

DISSERTATION

**ARTHROPOD DAMAGE IN CORN ACROSS SITE-SPECIFIC MANAGEMENT
ZONES AND DIFFERING WATER AND NITROGEN LEVELS**

Submitted by

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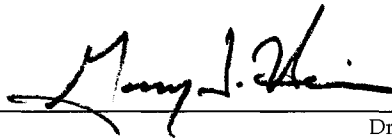
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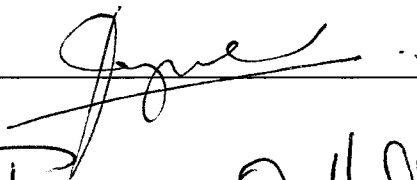
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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY SILAS DAVIDSON ENTITLED ARTHROPOD DAMAGE IN CORN ACROSS SITE-SPECIFIC MANAGEMENT ZONES AND DIFFERING WATER AND NITROGEN LEVELS BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.


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ABSTRACT OF DISSERTATION

ARTHROPOD DAMAGE IN CORN ACROSS SITE-SPECIFIC MANAGEMENT ZONES AND DIFFERING WATER AND NITROGEN LEVELS

Site-specific insect management has the potential to make pest management more efficient, but has yet to be implemented. One method of implementing site-specific management would be to make decisions at the management zone level. Management zones are homogenous subregions within a field that can be managed in a similar manner. No studies have yet related insect damage to management zones. In this study site-specific management zones (SSMZ) defined by yield potential were used with the purpose of determining whether arthropod damage differs across SSMZ. The influence of water and nitrogen levels were also analyzed. The study was conducted in a corn (*Zea mays* L.) agroecosystem at Colorado State University's Agricultural Research, Development, and Education Center (ARDEC) near Fort Collins, Colorado from 2002 to 2004. Four common arthropod pests of corn were studied: European corn borer (*Ostrinia nubilalis* [Hübner]), western corn rootworm (*Diabrotica virgifera virgifera* [Leconte]), western bean cutworm (*Richia albicosta* [Smith]), and Banks grass mite (*Oligonychus pratensis* [Banks]). Infestations of each pest were created within each SSMZ by artificially infesting pests or manipulating natural populations. Damage for western corn rootworm and Banks grass mites was greater in high yielding areas. European corn borer had differential survival across SSMZ. Differences in damage for western bean cutworm were unclear. The results indicated that arthropod damage for some pests did differ among SSMZ and therefore site-specific management might be beneficial.

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General Introduction

Site-specific management of insect pests is considered one of the possible contributions of precision agriculture (National Research Council 1997). Potential benefits of site-specific management are reduced insecticide loads (Weisz et al. 1996), increased preservation of natural enemies (Fleischer et al. 1997, Midgarden et al. 1997), and reduced rates of insecticide resistance development (Midgarden et al. 1997). The ability to apply site-specific management depends on being able to determine where insects should be treated within a field. Difficulties in describing the distribution of pests within fields have hindered the adoption of this approach (Fleischer et al. 1999). Most of the attempts to classify insect distributions within a field have involved intensive sampling based on grids (Ellsbury et al. 1998, Walter 2001). The cost and time required for grid sampling make this method unpractical (Krell et al. 2003).

A possible alternative to grid sampling would be to develop sampling plans based on management zones. Management zones are homogeneous subregions within fields that have similar yield limiting characteristics, and can therefore be managed in a similar manner (Mulla 1993, Doerge 1999). The use of management zones is one of the final steps in the process of adopting precision agriculture. The adoption process involves (1) measuring the variability within a field, (2) mapping the distribution of yield limiting characteristics, (3) expressing within field variability as management zones, and then (4) making input decisions at the management zone level (Doerge 1999). Input decisions have been made at the management zone level for water and fertilizers (Fleming et al. 1999, Khosla et al. 2002, Chang et al. 2004), but there have been few attempts to define management zones based on the distribution of insect pests. Management zones have

been created for the citrus root weevil, *Diaprepes abbreviatus* L., (Li et al. 2004) and the western corn rootworm, *Diabrotica virgifera virgifera* Leconte, (Park and Tollefson 2005). These two studies used predictive models based on field sampling to determine insect management zones. Environmental characteristics and potential within fields were not considered when delineating management zones.

There are potential advantages for relating insect pests to field characteristics associated with productivity. One advantage would be if field characteristics (soil texture, fertility, moisture level, etc.) were related to the distribution of insect pests. If so, the sampling costs associated with these management zones would be lower than the sampling costs required to produce insect management zones based on field sampling. In a previous study insect distributions were shown to correlate with management zones based on yield potential (Davidson 2003).

A second advantage is that management zones defined by productivity might predict where yield losses caused by insects will occur in a field more accurately than management zones based only on predicted spatial distributions. Yield losses caused by insect pests are related to the health of plants (Higley 2001). Field characteristics that are known to influence insect damage in corn include nitrogen and water levels (Dale 1998, Holtzer et al. 1998, Culy 2001). Management zones that take into account these factors could therefore, give better indications of where yield losses will occur.

Productivity potential could also be used to develop separate economic injury levels (EILs) for individual management zones. Economic injury levels define the level of pest injury that will economically justify the costs of management (Pedigo et al. 1986). The development of EILs requires knowledge of expected grain yield (Mason et al.

1996). Since productivity based management zones identify areas within a field of differing yield potential, EILs will therefore differ among management zones.

This study was conducted from 2002 through 2004 in a corn, *Zea mays* L., agroecosystem at Colorado State University's Agricultural Research Development and Education Center (ARDEC) near Fort Collins, CO. Four common arthropod pests of corn were evaluated among site-specific management zones (SSMZ) defined by yield potential. The objectives of this study were (1) to determine if arthropod survival and abundance differed across SSMZ, (2) to determine if the amount of damage caused by arthropod pests was influenced by SSMZ, and (3) to determine the effects of varying levels of water and nitrogen on insect abundance and damage.

General Literature Review

Precision Agriculture and Management Zones

Precision agriculture is an emerging discipline that uses advances in technology to enhance agricultural production. It began with the incorporation of information technologies into agriculture during the mid-1980s. It has been broadly defined as, “A management strategy that uses information technology to bring data from multiple resources to bear on decisions associated with crop production” (National Research Council 1997).

A major benefit of precision agriculture is the ability to manage the spatial variability of yield affecting factors within a field. The application of varying amounts of fertilizers or crop protection products to specific areas within a field is known as variable rate technology. Precision agriculture is not limited to variable rate technology; it also involves decisions about tillage and residue management, crop seeding and cultivar selection, and water application or drainage (Mulla and Schepers 1997).

Grid sampling has traditionally been used to define variability and develop variable rate application maps within fields. Various interpolation techniques have been applied to grid sampling to define the regions of variability in a field (Wollenhaupt et al. 1997). As the number of grid points sampled within an area increases, spatial interpolations become more accurate. Grid sampling provides an accurate basis for variable rate application, but the cost and labor can be prohibitive.

Due to the high costs required of intensive grid sampling, in the future variable rate application maps will most likely be derived from combinations of yield maps, remotely sensed images, and soil sampling (Ferguson et al. 1996). These factors can be

analyzed to identify similar regions within a field. Small, relatively homogenous regions within the field called management zones have been identified as a possible way to manage variability (Carr et al. 1991, Mulla 1993, Doerge 1999, Fleming et al. 1999, Khosla et al. 2002). Management zones are potentially useful because they define areas of significant variability with a reasonable amount of sampling. Many factors and combinations of factors have been used to delineate management zones such as; kriged soil test point data (Mulla 1991), soil survey maps (Robert 1989), topography (Kravchenko et al. 2000), remote sensing (McCann et al. 1996), topography and remote sensing (Tomer et al. 1995), electrical conductivity sensors (Sudduth et al. 1997), and yield maps (Stafford et al. 1999).

Farmer defined site-specific management zones (SSMZ) have been developed for eastern Colorado irrigated corn fields (Fleming et al. 1999). The management zones are based on soil color from aerial photographs, topography, and past management experience of the farmer. Using the above criteria the fields are delineated into high, medium, and low productivity zones. Each SSMZ describes average productivity potential in a large area of the field, although small areas of differing productivity may be located within each zone.

These SSMZ have been shown to adequately describe differences in soil organic matter (SOM), NO₃-N, K, Zn, conductivity data, and corn grain yield. Researchers have determined that management zones delineated in this manner would be adequate to make variable rate applications of nitrogen fertilizer (Fleming et al. 1999, Khosla et al. 2002, Hornung et al. 2003). Even though there is variability within management zones, SSMZ were found to be less spatially variable than the whole field (Inman et al. 2005). It has

also been shown to be more economical to apply N at the SSMZ level than the whole field level (Koch et al. 2004).

Site-Specific Arthropod Management

Precision agriculture or site-specific management of arthropod pests has not received as much attention as other aspects of precision agriculture despite the potential contributions. Site-specific management has the potential to reduce the amount of insecticides applied, reduce environmental contamination, preserve natural enemies, and manage resistance (Fleischer et al. 1997). Most of the studies demonstrating the potential contributions of site-specific management in integrated pest management have been conducted in potato, *Solanum tuberosum* L., with the Colorado potato beetle, *Leptinotarsa decemlineata* (Say). In these studies potato fields were treated with either whole-field insecticide applications or treated as subsections within a larger field. Using a site-specific approach to treat only infested portions of the field reduced the amount of pesticides needed to control the Colorado potato beetle by 30-40% (Weisz et al. 1996). The site-specific approach of treating only some areas of the field created refuges that increased the number of natural enemies (Fleischer et al. 1997, Midgarden et al. 1997). The development of insecticide resistance in Colorado potato beetle was also slowed with a site-specific approach compared to whole-field treatments (Midgarden et al. 1997).

Krell et al. (2003) studied the economic benefits of site-specific management using the bean leaf beetle, *Ceratoma trifucata* (Forster), in soybean, *Glycine max* L. Beetles were sampled on a 0.2 hectare grid layout in 12 to 20 hectare (30 to 45 acre) fields. A computer spreadsheet model showed that treating only the infested areas of the field would save the grower two to four dollars per hectare when sampling costs were

ignored. When the cost of increased sampling was calculated into the model, it was more economical to make whole-field treatments.

Developing site-specific sampling plans for arthropod pests has proved challenging. Spatial distributions of arthropod populations are considered nonrandom and heterogeneous (Liebhold et al. 1993). Distribution is the result of environmental influences and behavioral responses (Taylor 1984). The difficulty in producing reliable density maps of arthropod pests, and the rapid changes in distribution, led the National Research Council (1997) to question the feasibility of precision agriculture applied to insects. Fleischer et al. (1999) stated that, unless entomologists are able to produce relevant maps, precision agriculture will proceed for virtually all aspects of plant agricultural production except insect management.

A potential tool for mapping arthropod distribution is satellite remote sensing. This technology is desirable because it describes arthropod distribution at a fine resolution without the time constraints of point sampling (Fleischer et al. 1999). It has been used to characterize migratory insects as they move across large agricultural regions (Brewster et al. 1999). Remote sensing also has been used to select regions of the field for sampling that are more susceptible to arthropod damage (Willers and Akins 2000).

The technologies of geographic information systems (GIS) and global positioning systems (GPS) have the potential to help adequately map pest distributions (National Research Council 1997). These technologies have been used extensively to assess spatial variability in insect populations for predictive purposes in forest and rangeland ecosystems (Liebhold et al. 1993). Applications of GIS/GPS technology are being used in area-wide pest management programs for the corn rootworm, *Diabrotica sp.*, complex

and *Pectinophora gossypiella* (Saunders), the pink bollworm (Ellsbury et al. 2000).

There have been few published studies characterizing arthropod distribution in individual agricultural fields (Liebhold et al. 1993).

A few studies have used grid sampling to determine the spatial distribution of arthropod pests within corn fields. Walter (2001) studied the spatial distribution of three insects in eastern Colorado irrigated corn fields; western corn rootworm (*Diabrotica virgifera virgifera* Leconte), western bean cutworm (*Richia albicosta* Smith), and European corn borer (*Ostrinia nubilalis* Hübner). Pheromones were used to trap adult insects using a grid design placed over two fields. The captured adults were spatially and temporally variable within the fields and seemed to be influenced by factors external to the field. Wyse-Pester (2000) observed spatial distribution of western corn rootworm eggs in eastern Colorado using a similar grid. The distribution of eggs was not significantly correlated with soil properties. The spatial distribution of *Diabrotica virgifera virgifera* adult emergence has been studied in South Dakota (Ellsbury et al. 1998). Emergence cages were placed across a corn field in a grid design. Adult emergence was correlated with soil organic matter and drainage.

The management zone concept has rarely been used to classify the spatial distribution of insect pests. Management zones have been created for the citrus root weevil, *Diaprepes abbreviatus* L., in Florida citrus (*Citrus paradisi* McFad) orchards (Li et al. 2004). These management zones were created by trapping adult beetles as they emerged from the soil and then using kriging to create management zones. Although soil characteristics were not used to create management zones, soil EC and texture were related to beetle emergence. Management zones also have been created for western corn

rootworm in Iowa corn fields (Park and Tollefson 2005). In this study, visual counts were used to measure the number of adult beetles. Management zones were then delineated based on predicted beetle densities throughout the field. They found that beetle distributions varied from year to year and were not strongly correlated to any soil property. The best spatial prediction for beetle emergence the following year was the spatial distribution of adult beetles in the current year.

Western Corn Rootworm

The western corn rootworm is native to Central America. It was first recognized as a pest of corn in Colorado and western Kansas in 1912. The increase in acreage planted to corn in the 1950's allowed the beetle to expand its range, and it is now found throughout the Corn Belt and east to Delaware and Maryland (Sutter 1999). Several *Diabrotica* spp. are specialized to feed on corn and their ranges often overlap. In Colorado, the western corn rootworm can be found in most corn growing areas, and is the only species considered to be of economic importance (Peairs and Pilcher 2002).

The western corn rootworm has complete metamorphosis and completes one generation per year. It overwinters in the egg stage. The eggs are oval, creamy white, and measure about 0.3 to 0.5 mm. Eggs are usually deposited in the top 10 cm of soil but can be found as deep as 30 cm depending on soil moisture (Sutter 1999). In Colorado, warmer areas experience egg hatch in mid-May, while in cooler areas eggs hatch in early June (Peairs and Pilcher 2002).

The western corn rootworm has three larval instars. All instars have dark brown head capsules and anal plates, and the body is creamy white. Fully grown larvae are about 12 mm long (Sutter 1999). After hatching rootworm larvae are chemically

attracted to feed on corn roots. Smaller larvae feed on root hairs and small roots, and larger larvae feed on and tunnel inside primary roots (Chiang 1973). When larvae have reached maturity, feeding ceases and earthen cells are created for the pupae. The time required to develop from egg to adult is temperature driven and has a range of 23-46 days (Sutter 1999).

By mid-July most adults have emerged in Colorado (Peairs and Pilcher 2002). The adults feed on corn leaves but prefer pollen and silk. They are strong fliers and can leave the field to search for food. Females begin laying eggs when they are two weeks old, and each female can lay as many as 1000 eggs. Eggs are laid in cracks in the soil surface. Adults remain active in the field until lack of food or the first frost kills them (Sutter 1999).

The most serious injury due to western corn rootworm is from larvae feeding on corn roots. In heavy infestations the upper three nodes of below-ground roots can be completely destroyed. Destruction of roots causes plant stress by interfering with the uptake of water and nutrients, and by reducing the stability of the plant. Rootworm induced lodging decreases yields by lowering plant photosynthetic efficiency and by the difficulty of harvesting poorly anchored stalks (Sutter 1999). Adults can damage silks, but this is not believed to cause significant yield loss in Colorado (Peairs and Pilcher 2002). The persistent nature of corn rootworm problems has led to the application of soil insecticides to nearly 90% of continuous corn acres (Sutter 1999). Research in Colorado has shown that grain yield was reduced due to corn rootworm feeding by 10% on average over ten years (Peairs and Pilcher 2002).

Sampling is directed at three different life stages of the western corn rootworm; eggs, larvae, and adults. Egg sampling is advantageous because it can be conducted in either fall or spring. Larval sampling in the spring is more can be more accurate because it involves sampling the damaging stage of the insect. Sampling the adult stage is not as accurate, but is the most commonly used method because labor and economics do not justify the costs required to remove eggs and larvae from the soil for sampling purposes (Tollefson and Calvin 1994). In Colorado a treatment is recommended when fields average 44,500 adults per hectare in late summer (Peairs and Pilcher 2002).

Several factors influence the distribution of western corn rootworms. Moisture affects rootworm oviposition with more eggs being laid in moist soil (Kirk et al. 1968). Soil texture is also very important. Females are not accomplished burrowers and must use existing openings such as soil cracks, crevices at the plant/soil interface, earthworm burrows, and cavities left by decaying plant material to gain access to the soil for egg laying (Tollefson and Calvin 1994). Larvae are less likely to survive in sandy soil due to abrasion (Kirk et al. 1968).

European corn borer

The European corn borer is an introduced insect pest. It probably arrived in North America on broom corn imported from Hungary and Italy, and was first recognized as a pest in 1917 (Mason et al. 1996). The insect has spread rapidly and can now be found north into Canada, west to the Rocky Mountains, and south to Florida and New Mexico. The European corn borer feeds on many plants including sweet corn, popcorn, seed corn, peppers, snap bean, cotton, wheat, potatoes, and numerous vegetables. It is particularly a

pest of field corn and costs American corn producers an estimated 1 billion dollars annually in yield losses and control expenditures (Mason et al. 1996).

The life history of the European corn borer is influenced by local conditions and the genetics of the insect. In the United States there can be one to four generations per year. In Colorado the European corn borer usually has two generations, although a single generation may occur at higher elevations and a partial third generation has been observed on occasion (Peairs 2002a). The insect overwinters as mature larvae within corn stubble, corn ears, stems of other hosts, or plant debris on or in the soil (Calvin and Van Duyn 1999). In Colorado, overwintering larvae will pupate and emerge as adults during late May or early June (Peairs 2002a). Adult moths have an average wing span of 2.5 cm. The forewings of adults are a buff color with dark bands running in wavy lines across the wings. Male moths are darker, have a longer abdomen, and are slightly smaller than females (Calvin and Van Duyn 1999). Adults aggregate in weedy or grassy field margins or humid areas of fields to mate.

