14
	Saluda	2.02 ± 0.17	1.81 ± 0.45	12.48 ± 0.28	25.17 ± 1.77	99.42 ± 16.08

VITA

Lisa Covington Duke was born in Charlotte, North Carolina, on October 23, 1966. She attended elementary schools in Mount Holly, North Carolina, and graduated from East Gaston High School in June, 1985. The following August she entered Belmont Abbey College, Belmont, North Carolina, and in May, 1989, received a Bachelor of Arts Degree in Biology. In the summer of 1989, she accepted a research assistantship at The University of Tennessee, Knoxville, and began study toward a Master's degree under the supervision of Dr. Jerome F. Grant. In December of 1991, she received her Master of Science Degree with a major in Entomology and Plant Pathology. Lisa C. Duke is a member of the Entomological Society of America, Michigan Entomological Society and the Tennessee Entomological Society.