European corn borer moths are active at night. Mated females fly into corn fields and lay eggs in masses of 15 to 30. First generation females lay eggs in early June, and second generation females lay eggs in late July or early August (Peairs 2002a). The egg masses have a scaly white appearance and are normally laid on the underside of leaves, near the midrib. The developing black heads of the larvae are visible inside the eggs, which require three to seven days to hatch (Mason et al. 1996).

There are five larval instars. Newly hatched larvae are one to two mm long with a dark brown head and translucent white body. Mature larvae are 19 to 25 mm long with a medium to dark brown head and creamy white to grey body. All larvae have three pairs

of true legs on their thorax and five pairs of prolegs on their abdomen (Calvin and Van Duyn 1999). First generation larvae move directly into the whorl for shelter and food. There the first and second instars feed on the mesophyll of leaves producing a “windowpane” effect as the leaves emerge. The third through fifth instars burrow into the stalk of the corn plant to feed. They pupate inside the stalk after finishing feeding. Second generation larvae move to the leaf axils after egg hatch. They feed on sheath and collar tissue or on pollen that has accumulated in these sites. Some second generation larvae will feed in other protected areas such as the developing ear. By the fourth instar the majority of larvae will bore into the stalk, although some may continue to feed within the ear, sheath, and collar. Mature second generation larvae go into diapause and spend the winter protected in plant residue (Mason et al. 1996).

The larvae are the damaging stage of the European corn borer. First generation larvae damage plants by leaf feeding and stalk tunneling. Second generation larvae damage plants by leaf feeding, stalk tunneling, leaf sheath and collar feeding, and ear damage (Mason et al. 1996). Larval tunneling is the most significant damage. The effects of tunneling on the plants ability to move nutrients, minerals, and water often reduce grain weight and kernel number. Tunneling is most damaging if it occurs before or during the early reproductive stages of the plants. Yield reductions also occur due to stalk breakage and ear drop. Corn borer feeding wounds allow pathogens to enter the plant, which can significantly reduce grain yield and quality (Calvin and Van Duyn 1999).

Sampling for European corn borer is difficult, because of the short time period during which chemical controls are effective i.e., after egg hatch but before the larvae

bore into the plant. Black lights and pheromone traps are often used to indicate when moths will begin egg laying. Scouting usually involves inspecting plants for egg masses and live larvae (Tollefson and Calvin 1994). The growth stage of the plant is important when making management decisions because yield losses per corn borer vary with crop growth stage. Mason et al. (1996) have developed guidelines for constructing economic injury levels based on several important criteria.

European corn borer damage varies from field to field. First generation corn borers are attracted to taller and more mature corn. They usually do not survive on corn that has not reached the 6th-leaf stage. Second generation corn borers prefer corn that is pollinating to deposit their eggs (Mason et al. 1996). European corn borer moths and egg laying are often concentrated along field edges, grass waterways, and access roads (Tollefson and Calvin 1994).

Western Bean Cutworm

The western bean cutworm is to North America. It was first described in 1887 from moths collected in Arizona (Douglas et al. 1957). As of now, the western bean cutworm has been observed in Arizona, Idaho, Kansas, Nebraska, Iowa, Utah, Colorado, New Mexico, Texas, South Dakota, Wyoming, Oklahoma, and Minnesota (O'Rourke and Hutchison 2000). The western bean cutworm is recognized as a serious pest of corn and beans, *Phaseolus vulgaris* L. (Keaster 1999), and is not known to feed on other crops (Blickenstaff and Jolly 1982). It is recognized as a serious pest of dryland and irrigated field corn in northeastern Colorado (Peairs 2002b).

The western bean cutworm undergoes complete metamorphosis, with one generation per year. The western bean cutworm overwinters as a prepupa in earthen cells

12-25 cm below the soil surface. They pupate in late May and emerge as adults in early July. The adult moths are about two cm long with an average wing span of 3.8 cm. The body is light brown and the wings are darker. The forewings have a broad white stripe on the leading edge and distinctive white and dark markings. The hind wings are cream colored without any distinctive markings. Adult females release pheromones to attract males soon after emerging (Seymour et al. 1998).

Adults are active at night and females can fly several miles to lay eggs. In corn eggs are most often deposited on the upper surface of leaves, but can be deposited on the undersides of erect leaf varieties (Peairs 2002b). Eggs are laid in masses ranging from 30 to 100 eggs. The eggs start out white and dome-shaped with a thin red ring around the top, before turning a dark purple or black color immediately before hatching. Eggs hatch in five to seven days. There are five larval instars that develop and feed on the plant for an average total of 31 days. Young larvae are dark brown with faint diamond-shaped markings on their backs. Mature larvae have three short dark stripes along the top of the prothoracic shield (Keaster 1999). Before tassel emergence the larvae feed on the developing tassel within the whorl, and after tassel emergence they begin feeding in the ear. Western bean cutworm larvae are not cannibalistic and multiple larvae can be found feeding in a single ear (Seymour et al. 1998).

The larvae are the damaging stage of western bean cutworm. Most of the damage is due to feeding within the ear. The loss of kernels, misshapen ears, and entry of fungal pathogens contribute to reductions in corn yields (Keaster 1999). Infestations averaging one larva per ear result in a loss of about four bushels per acre. Severe reductions can reduce grain yield by 30 to 40 percent (Peairs 2002b).

Black lights and pheromone traps are often used to determine when western bean cutworms are active and scouting should begin (Seymour et al. 1998). Counts of egg masses and larvae are most often used to make management decisions. In Colorado chemical controls are recommended if at least eight percent of plants have egg masses or small larvae, and 95% of the corn has tasseled. An economic injury level has been developed in Nebraska that can be adjusted based on the crop's value and control costs (Appel et al. 1993).

Damage from western bean cutworm is not consistent. Cutworm numbers vary from year to year and there is a tendency for greater abundance every six to eight years. Moth emergence tends to be greater in sandy soils and may increase due to rainfall or irrigation (Seymour et al. 1998). In most years certain fields are much more heavily damaged than others. Because adults are active for a short time, variation in corn attractiveness can significantly influence egg deposition and thus damage. Holtzer (1983) observed that plants just beginning to tassel receive more eggs than plants at earlier or later growth stages. Walter (2001) captured more adult western bean cutworms in pheromone traps placed around the margins of corn fields than in the center.

Banks Grass Mite

The Banks grass mite is a major pest of irrigated corn grown on the semi-arid high plains of the United States. It is native to western and southern North America and feeds on more than 80 grass hosts (Peairs and Archer 1999). In Colorado it is a pest throughout the state, but is most common in drier corn producing areas (Peairs 2003).

The Banks grass mite passes through five stages of development; pearly white spherical eggs, six-legged larvae, eight-legged protonymphs, eight legged deutonymphs,

and sexually mature adults. Adult males and females differ in appearance. Males are smaller and have a pointed abdomen. Females are larger, 0.45 mm, and have a rounded abdomen. Both sexes accumulate green food balls that are visible around the periphery of the translucent abdomen (Peairs and Archer 1999). The tips of the tarsi have claw-like structures that are useful for microscopic identification (Logan et al. 1983).

Banks grass mites overwinter as mated adult females on grass hosts (Logan et al. 1983). When conditions are favorable the overwintering females will begin ovipositing on nearby grasses. The mites can enter corn fields by either walking short distances or being wind blown on silken threads. Because of this, mite infestations usually begin along the edges of fields. The Banks grass mite occurs on corn from the mid-whorl to the grain-filling growth stages (Peairs and Archer 1999).

Banks grass mite populations have the potential to rapidly reproduce. Generation time depends on temperature and is typically 10-20 days. Laboratory experiments have shown that that Banks grass mites can increase 70-fold in one generation (Peairs and Archer 1999). Infestations typically begin on the lower leaves of the corn plant. As the mite population increases, successive leaves are colonized moving up the plant (Logan et al. 1983). Spider mites feed by piercing corn leaf tissue and ingesting liquid cell contents. Feeding usually begins along the midrib and folded areas of the leaf. Mite feeding causes the development of pale chlorotic areas on the leaf surface. Severe feeding leads to tissue death and eventually death of entire leaves (Peairs and Archer 1999).

Banks grass mites can be serious pest of corn. Their feeding leads to a reduction in corn yields due to poor seed fill, and they have been associated with accelerated plant

dry down in the fall (Wright et al 1993). Schweissing (1973) observed grain losses ranging from 6 to 48 percent, with an eighteen year average of 21 percent in Colorado. Nominal economic thresholds have been developed by extension programs in states affected by Banks grass mites to determine when control methods should be applied. Archer and Bynum (1990a) developed an economic injury level in Texas based on the percent of infested leaves and leaf area damage.

There are several conditions that can lead to mite outbreaks. Feese and Wilde (1977) showed that high temperatures and drought stress favored Banks grass mite buildups. Other factors known to favor infestations are lack of natural enemies, absence of competitors, insecticide use, and adequate moisture for alternate hosts during the previous growing season (Peairs 2003). Wright et al. (1993) have suggested that sandy soils contribute to mite outbreaks, because crops grown on these soils are more likely to experience drought stress even when irrigated. Archer and Bynum (1990b) found that nitrogen fertilization promotes mite infestations and that excessive fertilizing can lead to severe outbreaks.

Chapter 1.

European Corn Borer Damage Across Site-Specific Management Zones

Introduction

The European corn borer, *Ostrinia nubilalis* (Hübner), is a key pest of corn, *Zea mays* L in the United States. It ranges from the Atlantic coast to the Rocky Mountains and from Canada south to Florida and New Mexico. It is particularly a pest of field corn and costs American corn producers 1 billion dollars annually in yield losses and control expenditures (Mason et al. 1996). Yield losses are due to larvae tunneling within stalks and ears and leaf feeding. In the major corn producing regions of Colorado there are two generations per year (Peairs 2002). The most common methods used to manage European corn borer are the use of insecticides targeted at young larvae (Mason et al. 1996), and the planting of genetically engineered hybrids resistant to corn borers (Ostlie et al. 1997). Applications of insecticides are usually targeted at the whole field level, whereas planting of transgenic hybrids requires that a portion of the field be planted as a refuge to prevent the development of resistance (Ostlie et al. 1997).

The spatial distribution of European corn borer has been studied extensively. The distribution of adult moths varies widely among fields, but within fields of similar growth stage, moths appear to be randomly distributed (Legg and Chiang 1985). Larvae appear to be randomly distributed within fields and spatial correlation has only been observed in plants 1 to 3 meters apart, suggesting larval movement from the same egg mass (Wright et al. 2002). Egg masses appear to be randomly distributed within fields at low densities, and begin to show spatial aggregation as populations increase (Chiang and Hodson 1959, Sorenson et al. 1993).

There could be many advantages for making site-specific management decisions for European corn borer, instead of treating the entire field. The benefits of site-specific management have been shown with other insect pests of field crops. These benefits include reduced insecticide loads (Weisz et al. 1996), increased preservation of natural enemies (Fleischer et al. 1997, Midgarden et al. 1997), and reduced rates of insecticide resistance (Midgarden et al. 1997). The ability to apply site-specific management depends on being able to determine where insects should be treated within a field. Difficulties in describing the distribution of pests within fields have hindered the adoption of this approach (Fleischer et al. 1999). Also the costs and time required to sample spatial distributions using grid sampling make this method impractical (Krell et al. 2003).

A possible alternative that allows the distribution of insect pests to be described in a more economical and practical manner is the use of management zones. Management zones are homogeneous subregions within fields that have similar yield limiting characteristics, and can therefore be managed in a similar manner (Mulla 1993, Doerge 1999). Management zones are suitable for making decisions on whether to apply variable rates of agricultural inputs (Doerge 1999). Input decisions have been made at the management zone level for water and fertilizers (Fleming et al. 1999, Khosla et al. 2002, Chang et al. 2004), but there have been relatively few attempts to define management zones based on the distribution of insect pests. Management zones have been created for the citrus root weevil, *Diaprepes abbreviatus* L., (Li et al. 2004) and the western corn rootworm, *Diabrotica virgifera virgifera* Leconte, (Park and Tollefson

2005). These two studies created management zones based on the predicted distribution of pests.

Another method of creating management zones for insect pests would be to correlate insect activity with field characteristics related to crop productivity. There are potential advantages for this method. One advantage would be if field characteristics (soil texture, fertility, moisture level, etc.) are related to the distribution of insect pests. If so, the sampling costs needed to produce these management zones would be lower than the sampling costs required to produce insect management zones based on field sampling. In a previous study in corn insect distributions were shown to correlate with site-specific management zones delineated based on yield potential (Davidson 2003).

A second advantage is that management zones based on field characteristics might correlate more accurately with areas within a field that are susceptible to yield losses than management zones based on predicted insect distributions. European corn borer damage is known to be influenced by several environmental factors. Moisture levels influence corn borer damage (Godfrey et al. 1992). Soil fertility can also influence damage (Cannon and Ortega 1966, Singer et al. 2000). Management zones that take into account these factors, could therefore give better indications of where yield losses will occur.

In this study European corn borer activity was compared across site-specific management zones (SSMZ) defined by yield potential. These SSMZ are based on field characteristics and not insect distributions. They have been shown to adequately describe differences in soil organic matter (SOM), NO₃-N, K, Zn, conductivity data, and corn grain yield. Researchers have determined that management zones delineated in this

manner would be adequate to make variable rate applications of nitrogen fertilizer (Fleming et al. 1999, Khosla et al. 2002, Hornung et al. 2003). Even though there is variability within management zones, SSMZ are less spatially variable than the whole field (Inman et al. 2005).

This study was designed to determine if European corn borer survival and damage differed across SSMZ. The influences of water and nitrogen levels were also evaluated. The objective was to determine if SSMZ are suitable management units for determining where European corn borer damage might occur.

Materials and Method

Study Location

This research was conducted from 2002 through 2004 at Colorado State University's Agricultural Research, Development, and Education Center (ARDEC) near Fort Collins, Colorado. A furrow irrigated 13 ha corn field was used in the study. The field was planted to winter wheat, *Triticum aestivum* L., in 2001 and has been in continuous corn since 2002.

The field was delineated into site-specific management zones (SSMZ) based on a technique developed at Colorado State University (Fleming et al. 1999, Khosla et al. 2002). This technique uses three data layers to delineate SSMZ; bare soil imagery, field topography, and farmer's previous management experience. These three data layers were then incorporated into a Geographic Information Database (GIS) and mathematical interpolation surfaces were run to create SSMZ. Three SSMZ were created at this field that represented areas of high, medium, and low productivity potential. The high SSMZ was characterized by dark soil color, low topography, and historically high yields. The

low SSMZ was characterized by light soil color, high topography, and historically lower yields. The SSMZ were delineated in March of 2002 (Kim Fleming, Department of Soil and Crop Sciences, Colorado State University, personal communication). The same three SSMZ were used throughout the study.

Crop Management and Experimental Design 2002

On 14 May 2002 the field was planted with Pioneer 37H26 corn hybrid at the rate of 80,000 seeds ha⁻¹. Nitrogen was applied at the rate of 55 kg N ha⁻¹ at planting. The field was irrigated every two weeks throughout the growing season.

The experiment was designed as a split-plot (Table 1.1 and Table 1.2). Three SSMZ delineated from the field served as whole plots. The computer software program Farm GPS (Agri-Tech Solutions, Onawa, IA) feature Grid Sampler was used to create a 45 m by 45 m grid. Five study sites were then randomly selected within each SSMZ (Fig. 1.1). The insect study sites were treated as independent replications within SSMZ.

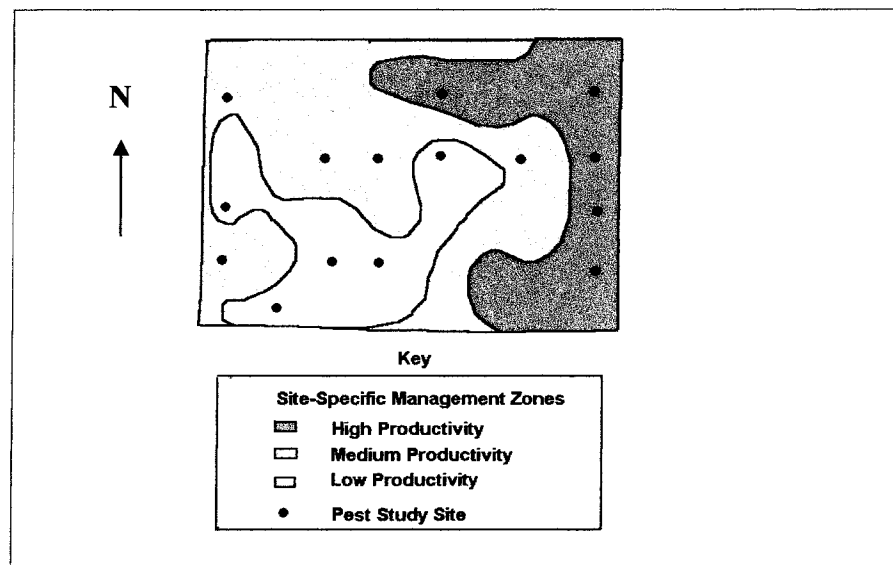


Fig. 1.1. Experimental layout of the field in 2002 showing site-specific management zones (SSMZ) and pest study sites, ARDEC, Fort Collins, CO.

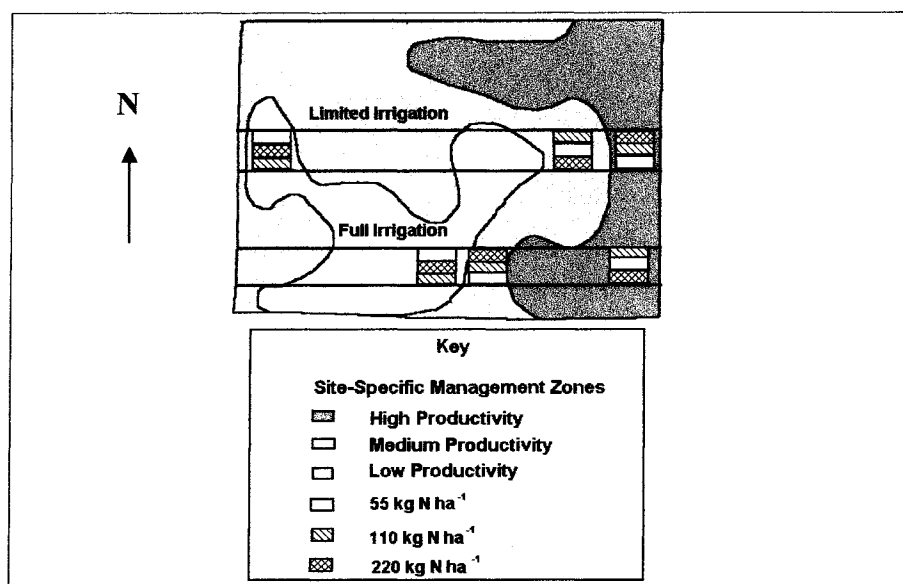


Fig. 1.2. Experimental layout of the field in 2003 and 2004 showing site-specific management zones (SSMZ), irrigation levels, and nitrogen levels, ARDEC, Fort Collins, CO.

At each study site three plots were created. Plots were 3 rows by 5 m long and randomly arranged in the direction of rows (west to east). Treatments were designated as first generation European corn borer (ECB 1), second generation European corn borer (ECB 2), and untreated controls (control). The possibility of natural infestation at this location was considered minimal due to low numbers of European corn borer moths collected in nearby pheromone traps.

Crop Management and Experimental Design 2003 and 2004

The experiment design was altered in 2003 and 2004 to include water and nitrogen variables (Table 1.3 and Table 1.4). In both years the field was planted with Garst 8802 corn hybrid. Planting dates were 6 May 2003 and 5 May 2004. In these two years the field was separated into strips consisting of two water levels, full irrigation and limited irrigation (Fig. 1.2). Forty consecutive rows were selected for each

level. The full irrigation set of rows was watered once every two weeks until grain fill was completed. The limited irrigation set of rows was managed to simulate dryland corn conditions in Colorado (Bauder and Waskom 2003). This set of rows was watered after planting to germinate the seeds, and then once again in early July to simulate a mid-summer rain. Irrigated areas were planted at 80,000 seeds ha⁻¹ and limited irrigated areas were planted at 50,000 seeds ha⁻¹. Water levels were unreplicated because of the size of the experiment. The lack of replication limited the ability to determine if differences between the two strips were due to treatment effects, other factors, or merely to chance alone.

Within the two water levels, SSMZ blocks were created. The SSMZ blocks had a length of 50 m and were 40 rows wide. There were three productivity level SSMZ blocks

Table 1.1 ANOVA table for comparison of grain yield in 2002.			Table 1.2 ANOVA table for comparison of first generation European corn borer survival in 2002.		
#	Source	df	#	Source	df
3	zone	2	3	zone	2
5	site		5	site	
error	site(zone)	12	error	site(zone)	12
3	trt	2	Total error	(zone*site)-1	14
	trt*zone	4			
error	trt*site(zone)	24			
Total error	(zone*site*trt)-1	44			
zone = Site-Specific Management Zone (High, Med, or Low)			zone = Site-Specific Management Zone (High, Med, or Low)		
site = study site (five per Site-Specific Management Zone)			site = study site (five per Site-Specific Management Zone)		
trt = insect treatment (ECB 1, ECB 2, control)					

within each water level: high productivity SSMZ, medium productivity SSMZ, and low productivity SSMZ. Management zone blocks were unreplicated due to the size of the study, limiting the inferences that could be drawn from differences in SSMZ.

Within each of the SSMZ blocks, a split-plot design was created. The whole plot factors in this design consisted of three nitrogen application rates; 55 kg N ha⁻¹, 110 kg N ha⁻¹, and 220 kg N ha⁻¹. In the fully irrigated strip, 110 kg N ha⁻¹ was near the

Table 1.3 ANOVA table for comparison of European corn borer survival in 2003 and 2004.			Table 1.4 ANOVA table for comparison of grain yield in 2003 and 2004.		
#	Source	df	#	Source	df
2	water	1	2	water	1
3	zone	2	3	zone	2
	water*zone	2		water*zone	2
3	N	2	3	N	2
	N*water	2		N*water	2
	N*zone	4		N*zone	4
	N*water*zone	4		N*water*zone	4
6	rep		6	rep	
error	rep(N*water*zone)	90	error	rep(N*water*zone)	90
2	trt	1	3	trt	2
	trt*water	1		trt*water	2
	trt*zone	2		trt*zone	4
	trt*water*zone	2		trt*water*zone	4
	trt*N	2		trt*N	4
	trt*N*water	2		trt*N*water	4
	trt*N*zone	4		trt*N*zone	8
	trt*N*water*zone	4		trt*N*water*zone	8
error	trt*rep(N*water*zone)	90	error	trt*rep(N*water*zone)	180 [#]
Total error	(water*zone*N*trt*rep)-1	215	Total error	(water*zone*N*trt*rep)-1	323
water = water level (full or limited irrigation) zone = Site-Specific Management Zone (High, Med, or Low) N = nitrogen level (55, 110, or 220 kg N per ha) rep = replication (six times) trt = insect treatment (ECB 1 or ECB 2)			[#] In 2003 missing data led to an error term of 179. water = water level (full or limited irrigation) zone = Site-Specific Management Zone (High, Med, or Low) N = nitrogen level (55, 110, or 220 kg N per ha) rep = replication (six times) trt = insect treatment (ECB 1, ECB 2, control)		

recommended rate of nitrogen, and 55 kg N ha^{-1} was near the recommended rate of nitrogen in the limited irrigation strip (Mortvedt et al. 2002). Groups of 12 rows within each management zone block received the three N rates. Nitrogen was applied by side-dressing UAN 32% onto rows at time of cultivation.

European corn borer treatments were established within the nitrogen application whole plots. Plots were three rows wide by four m long, with a one m buffer between plots. Three treatments were created: first generation European corn borer (ECB 1), second generation European corn borer (ECB 2), and an untreated control. Each treatment was randomly replicated six times within each nitrogen level.

European Corn Borer Infestation

European corn borer plots were artificially infested by purchasing egg masses from French Agricultural Research Inc. in Lamberton, Minnesota, and infesting plots with newly hatched larvae. Larvae were applied to plants in a mixture of corncob grits using a Davis applicator (Guthrie and Barry 1987). Infestations were scheduled to occur at the corn growth stages that are most commonly infested by first and second generation corn borers in Colorado (Peairs 2002). ECB 1 plots were infested at the V6 growth stage of the corn plants (Ritchie et al. 1996). Larvae were applied into the whorl of plants in the middle row of each plot. ECB 2 plots were infested when the corn was tasseling. Larvae were applied behind leaf sheaths near the ear region in the middle row of each plot. In 2002, approximately 25 larvae per plant were applied for each generation. In 2003 and 2004, approximately 40 larvae per plant were applied for each generation.

Data Collection

Stalks were split in all European corn borer plots at the time of harvest and the number of larval tunnels was recorded (average of 30 plants per plot in 2002, and 16 plants per plot in 2003 and 2004). The total number of larval tunnels recorded from each plot was divided by the total number of plants in each plot to calculate the average number of larvae per plant. This was done because full irrigation and limited irrigation strips differed in the number of plants per plot. Plants from the untreated controls were not split because European corn borer is not commonly found at the study location, and no egg masses or leaf damage were observed within control treatments.

Grain yield was measured for each plot by hand harvesting all corn ears from the center row of each plot. In 2002, 5.3 m (17.5 ft) were harvested from each plot. In 2003 and 2004, 3 m (10 ft) were harvested from the middle row of each plot. The harvested ears were placed into paper bags and dried at ARDEC facilities in Fort Collins, CO. They were then shelled and total grain weight, test weight, and moisture content were recorded. Grain moisture content was adjusted to 15.5%.

Statistical Analysis

Data were analyzed with PROC MIXED (SAS Institute 2001). The number of European corn borer larvae recorded when splitting stalks was transformed by the square root transformation, $y = \sqrt{y+1/2}$, to stabilize variance (Steel and Torrie 1980). Yield data comparisons were made with untransformed data, because variance in grain yield did not differ widely among means. LSMEANS method of comparison was used to compare means ($\alpha=0.05$).

Data were analyzed by a traditional analysis of variance approach, which assumes replication and randomization (Hong et al. 2005). However, the factors of SSMZ and water level were not properly replicated. Replication is the independent repetition of

experimental units. It serves to provide an estimate of experimental error that is used to formally test statistical hypotheses and to ensure that treatment effects are real and not due to chance alone (Gotway Crawford et al. 1997). The lack of replication limited the ability to determine if differences in comparison were due to treatment effects, other factors, or merely to chance alone.

The lack of randomization is common in precision agriculture research. The manner in which treatments are applied to plots in precision agriculture research (where plots are large and treatments are not randomly assigned) differs from traditional small-plot experiments (where plots are small and treatments may be applied randomly) (Hong et al. 2005). This leads to more spatial variability within and among plots than is typical in small-plot experiments. However, analysis of variance is still commonly used in precision agriculture studies, while noting that efficiency of treatment comparisons is reduced (Hong et al. 2005). Fleming et al. (2003) and Inman et al. (2005) provide examples of studies where analysis of variance has been used to compare means across SSMZ. Chilcutt et al. (2005) conducted a study similar to this one, in which insect pests were compared across two unreplicated water levels.

Results and Discussion

2002

Average grain yield differed among SSMZ in 2002 (df 2, 57; $F 4.09$; $p > F = 0.0219$). The high productivity SSMZ had an average yield of 9.9 ton ha^{-1} , the medium productivity SSMZ averaged 9.4 ton ha^{-1} , and the low productivity SSMZ averaged 8.4 ton ha^{-1} (Fig. 1.3). Yield differences observed among SSMZ matched the expected order

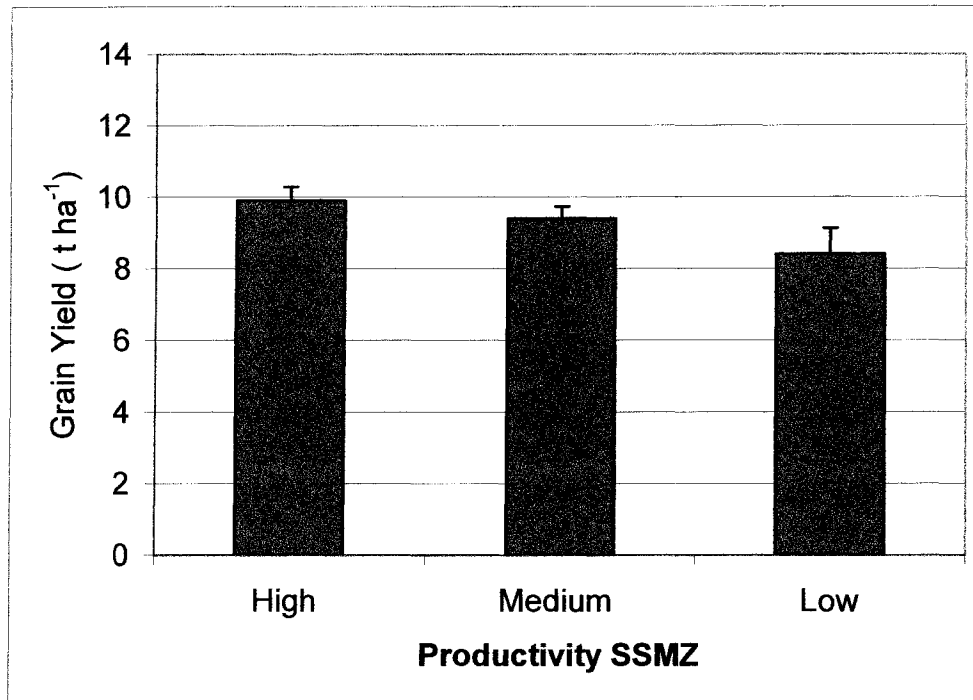


Fig. 1.3. Corn grain yield as affected by site-specific management zone (SSMZ) at ARDEC, Fort Collins, CO in 2002. Means are reported in ton ha⁻¹. Error bars represent standard error of means (SEM).

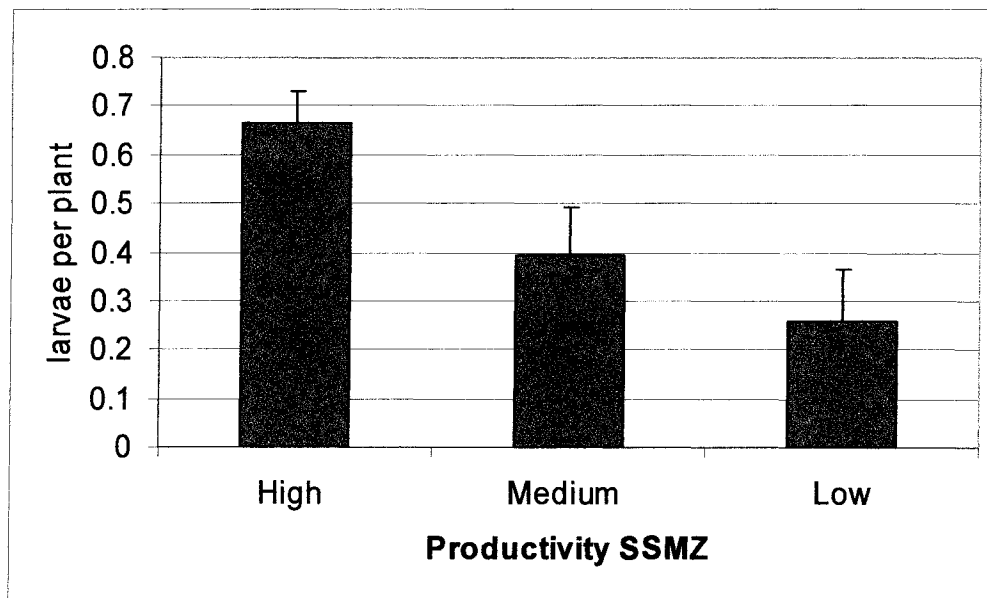


Fig. 1.4. Average number of first generation European corn borer larvae per plant by site-specific management zone (SSMZ) at ARDEC, Fort Collins, CO in 2002. Error bars represent the standard error of means (SEM).

based on productivity level SSMZ, indicating that the SSMZ delineated in this field provided a good estimate of yield potential in 2002. Survival of first generation European corn borer also differed among SSMZ (df 2, 12; $F = 5.53$; $p < F = 0.0199$). The high productivity SSMZ averaged 0.67 larvae per plant, the medium productivity SSMZ averaged 0.40 larvae per plant, and the low productivity SSMZ averaged 0.27 larvae per plant (Fig. 1.4). A LSMEANS comparison of means showed that all differences were significant.

Artificial infestations of second generation European corn borer were not successful in 2002. Because pest survival was low, differences in pest densities among SSMZ could not be determined.

2003

Average grain yields for first and second generation European corn borer plots and control plots are presented in Fig. 1.5. The four-way interaction between water, SSMZ, nitrogen level, and insect treatment was not significant (df 8, 179; $F = 0.53$; $p > F = 0.8311$). The most significant interaction was between water and insect treatment (df 2, 179; $F = 3.83$; $p > F = 0.0234$). The most important single factor explaining grain yield was water level (df 1, 90; $F = 787$; $p > F = 0.0001$). The effect of insect treatment on grain yield was not significant in any interaction.

In 2003, irrigation was not applied uniformly across the field. The west side of the field received more water than the east side. Because the low productivity SSMZ plots were located on the west side of the field (Fig. 1.2), they received more water than the other SSMZ. Yields were reversed from what was expected in the dryland area with

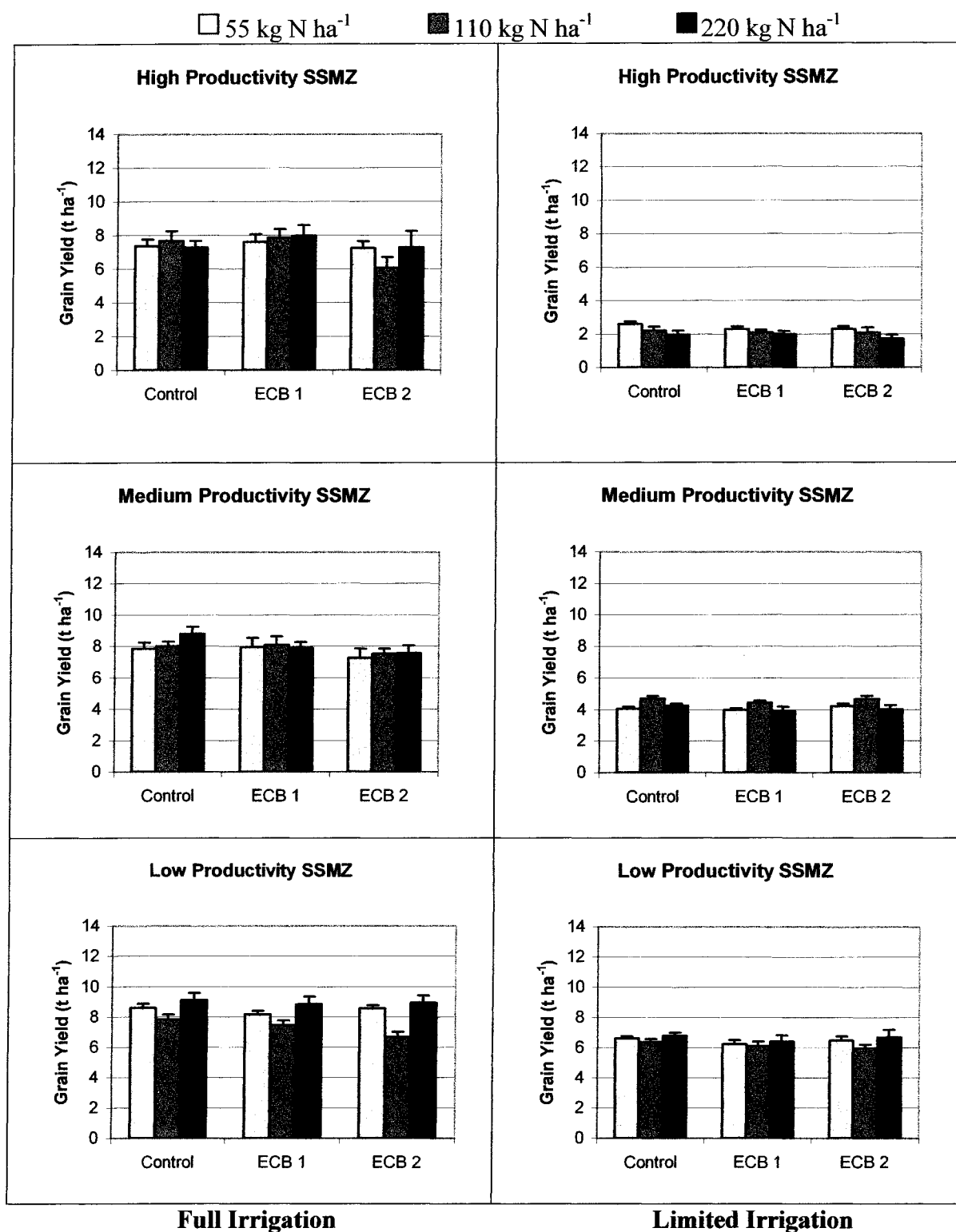


Fig 1.5. Corn grain yield as affected by irrigation level, site-specific management zone (SSMZ), nitrogen level and European corn borer treatment (ECB) at ARDEC, Fort Collins, CO in 2003. Means are reported in ton ha⁻¹. Error bars represent standard error of means (SEM).

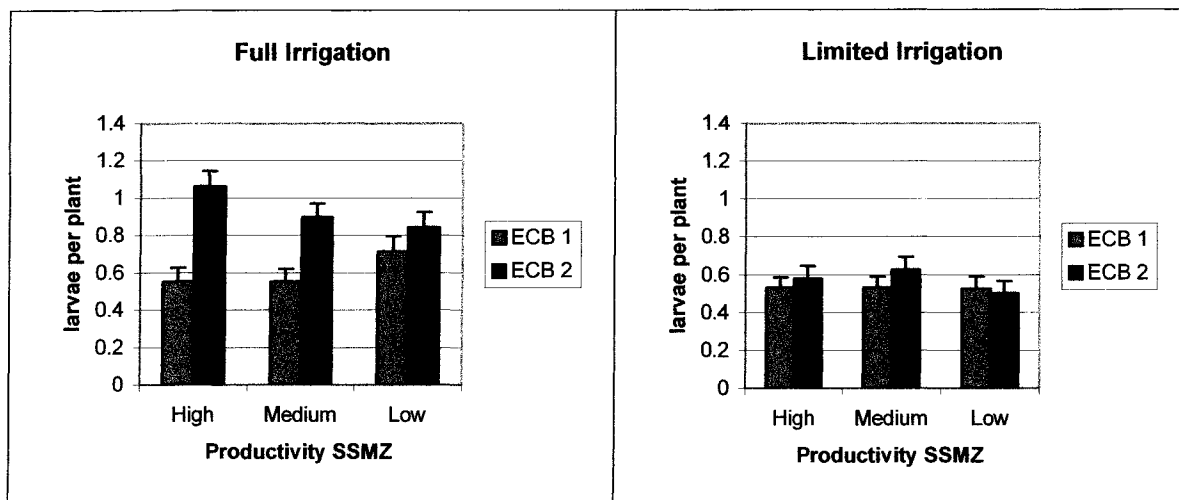


Fig 1.6. Average number of European corn borer larvae found per plant in each site-specific management zone (SSMZ) separated by water level at ARDEC, Fort Collins, CO in 2003. (ECB 1 = first generation European corn borer plot, ECB 2 = second generation European corn borer plot). Error bars represent standard error of means (SEM).

the low productivity SSMZ having the highest yield and the high productivity SSMZ having the lowest yield (Fig. 1.5). In the irrigated area yield was similar among the three SSMZ.

The larval survival of first and second generation European corn borers is presented in Fig. 1.6. The effects of nitrogen were not significant in any comparison so means in Fig. 1.6 are averaged over nitrogen treatments. There was a significant two-way interaction between water level and insect treatment (df 1, 88; F 13.7; $p > F = 0.0004$). The number of larvae found per plant was greater in irrigated areas than in dryland areas (Fig. 1.6). The survival of second generation larvae was greater than first generation survival in the full irrigation water strip, whereas first and second generations had similar survival in the limited irrigation strip.

Overall larval survival did not significantly differ among SSMZ. However, differential survival of second generation larvae did occur within the fully irrigated strip.

This treatment had the highest larval densities of all the treatments. Averages were 1.1 larvae per plant, 0.9 larvae per plant, and 0.8 larvae per plant, respectively for the high, medium, and low productivity SSMZ. Least Significant Means comparisons showed that larval counts in the high productivity SSMZ were greater than in the other SSMZ. These results are similar to trends in European corn borer survival observed in 2002.

2004

Average grain yields for all treatments are presented in Fig. 1.7. The four-way interaction between water, SSMZ, nitrogen level, and insect treatment was not significant (df 8, 176; F 0.71; $p > F = 0.6781$). There was a significant three-way interaction involving water level, SSMZ, and nitrogen level (df 4, 90; F 13.8; $p > F = 0.0001$). The most important single factor explaining grain yield was water level (df 1, 90; F 108; $p > F = 0.0001$). The effect of insect treatment on grain yield was not significant in any interactions.

There was no effect of SSMZ on grain yield (df 1, 90; F 0.22; $p > F = 0.799$). The expected grain yields were similar across SSMZ (Fig. 1.7). They were not reversed as in 2003.

The larval survival of first and second generation European corn borers is presented in Fig. 1.8. There was a significant two-way interaction between water level and insect treatment (df 1, 87; F 34.6; $p > F = 0.001$). Both insect treatment (df 1, 87; F 186; $p > F = 0.001$) and water level (df 1, 87; F 109; $p > F = 0.001$) had a great effect on larval survival. The highest larval density observed was for first generation larvae in the

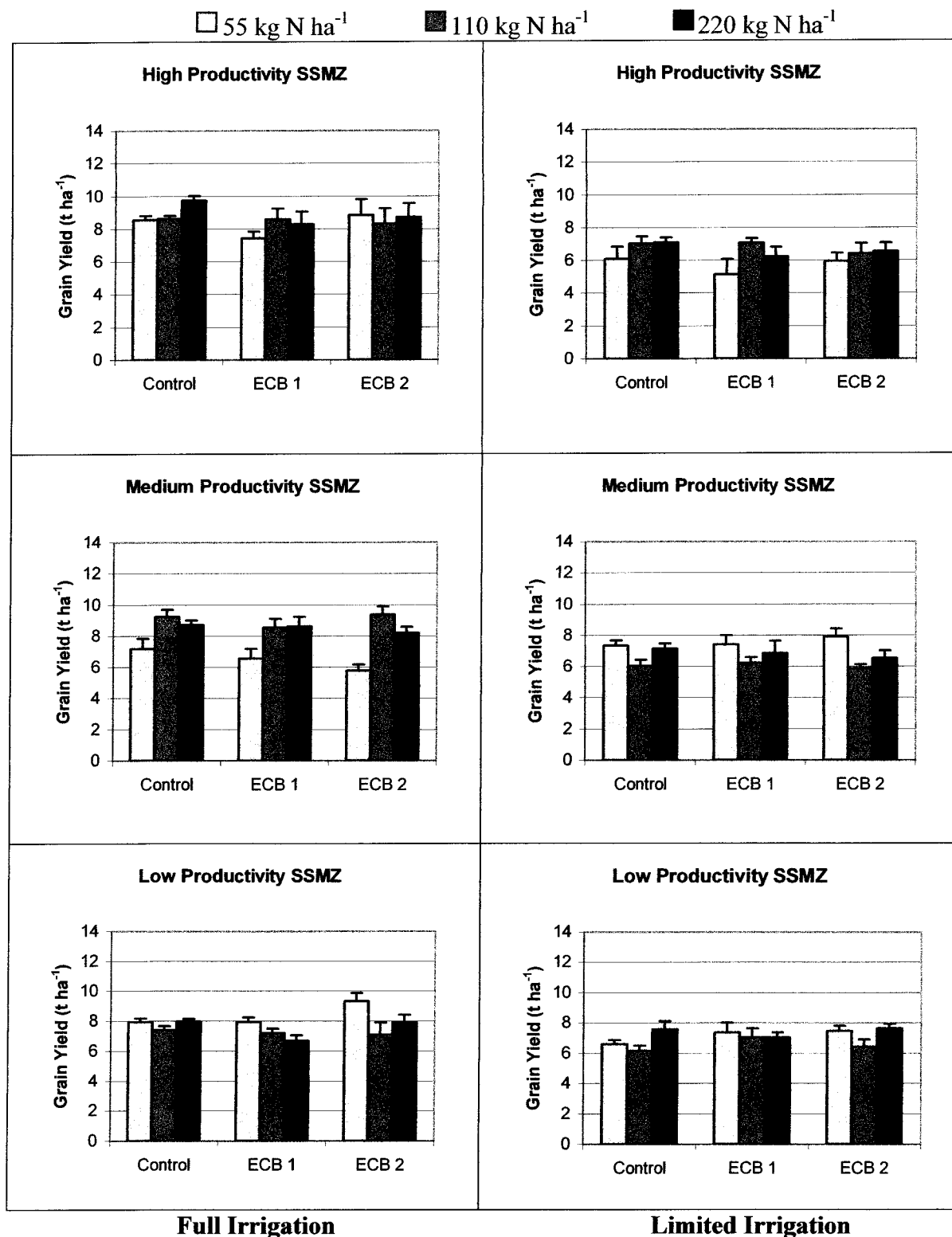


Fig 1.7. Corn grain yield as affected by irrigation level, site-specific management zone (SSMZ), nitrogen level and European corn borer treatment (ECB) at ARDEC, Fort Collins, CO in 2004. Means are reported in ton ha⁻¹. Error bars represent standard error of means (SEM).

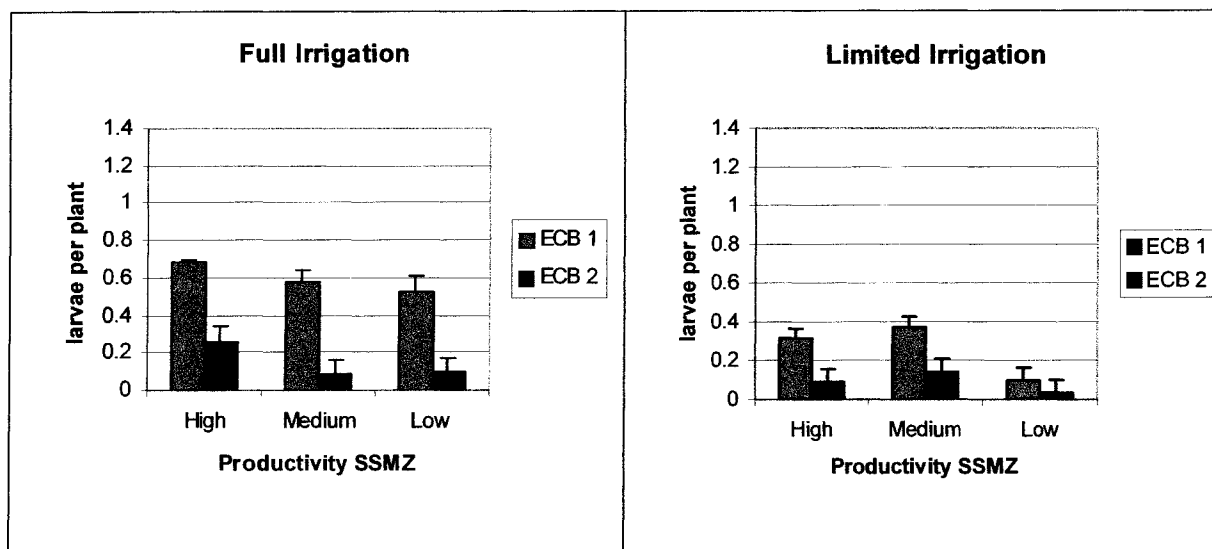


Fig 1.8. Average number of European corn borer larvae found per plant in each site-specific management zone separated by water level at Fort Collins, CO in 2004. (ECB 1 = first generation European corn borer plot, ECB 2 = second generation European corn borer plot). Error bars represent standard error of means (SEM).

full irrigation strip. First generation larvae had differential survival across SSMZ in the full irrigation strip. Averages were 0.70 larvae per plant, 0.58 larvae per plant, and 0.52 larvae per plant, respectively for the high, medium, and low productivity SSMZ. Least Significant Means comparisons showed that larval counts in the high productivity SSMZ were greater than in the other SSMZ. As in previous years, at high densities there was differential larval survival among SSMZ.

Discussion

The objective of this study was to determine if European corn borer damage and survival differed among SSMZ. Differences in grain yield between plots infested with European corn borer and uninfested control plots were never observed. A possible explanation is that grain yield effects due to corn borer damage were overshadowed by other variables affecting grain yield. A single European corn borer larvae tunneling

within a corn stalk is expected to reduce grain yields by 4-10% (Mason et al. 1996). The differences in grain yields between plots was often greater than 4-10%. This great variability was most likely due to factors such as uneven irrigation throughout the field.

Uneven irrigation most likely contributed in 2003 and 2004 to SSMZ not producing their expected yields. In 2003, the yields were reversed among SSMZ from what was expected. In 2004, grain yields were similar among SSMZ. It is also probable that in 2003 and 2004 grain yields within productivity SSMZ were not in the expected order because fewer sites within each SSMZ were sampled. In 2002, when five sites were selected among each SSMZ, yield differences matched the expected order based on productivity level SSMZ.

Differential European corn borer survival was, however, observed in the study. There were strong differences in larval survival among water levels in 2003 and 2004. Larval survival was much greater in full irrigation strips both years. Even though water levels were not replicated within year, it seems likely that the large differences for two years indicate a real difference.

There also appeared to be differences in larval survival among SSMZ. In 2002, there was differential survival of first generation corn borer across SSMZ. Second generation corn borer results were inconclusive because the artificial infestation was not successful. A severe drought in the late summer of 2002 likely contributed to the poor survival of second generation corn borer larvae.

In 2003 and 2004, when artificial infestations were most successful, more larvae survived in high productivity SSMZ and fewer larvae survived in low productivity SSMZ. In 2003, there was differential survival of second generation larvae across SSMZ

in the full irrigation strip. In 2004, there was differential survival of first generation larvae in the full irrigation strip. An exact reason why differential survival occurred is difficult to explain. In 2002, first generation larval survival rates matched the grain yields from SSMZ. However, in 2003 and 2004 grain yields were not different among SSMZ, but still larval survival rates varied among SSMZ. Varying levels of nitrogen have been shown to affect European corn borer larval survival in other studies (Cannon and Ortega 1966, Singer et al. 2000). Nitrogen is unlikely to be the explanation at this location as no effects of larval survival were observed among the three levels of nitrogen used.

Conclusions

This study indicates that European corn borer activity, as it relates to larval survival, does differ among productivity SSMZ. This result could be significant if economic injury levels (EILs) are developed for separate SSMZ. There are two reasons why it would be appropriate to develop EILs for separate SSMZ. The first reason is that the calculation of EILs requires prior knowledge of the yield potential of a field (Mason et al. 1996). Productivity SSMZ as defined in this study are intended to give a more accurate estimation of yield potential for specific areas within a field, and thus could provide more accurate EILs. Another reason is that loss factors will also differ among SSMZ. Although differences in damage were not detected among SSMZ in this study, there was indication that loss factors might differ among SSMZ. When calculating EILs for European corn borer, loss factors are calculated based on the amount of damage that egg masses or young larvae are expected to cause (Mason et al. 1996). Because

differential survival was observed among SSMZ in this study, it is likely that the amount of damage caused by an egg mass or young larvae will also differ among SSMZ.

Before EILs can be developed for separate SSMZ, loss factors must be determined for individual SSMZ. This study indicated that loss factors might differ because larval survival differed among SSMZ. Loss factors need to be developed that give a quantifiable estimate of how damage will change among productivity level SSMZ. Determining loss factors is the most critical step in establishing accurate EILs (Peterson and Higley 2001).

The development of separate EILs for SSMZ within a field would allow for SSMZ to be sampled and managed independently, realizing the benefits of site-specific management. Site-specific management zones could be treated independently either by the use of variable rate technology to precisely apply insecticides or prescription planting of genetically engineered resistant hybrids. Variable rate applicators of insecticide are currently commercially available and the technology to prescription plant seeds is under development (Shanahan et al. 2004). The prescription planting of resistant hybrids is of interest to European corn borer management because current guidelines require that certain percentages of fields that are planted with genetically modified hybrids be maintained as susceptible refuges (Ostlie et al. 1997, Peairs 2002). Knowing which areas of a field are most susceptible to insect damage will allow producers to plant those areas with resistant seeds. Areas of the field that will suffer less damage could then be maintained as refuges.

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Chapter 2.

Western Corn Rootworm Damage Across Site-Specific Management Zones

Introduction

The western corn rootworm, *Diabrotica virgifera virgifera* Leconte, is a key pest of corn, *Zea mays* L., in the United States. It was first recognized as a pest of corn in Colorado and western Kansas in 1912. The increase in acreage planted to corn in the 1950's allowed the beetle to expand its range, and it is now found throughout the Corn Belt and east to Delaware and Maryland (Sutter 1999). Western corn rootworm damage is due primarily to larval stages feeding on the root system. Destruction of roots causes plant stress by interfering with the uptake of water and nutrients, and by reducing the stability of the plant. Rootworm induced lodging decreases yields by lowering plant photosynthetic efficiency and by interfering with harvest due to poorly anchored stalks (Sutter 1999). Adults can cause damage by feeding on silks, but this is not believed to cause significant yield loss in Colorado (Peairs and Pilcher 2002). The persistent nature of corn rootworm problems has led to the application of soil insecticides to nearly 90% of continuous corn acres in much of the country (Sutter 1999). Research in Colorado has shown that grain yield was reduced by 10% on average over ten years due to corn rootworm feeding (Peairs and Pilcher 2002).

Several factors influence the distribution of western corn rootworms. Moisture affects rootworm oviposition with more eggs being laid in moist soil (Kirk et al. 1968). Soil texture is also very important. Females are not accomplished burrowers and must use existing openings such as soil cracks, crevices at the plant/soil interface, earthworm burrows, and cavities left by decaying plant material to gain access to the soil for egg

laying (Tollefson and Calvin 1994). Larvae are less likely to survive in sandy soil due to abrasion (Kirk et al. 1968). Efforts to determine the geospatial distribution of western corn rootworms have focused on sampling for newly emerged adults (Ellsbury et al. 1998, Park and Tollefson 2005) and eggs (Wyse-Pester 2000).

There could be many advantages for making site-specific management decisions for western corn rootworm, instead of treating the entire field. The benefits of site-specific management have been shown with other insect pests of field crops. These benefits include reduced insecticide loads (Weisz et al. 1996), increased preservation of natural enemies (Fleischer et al. 1997, Midgarden et al. 1997), and reduced rates of insecticide resistance development (Midgarden et al. 1997). The ability to apply site-specific management depends on being able to determine where insects should be treated within a field. Difficulties in describing the distribution of pests within fields have hindered the adoption of this approach (Fleischer et al. 1999). Also, the costs and time required to sample spatial distributions using grid sampling can make this method unpractical (Krell et al. 2003).

A possible alternative that allows the distribution of insect pests to be described in a more economical and practical manner is the use of management zones. Management zones are homogeneous subregions within fields that have similar yield limiting characteristics, and can therefore be managed in a similar manner (Mulla 1993, Doerge 1999). Management zones are suitable for making decisions on whether to apply variable rates of agricultural inputs (Doerge 1999). Input decisions have been made at the management zone level for water and fertilizers (Fleming et al. 1999, Khosla et al. 2002, Chang et al. 2004), but there have been relatively few attempts to define

management zones based on the distribution of insect pests. Management zones have been created for the citrus root weevil, *Diaprepes abbreviatus* L., (Li et al. 2004) and the western corn rootworm (Park and Tollefson 2005). These two studies used field sampling of adult insects and then spatial statistics to map predicted pest distributions.

Another method of creating management zones for western corn rootworm would be to correlate rootworm activity with other field characteristics. There are potential advantages for this method. One advantage would occur if field characteristics related to productivity (soil texture, fertility, moisture level, etc.) are also related to the distribution of rootworms. If so, sampling costs might be lower than the costs of developing pest management zones that require extensive sampling throughout a growing season. In addition, the same SSMZ could be used for other production inputs such as water and nutrients.

A second advantage is that management zones based on field characteristics might correlate more accurately with areas within a field that are susceptible to rootworm damage than management zones created based solely on insect distributions. Western corn rootworm damage is influenced by several environmental factors. Moisture levels are known to influence corn rootworm damage (Hou et al. 1997, Riedell and Sutter 1995). Soil fertility can also influence damage (Riedell et al. 1996, Spike and Tollefson 1991). Management zones that take into account these factors could, therefore, give better indications of where yield losses will occur.

In this study western corn rootworm activity was studied as it relates to site-specific management zones (SSMZ) defined by yield potential. These SSMZ are based on field characteristics and not insect distributions. They have been shown to adequately

describe differences in soil organic matter (SOM), NO₃-N, K, Zn, conductivity data, and corn grain yield. Researchers have determined that management zones delineated in this manner would be adequate to make variable rate applications of nitrogen fertilizer (Fleming et al. 1999, Khosla et al. 2002, Hornung et al. 2003). Even though there is variability within management zones, SSMZ were found to be less spatially variable than the whole field (Inman et al. 2005). In a previous study, western corn rootworm distributions were shown to correlate with site-specific management zones delineated by yield potential (Davidson 2003).

This study was conducted to determine if western corn rootworm damage differed among SSMZ. The influences of water and nitrogen levels on rootworm damage were also studied. The objective was to determine if SSMZ are suitable units for determining where western corn rootworm damage might occur.

Materials and Methods

Study Location

This research was conducted from 2002 through 2004 at Colorado State University's Agricultural Research, Development, and Education Center (ARDEC) near Fort Collins, Colorado. A furrow irrigated 13 ha corn field was used in the study. Most of the field had been planted to winter wheat, *Triticum vulgare* L., in 2001 with only the northern portion of the field planted to corn.

The field was delineated into site-specific management zones (SSMZ) based on a technique developed at Colorado State University (Fleming et al. 1999, Khosla et al. 2002). This technique uses three data layers to delineate SSMZ; bare soil imagery, field topography, and farmer's previous management experience. These three data layers

were then incorporated into a Geographic Information Database (GIS) and mathematical interpolation surfaces were run to create SSMZ. Three SSMZ were created at this field that represented areas of high, medium, and low productivity potential. The high SSMZ was characterized by dark soil color, low topography, and historically high yields. Low SSMZ was characterized by light soil color, high topography, and historically low yields. The SSMZ were delineated in March of 2002 (Kim Fleming, Department of Soil and Crop Sciences, Colorado State University, personal communication). The same SSMZ were used throughout the study.

Crop Management and Experimental Design 2002

On 14 May 2002 the field was planted with Pioneer 37H26 corn hybrid at the rate of 80,000 seeds ha⁻¹. Nitrogen was applied at the rate of 55 kg N ha⁻¹ at planting. The field was irrigated every two weeks throughout the growing season.

The western corn rootworm part of the study was limited to the north side of the field, because the rest of the field was in first year corn (Fig. 2.1). First year corn in Colorado is not expected to contain corn rootworms (Peairs and Pilcher 2002). The area of the field planted to continuous corn did not include any area within the low productivity SSMZ, so only the medium and high productivity SSMZ were used. Within the two SSMZ, twenty plots were created. Plots were 7.5 m long and one row wide. Ten plots were designated as western corn rootworm plots (WCR) and the other ten plots were designated as control plots. Control plots were created by treating plots with terbufos (Counter[®] 20 CR, BASF Corp., Research Triangle Park, NC) 1.4 kg (AI) ha⁻¹ at time of cultivation. The insecticide was banded over the row through granular applications on 15 June. WCR plots were untreated. The northern edge of the field was naturally infested with western

corn rootworm from the previous year. Table 2.1 shows the ANOVA table used for making comparisons.

Crop Management and Experimental Design 2003

The experimental design was altered in 2003 to include water and nitrogen variables (Table 2.2). The field was planted with Garst 8802 corn hybrid on 6 May 2003. The field was separated into strips consisting of two water levels, full irrigation and limited irrigation (Fig. 2.2). Forty consecutive rows were selected for each level. The full irrigation set of rows was watered once every two weeks until grain fill was complete. The limited irrigation set of rows was managed so as to simulate dryland corn conditions in Colorado (Bauder and Waskom 2003). This set of rows was watered after planting to germinate the seeds, and then once again in early July to simulate a mid-summer rain. Fully irrigated areas were planted at 80,000 seeds ha⁻¹ and limited irrigated areas were planted at 50,000 seeds ha⁻¹. These two levels were unreplicated because of the size of

Table 2.1 ANOVA table for comparison of grain yield and western corn rootworm larval abundance in 2002.

#	Source	df
2	zone	1
2	trt	1
	trt*zone	1
10	reps	
error	rep(trt*zone)	36
Total error	(zone*site*trt)-1	39

zone = Site-Specific Management Zone (High or Med)

trt = insect treatment (WCR and control)

rep = replication (ten per Site-Specific Management Zone)

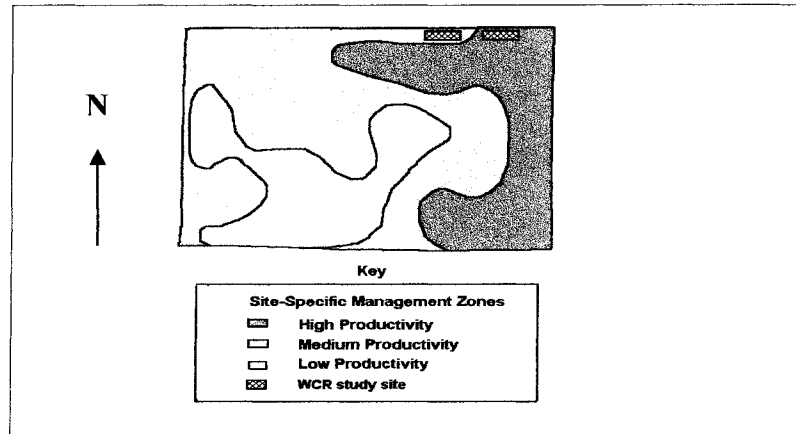


Fig. 2.1. Experimental layout of the field in 2002 showing site-specific management zones (SSMZ) and western corn rootworm (WCR) study sites, ARDEC, Fort Collins, CO.

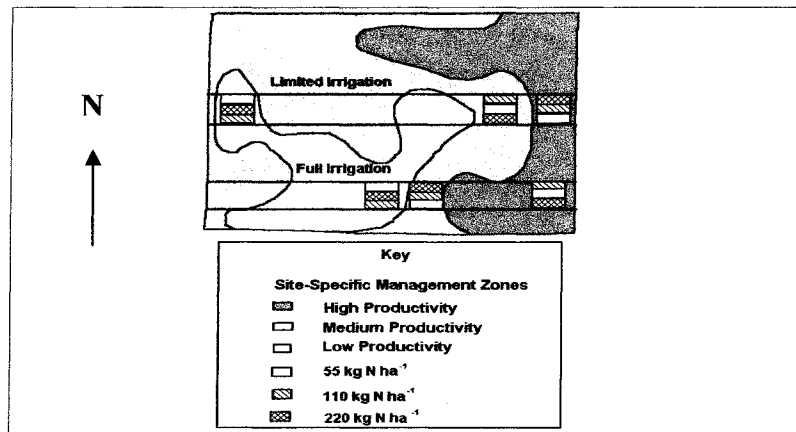


Fig. 2.2. Experimental layout of the field in 2003 showing site-specific management zones (SSMZ) and nitrogen levels, ARDEC, Fort Collins, CO.

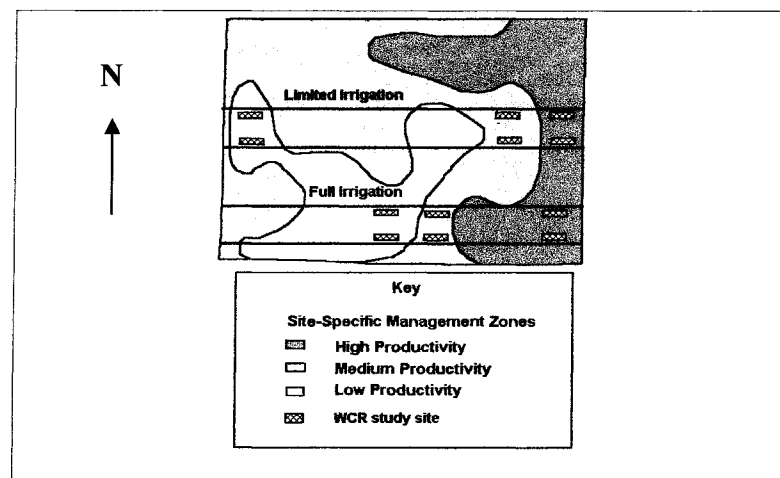


Fig. 2.3. Experimental layout of the field in 2004 showing site-specific management zones (SSMZ) and western corn rootworm (WCR) study sites, ARDEC, Fort Collins, CO.

the experiment. The lack of replication limited the ability to determine if differences between the two strips were due to treatment effects or merely to chance alone.

Within the two water levels, SSMZ blocks were created. The SSMZ blocks had a length of 50 m and were 40 rows wide. There were three productivity level SSMZ blocks within each water level: high productivity SSMZ, medium productivity SSMZ, and low productivity SSMZ. Management zone blocks were unreplicated due to the size of the study, limiting the inferences that could be drawn from differences in SSMZ.

Within each of the SSMZ blocks, a split-plot design was created. The whole plot factors in this design consisted of three nitrogen application rates; 55 kg N ha⁻¹, 110 kg N ha⁻¹, and 220 kg N ha⁻¹. In the fully irrigated strip, 110 kg N ha⁻¹ was near the recommended rate of nitrogen, and 55 kg N ha⁻¹ was near the recommended rate of nitrogen in the limited irrigation strip (Mortvedt et al. 2002). Whole plots consisted of 12 rows that were 40 m long. Nitrogen was applied by side-dressing UAN 32% onto rows at time of cultivation.

Western corn rootworm treatment plots were established within the nitrogen application whole plots. Plots were three rows wide by four meters long, with a one meter buffer between plots. Two types of treatments were created: control plots and western corn rootworm (WCR) plots. Control plots were created by treating plots with terbufos (Counter[®] 20 CR, BASF Corp., Research Triangle Park, NC) 1.4 kg (AI) ha⁻¹ at time of cultivation. The insecticide was banded over the row through granular applications on 19 June. WCR plots were created by leaving plots untreated. Plots were naturally infested with western corn rootworm. Each treatment was randomly replicated six times within each of the three nitrogen whole plot treatments.

Table 2.2 ANOVA table for comparison of western corn rootworm larval abundance and grain yield in 2003.

#	Source	df
2	water	1
3	zone	2
	water*zone	2
3	N	2
	N*water	2
	N*zone	4
	N*water*zone	4
6	rep	
error	rep(N*water*zone)	90
2	trt	1
	trt*water	1
	trt*zone	2
	trt*water*zone	2
	trt*N	2
	trt*N*water	2
	trt*N*zone	4
	trt*N*water*zone	4
error	trt*rep(N*water*zone)	90
Total error	(water*zone*N*trt*rep)-1	215

water = water level (full or limited irrigation)

zone = Site-Specific Management Zone (High, Med, or Low)

N = nitrogen level (55, 110, or 220 kg N per ha)

rep = replication (six times)

trt = insect treatment (WCR and control)

Crop Management and Experimental Design 2004

The experimental design in 2004 included two water levels (Table 2.3). The two water levels were designed in a manner similar to 2003. The full irrigation water level was irrigated every two weeks throughout the growing season. The limited irrigation strip was irrigated immediately after planting and then once again in mid summer.

Nitrogen was applied uniformly across all study sites at a rate of 55 kg N ha⁻¹.

The two water levels passed through the each of the three SSMZ (Fig. 2.3).

Within each SSMZ, two study sites were selected. The study sites were 16 meters long and five rows wide.

Within each of the two study sites, ten plots were created. Individual plots were one row wide and eight meters (25 feet) long. Five plots were designated as western corn rootworm (WCR) plots and five plots were designated as controls. Control treatments consisted of a corn hybrid engineered to be resistant to corn rootworms, containing event MON 863 (Dekalb[®] hybrid DKC46-24). The WCR treatment plots were planted to a nearly isogenic hybrid lacking the MON 863 event (Dekalb[®] hybrid DKCC46-28). The field was naturally infested with western corn rootworms.

Table 2.3 ANOVA table for comparison of western corn rootworm larval abundance and grain yield in 2004.

#	Source	df
2	water	1
3	zone	2
	water*zone	2
2	site	
error	site(water*zone)	6
2	trt	1
	trt*water	1
	trt*zone	2
	trt*water*zone	2
	trt*site(water*zone)	6
5	rep	
error	rep(trt*site*zone*water)	96
Total error	(water*zone*trt*rep)-1	119

water = water level (full or limited irrigation)

zone = Site-Specific Management Zone (High, Med, or Low)

N = nitrogen level (55, 110, or 220 kg N per ha)

rep = replication (five times)

trt = hybrid choice (resistant or susceptible)

Data Collection

Western corn rootworm larval densities were measured from all plots. Larval densities were measured by digging three plants up by the roots and placing the roots on Fromm funnels (Fromm et al. 1997). Fromm funnels were constructed from plastic drinking cups and plastic insect screening. The funnels recover corn rootworm larvae by drying single root systems over a pool of water. Hammak et al. (2003) have shown that larvae recovered with the use of Fromm funnels correlated significantly with the density of larvae in the surrounding soil. Larvae were sampled when corn plants were near the V6 growth stage (Ritchie et al. 1996). The dates of larval sampling were 27 June 2002, 24 June 2003, and 27 June 2004 for the three years of the study.

Grain yield was measured for each plot by hand harvesting all corn ears from the center row of each plot. In 2002 and 2004, 5.3 m (17.5 ft) were harvested from each plot. In 2003, 3 m (10 ft) were harvested from each plot. The harvested ears were placed into paper bags and dried at ARDEC facilities in Fort Collins, CO. They were then shelled and total grain weight, test weight, and moisture content were recorded. Grain moisture content was adjusted to 15.5%.

Statistical Analysis

The data were analyzed with PROC MIXED (SAS Institute 2001). The number of western corn rootworm larvae recorded from Fromm funnels was transformed by the square root transformation, $y = \sqrt{y+1/2}$, to stabilize variance (Steel and Torrie 1980). Yield data comparisons were made with untransformed data, because grain yield did not

show wide variance as means changed. LSMEANS method of comparison was used to compare means.

Data were analyzed by a traditional analysis of variance approach, which assumes replication and randomization (Hong et al. 2005). However, the factors of SSMZ and water level were not properly replicated. Replication is the independent repetition of experimental units. It serves to provide an estimate of experimental error that is used to formally test statistical hypotheses and to ensure that treatment effects are real and not due to chance alone (Gotway Crawford et al. 1997). The lack of replication limited the ability to determine if differences in comparison were due to treatment effects, other factors, or merely to chance alone.

The lack of randomization is common in precision agriculture research. The manner in which treatments are applied to plots in precision agriculture research (where plots are large and treatments are not randomly assigned) differs from traditional small-plot experiments (where plots are small and treatments may be applied randomly) (Hong et al. 2005). This leads to more spatial variability within and among plots than is typical in small-plot experiments. However, analysis of variance is still commonly used in precision agriculture studies, while noting that efficiency of treatment comparisons is reduced (Hong et al. 2005). Fleming et al. (2003) and Inman et al. (2005) provide examples of studies where analysis of variance has been used to compare means across SSMZ. Chilcutt et al. (2005) conducted a study similar to this one, in which insect pests were compared across two unreplicated water levels

Results

2002

In the area of the field containing western corn rootworm, there was on average more rootworms per plant in the high productivity SSMZ, 3.6 larvae per plant, than in the low productivity SSMZ, 1.7 larvae per plant; however this difference was not significant (df 1, 12; $F = 3.19$; $p > F = 0.0994$).

Differences in grain yield between the medium and high productivity SSMZ were not observed in the rootworm study sites (df 1, 36; $F = 0.04$; $p > F = 0.9790$). Grain yields also were not significantly different among plots naturally infested by corn rootworms and control plots treated with an insecticide to limit rootworms (df 1, 36; $F = 0.50$; $p > F = 0.4843$), perhaps due to irregularities in furrow irrigation. In 2002 some rows received more water than others and the medium SSMZ often received more water than the high SSMZ.

2003

The number of western corn rootworm larvae recovered per plant did not differ among water level, SSMZ, or nitrogen level (three-way interaction, df 4, 90; $F = 0.49$; $p > F = 0.7445$) (Fig. 2.4). No other interactions related to the number of larvae were significant.

There was a significant three-way interaction with grain yield between water level, SSMZ, and nitrogen level (df 4, 88; $F = 5.08$; $p > F = 0.001$). Water level was the single most important factor that influenced grain (df 1, 88; $F = 819$; $p > F = 0.0001$).

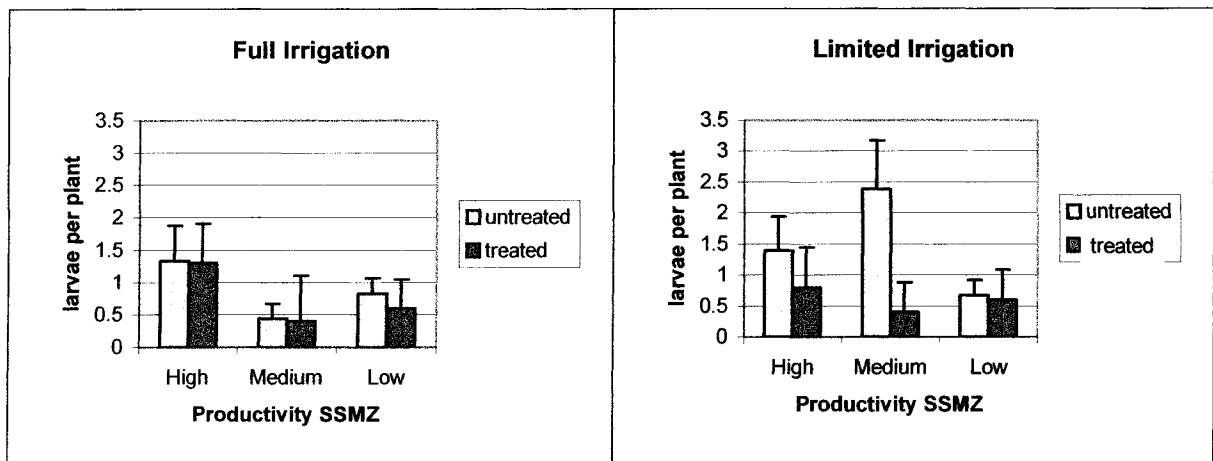


Fig 2.4. Average number of western corn rootworm larvae recovered per plant in each site-specific management zone (SSMZ) separated by water level at ARDEC, Fort Collins, CO in 2003. Error bars represent standard error of means (SEM).

In 2003, irrigation was not applied uniformly across the field. The west side of the field received more water than the east side. Because the low productivity SSMZ were located on the west side of the field (Fig. 2.2), they received more water than the other SSMZ. Yields were reversed from what was expected in the dryland area with the low productivity SSMZ having the highest yield and the high productivity SSMZ having the lowest yield (Fig. 2.4). In the irrigated area yield was similar among the three SSMZ. There were no yield differences in comparison involving western corn rootworm plots and control plots.

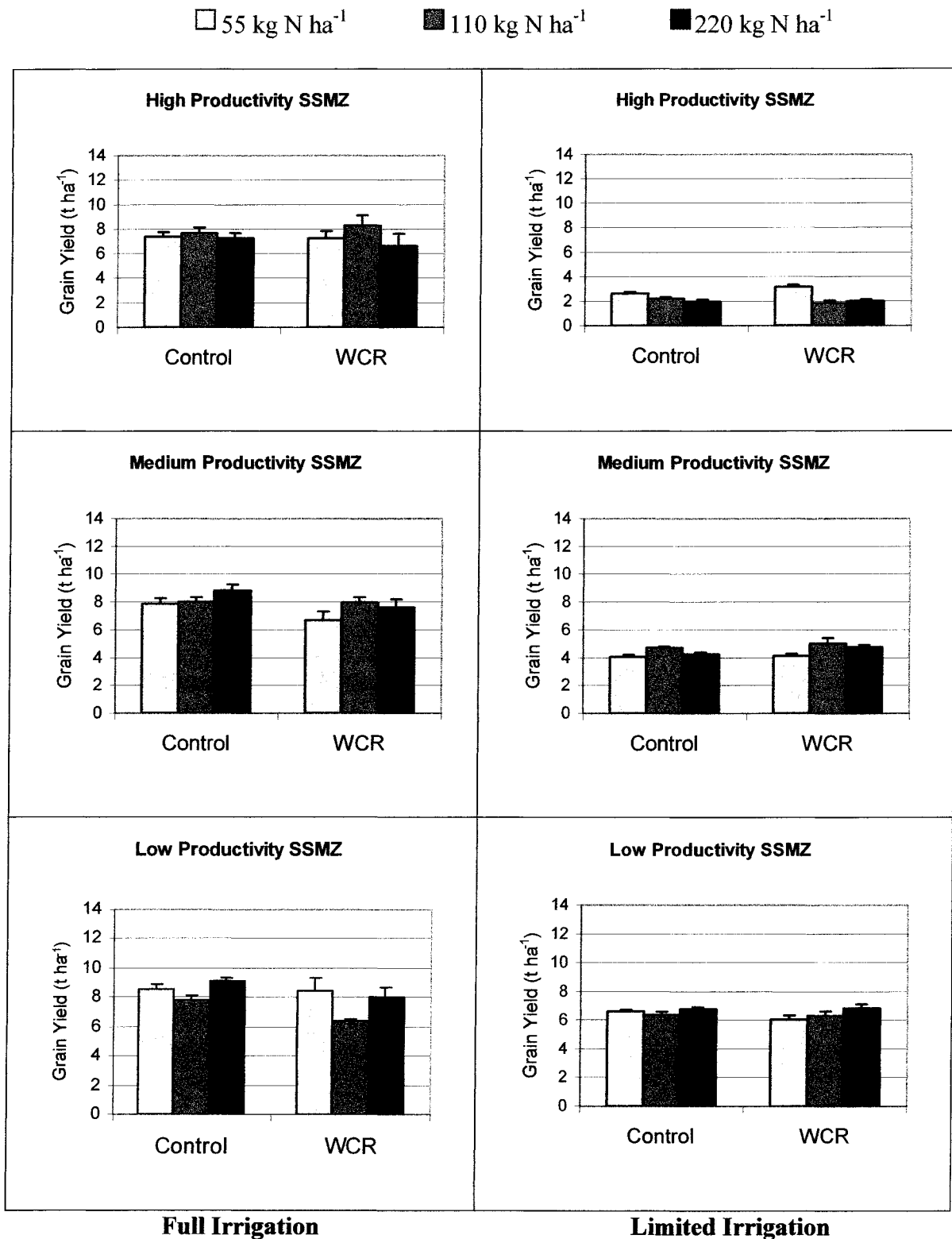


Fig 2.5. Corn grain yield as affected by irrigation level, site-specific management zone (SSMZ), nitrogen level and control of western corn rootworm (WCR) at ARDEC, Fort Collins, CO in 2003. Means are reported in ton ha⁻¹. Error bars represent standard error of means (SEM).

2004

The number of western corn rootworm larvae recovered per plant had a significant two-way interaction between SSMZ and plot treatment (df 2, 80; $F = 8.7$; $p > F = 0.0004$) (Fig. 2.6). The effect of plot treatment was the most important single factor (df 1, 80; $F = 202$; $p > F = 0.0001$). The control plots planted with a genetically engineered resistant hybrid consistently had fewer larvae recovered per plant than the nearly isogenic susceptible hybrid.

In regards to grain yield there was a significant three-way interaction between water level, SSMZ, and insect treatment (df 2, 42; $F = 5.25$; $p > F = 0.0092$) (Fig. 2.7). Of these three factors, plot treatment had the most significant impact (df 1, 42; $F = 8.31$; $p > F = 0.0001$). The control plots planted with a genetically modified resistant hybrid consistently yielded more than western corn rootworm plots planted with susceptible hybrids.

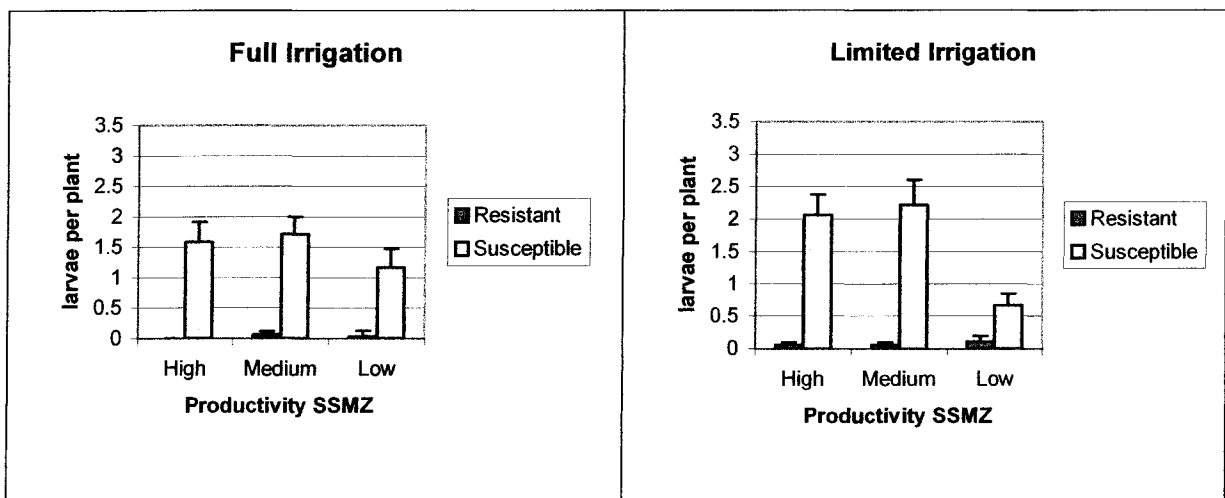


Fig 2.6. Average number of western corn rootworm larvae recovered per plant in each site-specific management zone (SSMZ) separated by water level at ARDEC, Fort Collins, CO in 2004. Error bars represent standard error of means (SEM).

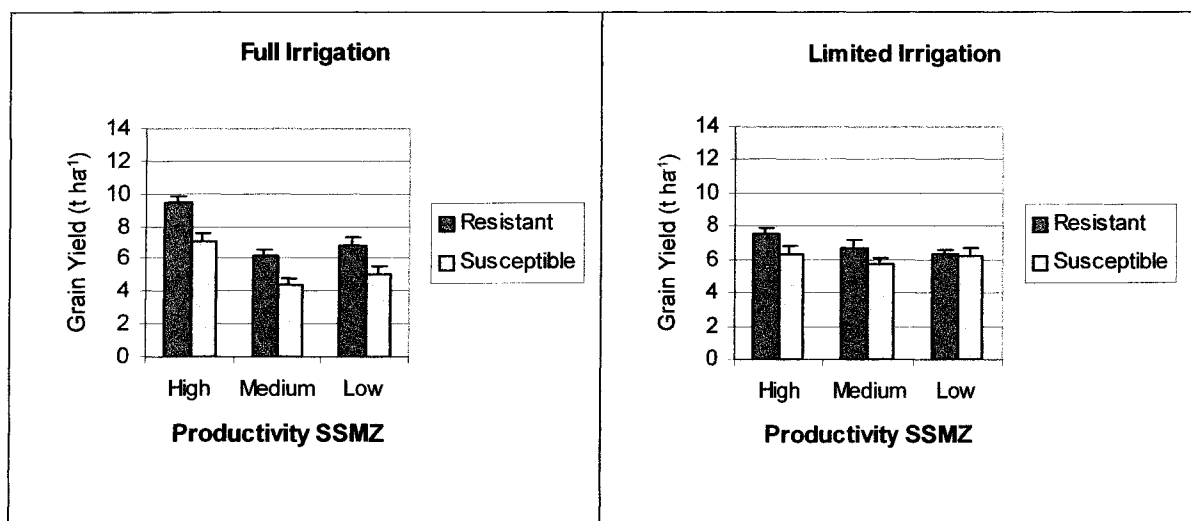


Fig 2.7. Corn grain yield as affected by irrigation level, site-specific management zone (SSMZ), western corn rootworm (WCR) treatment at ARDEC, Fort Collins, CO in 2004. Means are reported in ton ha^{-1} . Error bars represent standard error of means (SEM).

Western corn rootworm damage was measured as the difference in grain yield between resistant plots and susceptible plots at each study site. There was greater damage in the full irrigation area compared to the limited irrigation area. In the full irrigation area grain yields were reduced 2.4 ton ha^{-1} (26%), 1.8 ton ha^{-1} (29%), and 1.8 ton ha^{-1} (26%) in the high, medium, and low SSMZ respectively. In the limited irrigation area grain yields were reduced 1.3 ton ha^{-1} (16%), 1.0 ton ha^{-1} (15%), and 0.2 ton ha^{-1} (2%) in the high, medium, and low SSMZ respectively. These results indicate that more corn rootworm damage occurred in the fully irrigated areas and also in higher productivity SSMZ. Since larval sampling in late June indicated that the number of larvae per plant was not significantly different between the two water levels or SSMZ (Fig. 2.6), it seems likely that the observed differences in damage was due to plant response to rootworm injury rather than the number of larvae feeding on roots.

Discussion

The study examined whether western corn rootworm damage differed among SSMZ, water levels, and nitrogen levels. A difference in damage was observed among water levels and SSMZ in 2004. Damage was significantly higher in the full irrigation area and in the high productivity SSMZ. No differences in yield were observed in 2002 and 2003. The reason why damage did not differ in 2002 and 2003 was likely due to irregularities in irrigation and the method used to create control plots. In 2002 and 2003 an insecticide was applied to limit corn rootworms in control plots. In 2004, control plots were created with the use of a genetically engineered resistant hybrid. The resistant hybrid appeared much more effective at limiting the number of rootworms per plant than conventional soil insecticide (compare Fig. 2.4 and Fig. 2.6). It is possible that the insecticide applied to limit rootworm injury was not effective or there was an insufficient density of rootworms in untreated plots.

There were also differences in the ratio of larvae per plant in untreated and treated plots, depending on whether insecticides or resistant hybrids were used. The difference between untreated and treated plots was small when insecticides were used (Fig. 2.4). The difference was much greater when a resistant hybrid was used (Fig. 2.6). This indicates that the resistant hybrids were better at limiting the number of western corn rootworm larvae feeding on roots at the time of larval sampling.

There was not a strong correlation between the number of rootworm larvae per plant and SSMZ any year of this study. In a previous study larval sampling indicated that rootworm densities differed among SSMZ, with more larvae being recovered from plants in high productivity SSMZ (Davidson 2003). In this study relatively few sites were

sampled within each SSMZ, which may have led to non-significant differences among SSMZ.

However, differences in rootworm damage were observed in this study. In 2004, rootworm damage was greater in areas of the field that received full irrigation compared to areas that received limited irrigation. The amount of rootworm damage also varied across SSMZ in both the full and limited irrigation areas in 2004. The fact that damage varied across SSMZ is of interest and could be useful in implementing site-specific management.

Conclusions

A major obstacle in the implementation of site-specific management for insect pests is the difficulty and high costs involved in determining where pests should be treated (Fleischer et al. 1999, Krell et al. 2003). A possible solution would be to correlate insect pests to field attributes that are stable throughout time. Park and Tollefson (2005) suggest that correlating western corn rootworm distributions with field attributes might be a suitable way to lower the costs involved in treating rootworms in a site-specific manner.

This study was conducted to determine if SSMZ are suitable units for managing western corn rootworm in a site-specific manner. Site-specific management zones used in this study were based on expected yield potential and are stable throughout time. Two ways that SSMZ could contribute to site-specific western corn rootworm management is if rootworm spatial distributions are correlated with SSMZ or if damage cause by rootworms correlates with SSMZ. This study did not find a strong correlation between

larval corn rootworm densities and SSMZ. However, in 2004 differences in damage were observed among water levels and SSMZ.

Additional research is needed to demonstrate if corn rootworm densities differ among SSMZ. More studies are also needed to confirm that rootworm damage does differ among productivity level SSMZ. Knowledge of these two factors should allow rootworms to be managed at the SSMZ level.

Western corn rootworm management is usually conducted in a preventative manner; either with the use of soil insecticides or by the planting of genetically engineered resistant hybrids (Sutter 1999, Peairs and Pilcher 2002, EPA 2004). Since SSMZ remain constant throughout time and rootworm damage was observed to differ among SSMZ, they could be used to make preventative decisions about where rootworm damage will be most severe. Site-specific management zones could be used to target the application of insecticides or plant resistant hybrids. The ability to prescription plant resistant hybrids is currently in development (Shanahan et al. 2004). Also if the distribution of western corn rootworm larvae is correlated with SSMZ, it would give further incentive to use SSMZ as management units for other management inputs.

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Chapter 3.

Western Bean Cutworm Damage Across Site-Specific Management Zones

Introduction

The western bean cutworm, *Richia albicosta* (Smith), is recognized as a pest of corn and dry edible beans, *Phaseolus vulgaris* L. (Keaster 1999). It has been recorded in Arizona, Idaho, Colorado, Utah, New Mexico, Texas, Wyoming, Oklahoma, Kansas, Nebraska, Iowa, South Dakota, and Minnesota (O'Rourke and Hutchison 2000). It is recognized as a serious pest of dryland and irrigated field corn in northeastern Colorado (Peairs 2002). Damage in corn is due to larvae feeding within ears. The loss of kernels, misshapen ears, and entry of fungal pathogens contribute to reductions in corn yields (Keaster 1999). Severe infestations can reduce grain yield by 30 to 40 percent (Peairs 2002).

Damage from western bean cutworm is not consistent throughout time and space. Cutworm numbers vary from year to year and there is a tendency for greater abundance every six to eight years. Moth emergence tends to be greater in sandy soils and may increase due to rainfall or irrigation (Seymour et al. 1998). In most years certain fields are much more heavily damaged than others. Because adults are active for a short time, variation in corn attractiveness can significantly influence egg deposition and thus damage. Holtzer (1983) observed that plants just beginning to tassel receive more egg masses than plants at earlier or later growth stages. Walter (2001) captured more adult western bean cutworms in pheromone traps placed around the margins of corn fields than in the centers.

There could be many advantages for making site-specific management decisions for western bean cutworm instead of uniform decisions throughout a field. The benefits of site-specific management have been shown with other insect pests of field crops. These benefits include reduced insecticide loads (Weisz et al. 1996), increased preservation of natural enemies (Fleischer et al. 1997, Midgarden et al. 1997), and reduced rates of insecticide resistance (Midgarden et al. 1997). The ability to apply site-specific management depends on being able to determine where insects should be treated within a field. Difficulties in describing the distribution of pests within fields have hindered the adoption of this approach (Fleischer et al. 1999). Also, the costs and time required to sample spatial distributions using grid sampling can make this method unpractical (Krell et al. 2003).

A possible alternative that allows the distribution of insect pests to be described in a more economical and practical manner is the use of management zones. Management zones are homogeneous subregions within fields that describe similar yield limiting characteristics, and can therefore be managed in a similar manner (Mulla 1993, Doerge 1999). Management zones are suitable for making decisions on whether to apply variable rates of agricultural inputs (Doerge 1999). Input decisions have been made at the management zone level for water and fertilizers (Fleming et al. 1999, Khosla et al. 2002, Chang et al. 2004), but there have been relatively few attempts to define management zones based on the distribution of insect pests. Management zones have been created for the citrus root weevil, *Diaprepes abbreviatus* L., (Li et al. 2004) and the western corn rootworm (Park and Tollefson 2005). These two studies used field sampling of adult insects and then spatial statistics to map predicted pest distributions.

A possible way to use management zones for insect control would be to relate pest activity with field characteristics. There are potential advantages for this method. One advantage would be if field characteristics related to productivity (soil texture, fertility, moisture level, etc.) are related to the distribution of western bean cutworm. If so, sampling costs might be lower than the costs of developing pest management zones that require extensive sampling throughout a growing season. In addition, the same SSMZ could be used for other production inputs such as water and nutrients.

A second advantage is that management zones based on field characteristics might correlate more accurately with areas within a field that are susceptible to western bean cutworm damage. There is currently little information about how various environmental factors affect plants response to western bean cutworm damage. General reviews report that corn plants can be either more susceptible or less susceptible to insect herbivores when they are stressed (Dale 1988, Holtzer et al. 1988, Culy 2001).

In this study western bean cutworm activity was studied as it relates to site-specific management zones (SSMZ) delineated according to yield potential. These SSMZ are based on field characteristics related to yield and not necessarily insect distributions. They have been shown to adequately describe differences in soil organic matter (SOM), NO₃-N, K, Zn, conductivity data, and corn grain yield. Researchers have determined that management zones delineated in this manner would be adequate to make variable rate applications of nitrogen fertilizer (Fleming et al. 1999, Khosla et al. 2002, Hornung et al. 2003). Even though there is variability within management zones, SSMZ were found to be less spatially variable than the whole field (Inman et al. 2005).

This study was conducted to determine if western bean cutworm damage differed among SSMZ. The influence of water level on western bean cutworm damage was also studied. The objective was to determine if SSMZ are suitable units for determining where varying levels of western bean cutworm damage might occur.

Methods and Materials

Study Location

This research was conducted in 2004 at Colorado State University's (CSU) Agricultural Research, Development, and Education Center (ARDEC) near Fort Collins, Colorado. A furrow irrigated 13 ha corn field was used in the study. The field had been in continuous corn since 2002.

The field was delineated into site-specific management zones (SSMZ) based on a technique developed at Colorado State University (Fleming et al. 1999, Khosla et al. 2002). This technique uses three data layers to delineate SSMZ; bare soil imagery, field topography, and farmer's previous management experience. These three data layers were then incorporated into a Geographic Information Database (GIS) and mathematical interpolation surfaces were run to create SSMZ. Three SSMZ were created at this field that represented areas of high, medium, and low productivity potential. The high SSMZ was characterized by dark soil color, low topography, and historically high yields. Low SSMZ was characterized by light soil color, high topography, and historically low yields. The SSMZ were delineated at this field in March of 2002 (Kim Fleming, Department of Soil and Crop Sciences, Colorado State University, personal communication).

Crop Management and Experimental Design

The field was planted with Garst 8802 corn hybrid on 5 May 2004. It was separated into strips consisting of two water levels, full irrigation and limited irrigation (Fig. 3.1). Forty consecutive rows were selected for each level. The full irrigation set of rows was watered once every two weeks until grain fill had occurred. The limited irrigation set of rows was managed to simulate dryland corn conditions in Colorado (Bauder and Waskom 2003). This set of rows was watered after planting to germinate the seeds, and then once again in early July to simulate a mid-summer rain. Irrigated areas were planted at 80,000 seeds ha^{-1} and limited irrigated areas were planted at 50,000 seeds ha^{-1} . These two levels were unreplicated because of the size of the experiment. Without true replication, it was difficult to determine if differences between the two strips were due to treatment effects or merely to chance alone.

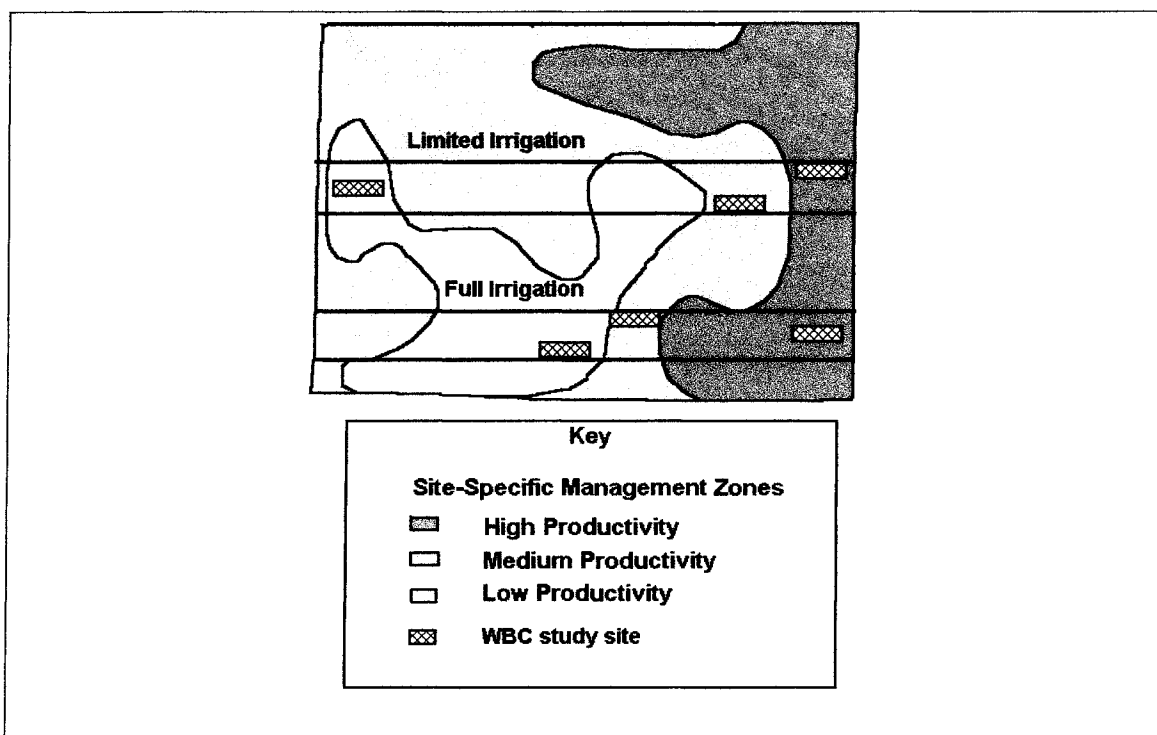


Fig 3.1. Experimental layout of the field at ARDEC, Fort Collins, CO in 2004 showing site-specific management zones (SSMZ) and western bean cutworm (WBC) study sites.

Artificial Infestation

Western bean cutworm plots were artificially infested by purchasing field-collected egg masses from Appel Crop Consulting Inc., Grant, Nebraska, and attaching them to plants. Masses were attached by stapling leaf sections containing egg masses (enclosed within plastic insect screening) to leaves near the ear region. One egg mass was attached to every other plant in the center row of each plot. Western bean cutworm egg masses usually range from 30 to 100 eggs (Seymour et al. 1998) and no effort was made to count the number of individual eggs in each plot. Western bean cutworm larvae are highly mobile (Seymour et al. 1998), and it is expected that larvae from a single egg mass would colonize several adjacent plants. Plastic insect screening served to anchor the egg masses to the leaves. The larvae could then escape through the screening and feed on plants. Egg masses were attached on 22 July 2004 when the corn was at the V13 growth stage (Ritchie et al. 1996).

Control plots were left untreated. Western bean cutworms are not expected to be present at this location in Colorado and none were observed in control plots throughout the study.

Data Collection

Western bean cutworm survival was recorded as the number of fifth instar larvae feeding at the end of the season. On 9 September 2004, the husks were pulled back on all corn ears in infested plots and the number of larvae was recorded (approximately 16 plants per plot).

Grain yield was measured for each plot by hand harvesting all corn ears from 3 m (10 ft) in the center row of each plot in October. The harvested ears were placed into

paper bags and dried at ARDEC facilities in Fort Collins, CO. They were then shelled and total grain weight, test weight, and moisture content were recorded. Grain moisture content was adjusted to 15.5%. Western bean cutworm damage was classified as the difference in grain yields between WBC plots and control plots.

Statistical Analysis

The data were analyzed with PROC MIXED (SAS Institute 2001). The number of western bean cutworm larvae found feeding within ears was transformed by the square root transformation, $y = \sqrt{y+1/2}$, to stabilize variance (Steel and Torrie 1980). Yield data comparisons were made with untransformed data, because variance between grain yields did not change as means increased. LSMEANS method of comparison was used to compare means.

Data were analyzed by a traditional analysis of variance approach, which assumes replication and randomization (Hong et al. 2005). However, the factors of SSMZ and water level were not properly replicated. Replication is the independent repetition of experimental units. It serves to provide an estimate of experimental error that is used to formally test statistical hypotheses and to ensure that treatment effects are real and not due to chance alone (Gotway Crawford et al. 1997). The lack of replication limited the ability to determine if differences in comparison were due to treatment effects, other factors, or merely to chance alone.

The lack of randomization is common in precision agriculture research. The manner in which treatments are applied to plots in precision agriculture research (where plots are large and treatments are not randomly assigned) differs from traditional small-plot experiments (where plots are small and treatments may be applied randomly) (Hong

et al. 2005). This leads to more spatial variability within and among plots than is typical in small-plot experiments. However, analysis of variance is still commonly used in precision agriculture studies, while noting that efficiency of treatment comparisons is reduced (Hong et al. 2005). Fleming et al. (2003) and Inman et al. (2005) provide examples of studies where analysis of variance has been used to compare means across SSMZ. Chilcutt et al. (2005) conducted a study similar to this one, in which insect pests were compared across two unreplicated water levels.

Results

The number of western bean cutworm larvae per plant did not differ among the two-way interaction of water level and SSMZ ($df\ 2,12$; $F\ 1.26$; $p > F = 0.381$) (Fig. 3.2). Although more larvae survived in the high productivity SSMZ, this relationship was not significant due to wide variability within plots. Overall survival of western bean.

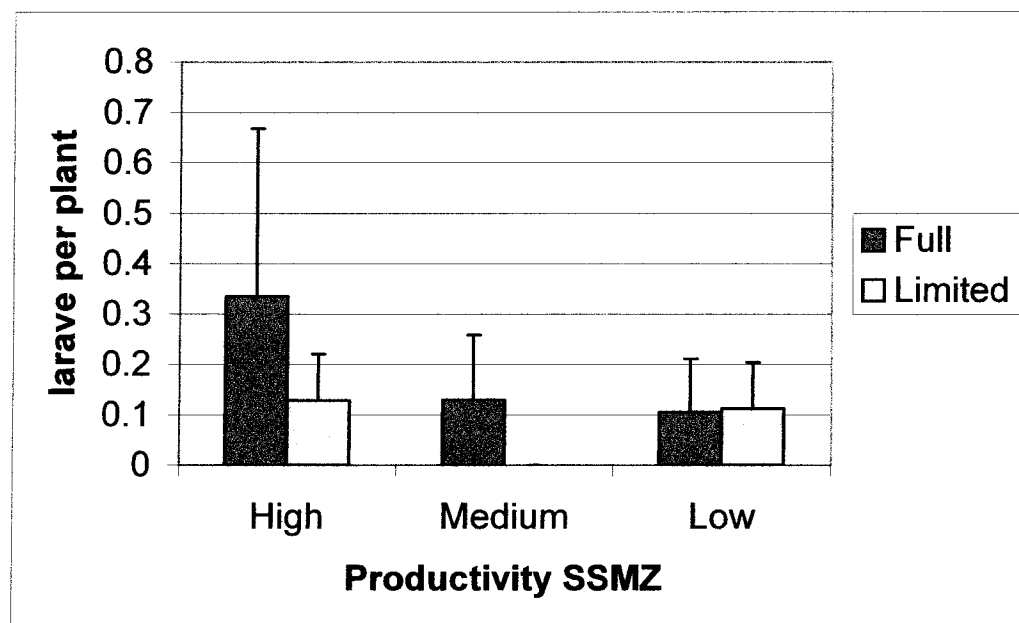


Fig 3.2. Average number of western bean cutworm larvae found per plant at ARDEC, Fort Collins, CO in 2004. Means are separated by irrigation level and site-specific management zone (SSMZ). Water levels represented by: FULL = full irrigation, LIMIT = limited irrigation. Error bars represent standard error of means (SEM).

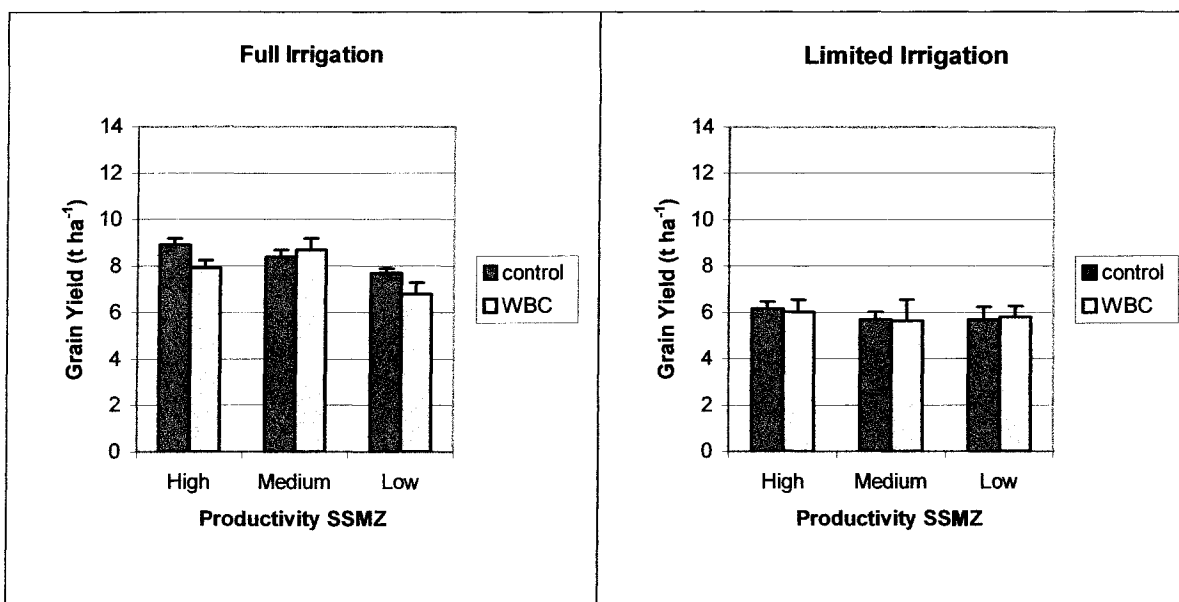


Fig 3.3. Grain yields from plots at ARDEC, Fort Collins, CO in 2004. Means are separated by site-specific management zone (SSMZ) and water level. Error bars represent standard error of means (SEM). (WBC = western bean cutworm).

cutworm was very low. The greatest survival in any SSMZ was only 0.3 larvae per plant.

The medium SSMZ in the limited irrigation strip had no larvae that survived

No differences in yield were observed among the three-way interaction between water levels, SSMZ, and insect treatments (df 2,30; F 1.8; $p > F = 0.283$) (Fig. 3.3). The only significant factor involved water levels, with grain yields being higher in the full irrigation area (df 1,30; F 41.8; $p > F = 0.0001$). There were no difference in yield between plots infested with western bean cutworm egg masses and control plots.

Discussion

The objectives of this study were to determine if western bean cutworm survival and damage differed among SSMZ. Larval survival in this study was very low. The

reason that larval survival was low is most likely due to the timing when plots were infested. Plots were infested when corn plants were at the V13 growth stage because that is when the available egg masses were ready to hatch. Western bean cutworm larvae typically feed on the tassel after emerging (Seymour et al. 1998). In this study tassels were not available to feed on until two weeks after larvae had emerged. This lack of preferred food source likely led to high mortality of young larvae.

Differences in grain yield between western bean cutworm treatments and untreated control was not observed. The reason that no differences in yield were observed can be explained by the low level of larval survival. The levels of western bean cutworm larvae that survived were most likely so low that yield reductions were undetectable.

Conclusions

No differences were observed in western bean cutworm survival or damage among water levels and SSMZ. The reason significant differences were not observed was due to larvae hatching before tassels were available to feed on. This problem can be corrected in future studies by infesting larvae immediately before tassels emerge.

There would be several potential benefits for correlating western bean cutworm activity with SSMZ. One benefit would be to develop separate economic injury levels (EILs) for SSMZ within a field. SSMZ are feasible units for developing separate EILs within a field because SSMZ differ in yield potential. One of the factors used to calculate EILs is expected yield (Mason et al. 1996), and therefore management zones based on yield potential would provide more accurate EILs. Site-specific management zones also might correlate with the areas within a field that experience different levels of damage.

Western bean cutworms cause direct damage by feeding on corn ears (Keaster 1999). The loss factors calculated for western bean cutworm egg masses and first instar larvae, are based on expected survival rates. Differential survival across SSMZ would lead to differing damage across SSMZ. Although differential survival was not observed in this study, it was observed in a previous study (Davidson 2003). Separate EILs would allow management decisions to be made at the SSMZ level instead of making uniform decisions for the whole field.

Before EILs can be developed for separate SSMZ, loss factors must be determined for individual SSMZ. This study was unable to indicate whether loss factors will differ among SSMZ. Loss factors need to be developed that give a quantifiable estimate of how damage will change among productivity level SSMZ. Determining loss factors is the most critical step in establishing accurate EILs (Peterson and Higley 2001).

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Chapter 4.

Banks Grass Mite Damage Across Site-Specific Management Zones

Introduction

The Banks grass mite, *Oligonychus pratensis* (Banks), is a major pest of irrigated corn grown on the semi-arid high plains of the United States. It is native to western and southern North America and feeds on more than 80 grass hosts (Peairs and Archer 1999). In Colorado it is a pest throughout the state, but is most common in drier corn producing areas (Peairs 2003). Their feeding leads to a reduction in corn yields due to poor seed fill, and they have been associated with accelerated plant dry down in the fall (Wright et al 1993). Schweissing (1973) observed grain losses ranging from 6 to 48 percent, with an eighteen-year average of 21 percent in Colorado.

The spatial distribution of Banks grass mite has not been extensively studied. Banks grass mites overwinter as mated adult females on grass hosts (Logan et al. 1983), and enter corn fields by either walking short distances or being wind blown on silken threads. Because of this, mite infestations usually begin along the edges of fields. Banks grass mite occurs on corn from the mid-whorl to the grain-filling growth stages (Peairs and Archer 1999).

There could be many advantages for making site-specific management decisions for Banks grass mite instead of uniform decisions throughout a field. The benefits of site-specific management have been shown with other arthropod pests of field crops. These benefits include reduced insecticide loads (Weisz et al. 1996), increased preservation of natural enemies (Fleischer et al. 1997, Midgarden et al. 1997), and reduced rates of insecticide resistance (Midgarden et al. 1997). The ability to apply site-

specific management depends on being able to determine where pests should be treated within a field. Difficulties in describing the distribution of pests within fields have hindered the adoption of this approach (Fleischer et al. 1999). Also, the costs and time required to sample spatial distributions using grid sampling can make this method unpractical (Krell et al. 2003).

A possible alternative that allows the distribution of insect pests to be described in a more economical and practical manner is the use of management zones. Management zones are homogeneous subregions within fields that describe similar yield limiting characteristics, and can therefore be managed in a similar manner (Mulla 1993, Doerge 1999). Management zones are suitable for making decisions on whether to apply variable rates of agricultural inputs (Doerge 1999). Input decisions have been made at the management zone level for water and fertilizers (Fleming et al. 1999, Khosla et al. 2002, Chang et al. 2004), but there have been relatively few attempts to define management zones based on the distribution of arthropod pests. Management zones have been created for the citrus root weevil, *Diaprepes abbreviatus* L., (Li et al. 2004) and the western corn rootworm (Park and Tollefson 2005). These two studies used field sampling of adult insects and then spatial statistics to map predicted pest distributions.

A possible alternative way to use management zones for insect control would be to relate pest activity with field characteristics. There are potential advantages for this method. One advantage would be if field characteristics (soil texture, fertility, moisture level, etc.) are related to the distribution of Banks grass mite. If so, sampling costs might be lower than the costs of developing pest management zones that require extensive

sampling throughout a growing season. In addition, the same SSMZ could be used for other production inputs such as water and nutrients.

A second advantage is that management zones based on field characteristics might correlate more accurately with areas within a field that are susceptible to Banks grass mite damage. There are several factors that are known to influence Banks grass mite damage and outbreaks. Feese and Wilde (1977) showed that high temperatures and drought stress favored Banks grass mite buildups. Wright et al. (1993) have suggested that sandy soils contribute to mite outbreaks, because crops grown on these soils are more likely to experience drought stress even when irrigated. Archer et al. (1990) found in sorghum that nitrogen fertilization promotes mite infestations and that excessive fertilizing can lead to severe outbreaks.

In this study Banks grass mite activity was studied as it relates to site-specific management zones (SSMZ) delineated according to yield potential. These SSMZ are based on field characteristics and not pest distributions. They have been shown to adequately describe differences in soil organic matter (SOM), $\text{NO}_3\text{-N}$, K, Zn, conductivity data, and corn grain yield. Researchers have determined that management zones delineated in this manner would be adequate to make variable rate applications of nitrogen fertilizer (Fleming et al. 1999, Khosla et al. 2002, Hornung et al. 2003). Even though there is variability within management zones, SSMZ were found to be less spatially variable than the whole field (Inman et al. 2005).

This study was conducted to determine if Banks grass mite damage differed among SSMZ. The influence of water and nitrogen levels on mite damage was also

studied. The objective was to determine if SSMZ are suitable units for determining where varying levels of Banks grass mite damage might occur.

Materials and Methods

Study Location

This research was conducted in 2003 at Colorado State University's (CSU) Agricultural Research, Development, and Education Center (ARDEC) near Fort Collins, Colorado. A furrow irrigated 13 ha corn field was used in the study. The field has been in continuous corn since 2002.

The field was delineated into site-specific management zones (SSMZ) based on a technique developed at CSU. This technique uses three data layers to delineate SSMZ; bare soil imagery, field topography, and farmer's previous management experience (Fleming et al. 1999, Khosla et al. 2002). These three data layers were then incorporated into a Geographic Information Database (GIS) and mathematical interpolation surfaces were run to create SSMZ. Three SSMZ were created at this field that represented areas of high, medium, and low productivity potential. The high SSMZ was characterized by dark soil color, low topography, and historically high yields. Low SSMZ was characterized by light soil color, higher topography, and historically lower yields. The SSMZ were delineated in March of 2002 (Kim Fleming, Department of Soil and Crop Sciences, Colorado State University, personal communication).

Experimental Design

The field was planted with Garst 8802 corn hybrid on 6 May 2003. The field was separated into strips consisting of two water levels, full irrigation and limited irrigation (Fig. 4.1). Forty consecutive rows were selected for each level. The full irrigation set of

rows was watered once every two weeks until grain fill had occurred. The limited irrigation set of rows was managed to simulate dryland corn conditions in Colorado (Bauder and Waskom 2003). This set of rows was watered after planting to germinate the seeds, and then once again in early July to simulate a mid-summer rain. Irrigated areas were planted at 80,000 seeds ha^{-1} and limited irrigated areas were planted at 50,000 seeds ha^{-1} . These two levels were unreplicated because of the size of the experiment. Without true replication, it was difficult to determine if differences between the two strips were due to treatment effects or merely to chance alone.

Within the two water levels, SSMZ blocks were created. The SSMZ blocks had a length of 50 m and were 40 rows wide. There were three productivity level SSMZ blocks

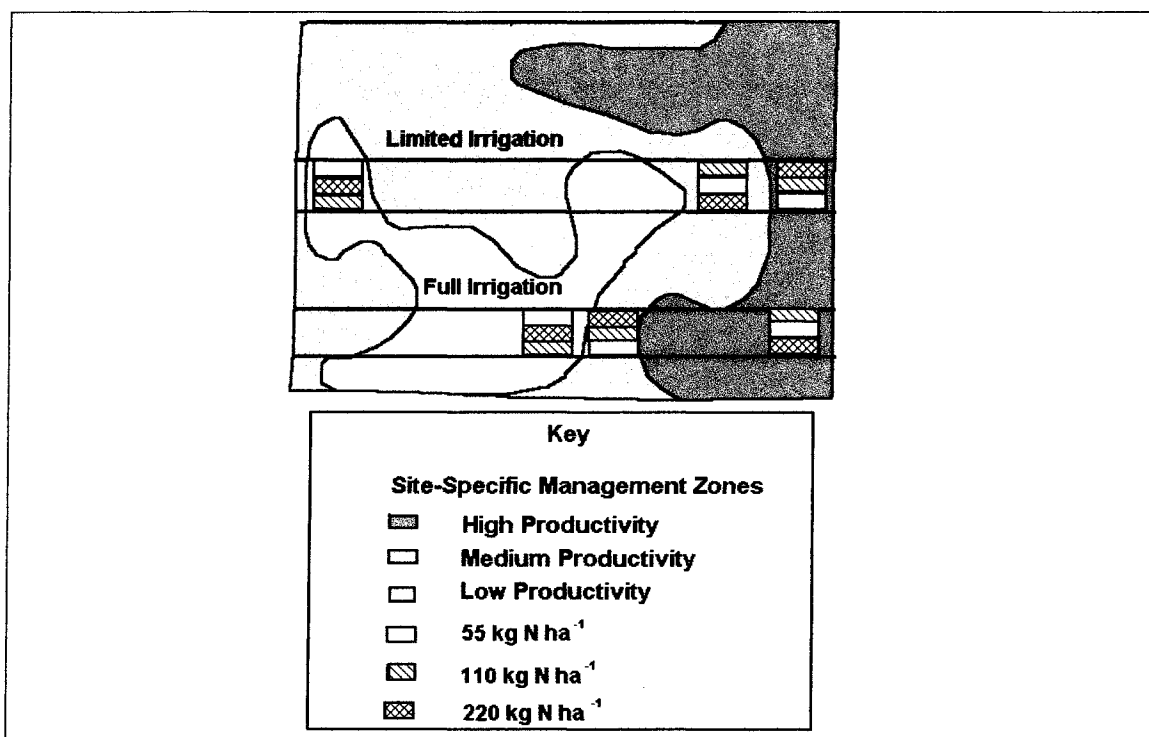


Fig. 4.1. Experimental layout of the field at ARDEC, Fort Collins, CO in 2003 showing site-specific management zones (SSMZ) and nitrogen levels.

within each water level: high productivity SSMZ, medium productivity SSMZ, and low productivity SSMZ. Management zone blocks were unreplicated due to the size of the study, limiting the inferences that could be drawn for differences in SSMZ.

Within each of the SSMZ blocks, a split-plot design was created. The whole plot factors in this design consisted of three nitrogen application rates; 55 kg N ha⁻¹, 110 kg N ha⁻¹, and 220 kg N ha⁻¹. In the full irrigation strip, 110 kg N ha⁻¹ was near the recommended rate of nitrogen, and 55 kg N ha⁻¹ was near the recommended rate of nitrogen in the limited irrigation strip (Mortvedt et al. 2002). Groups of 12 rows within each management zone block received the three N rates. Nitrogen was applied by side-dressing UAN 32% onto rows at time of cultivation.

Banks grass mite plots were established within the nitrogen application whole plots. Plots were three rows wide by four meters long, with a one meter buffer between plots. Two plots were created: Banks grass mite (BGM) and untreated controls. Each plot was randomly replicated six times within the three nitrogen treatments. ANOVA tables listing the factors compared are presented (Table 4.1 and Table 4.2).

Banks Grass Mite Infestation

Banks grass mites were artificially infested using the methods of Archer and Bynum (1990). Mite infested leaves were collected from locally infested fields and placed onto the middle row of each plot. One mite infested leaf was placed onto the lower third of each plant on 9 July 2003. Infestations occurred shortly before corn tasseling, so that mite activity would peak during the period between corn tasseling and grain fill. This stage of corn growth is the most susceptible to mite injury (Peairs and Archer 1999).

Data Collection

Mite densities were sampled from each BGM plot. Sampling consisted of selecting three plants per plot and then removing all leaves containing mites from each plant. The leaves were placed in 38 cm Berlese funnels equipped with 80 watt light bulbs. The leaves remained on the funnels for 24 hours. Mites were collected from the Berlese funnels in jars containing 90% alcohol for subsequent counting. Sampling was twice; on 22-24 August and 29-31 August. The timing of sampling occurred during grain fill when corn is most susceptible to Banks grass mite damage (Peairs and Archer 1999). The average number of mites per plant was combined for the two sampling dates for statistical analysis.

Grain yield was measured for each plot by hand harvesting all corn ears from 3 m (10 ft) in the center row of each plot. The harvested ears were placed into paper bags and dried at ARDEC facilities in Fort Collins, CO. They were then shelled and total grain weight, test weight, and moisture content were recorded. Grain moisture content was adjusted to 15.5%.

Statistical Analysis

The data were analyzed with PROC MIXED (SAS Institute 2001). The number of Banks grass mites per plant was transformed by the square root transformation, $y = \sqrt{y}$, to stabilize variance (Steel and Torrie 1980). Yield data comparisons were made with untransformed data. LSMEANS method of comparison was used to compare means.

Data were analyzed by a traditional analysis of variance approach, which assumes replication and randomization (Hong et al. 2005). However, the factors of SSMZ and water level were not properly replicated. Replication is the independent repetition of

experimental units. It serves to provide an estimate of experimental error that is used to formally test statistical hypotheses and to ensure that treatment effects are real and not due to chance alone (Gotway Crawford et al. 1997). The lack of replication limited the ability to determine if differences in comparison were due to treatment effects, other factors, or merely to chance alone.

The lack of randomization is common in precision agriculture research. The manner in which treatments are applied to plots in precision agriculture research (where plots are large and treatments are not randomly assigned) differs from traditional small-plot experiments (where plots are small and treatments may be applied randomly) (Hong et al. 2005). This leads to more spatial variability within and among plots than is typical in small-plot experiments. However, analysis of variance is still commonly used in precision agriculture studies, while noting that efficiency of treatment comparisons is reduced (Hong et al. 2005). Fleming et al. (2003) and Inman et al. (2005) provide examples of studies where analysis of variance has been used to compare means across SSMZ. Chilcutt et al. (2005) conducted a study similar to this one, in which insect pests were compared across two unreplicated water levels.

Results

There was a significant three-way interaction between water level, SSMZ, and nitrogen level on the average number of Banks grass mites per plant (df 4,90; $F_{9.8}$; $p > F = 0.0001$) (Fig. 4.2). Even though there were many significant differences when mite densities were compared, the only likely factor affecting mite density was water level (df 1,90; F_{23} ; $p > F = 0.0001$). There are no clear patterns in SSMZ or water levels that

indicate that these variables influenced mite densities. Mite densities within the same SSMZ or across the same nitrogen level did not appear to be related.

Grain yield had two significant two-way interactions between water level and mite treatment (df 1,87; F 29.5; $p > F = 0.0001$), and water level and SSMZ (df 2,90; F 20.1; $p > F = 0.0001$) (Fig. 4.3). Nitrogen level was not significant and was averaged over for comparisons. In the full irrigation area grain yields were reduced 0.7 ton ha⁻¹ (-9.7%), 1.8 ton ha⁻¹ (-22%), and 1.87 ton ha⁻¹ (-22%) in the high, medium, and low SSMZ respectively. In the limited irrigation area grain yields in the BGM plots were greater by 0.1 ton ha⁻¹ (+5%), greater by 0.2 ton ha⁻¹ (+4%), and reduced by 0.6 ton ha⁻¹ (-9%) in the

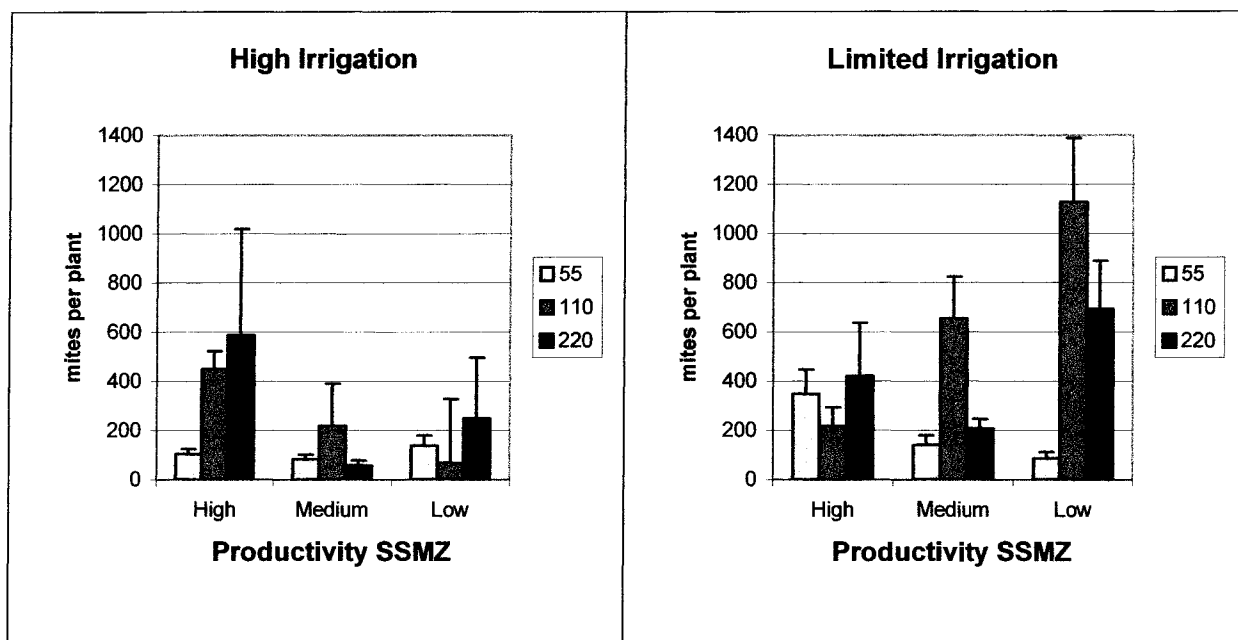


Fig. 4.2. Average number of Banks grass mites per plant at ARDEC, Fort Collins, CO in 2003. Means are separated by water level, site-specific management zone (SSMZ), and nitrogen level. Nitrogen levels are; 55 = 55 kg N ha⁻¹, 110=110 kg N ha⁻¹, and 220 = 220 kg N ha⁻¹. Error bars represent standard error of means (SEM).

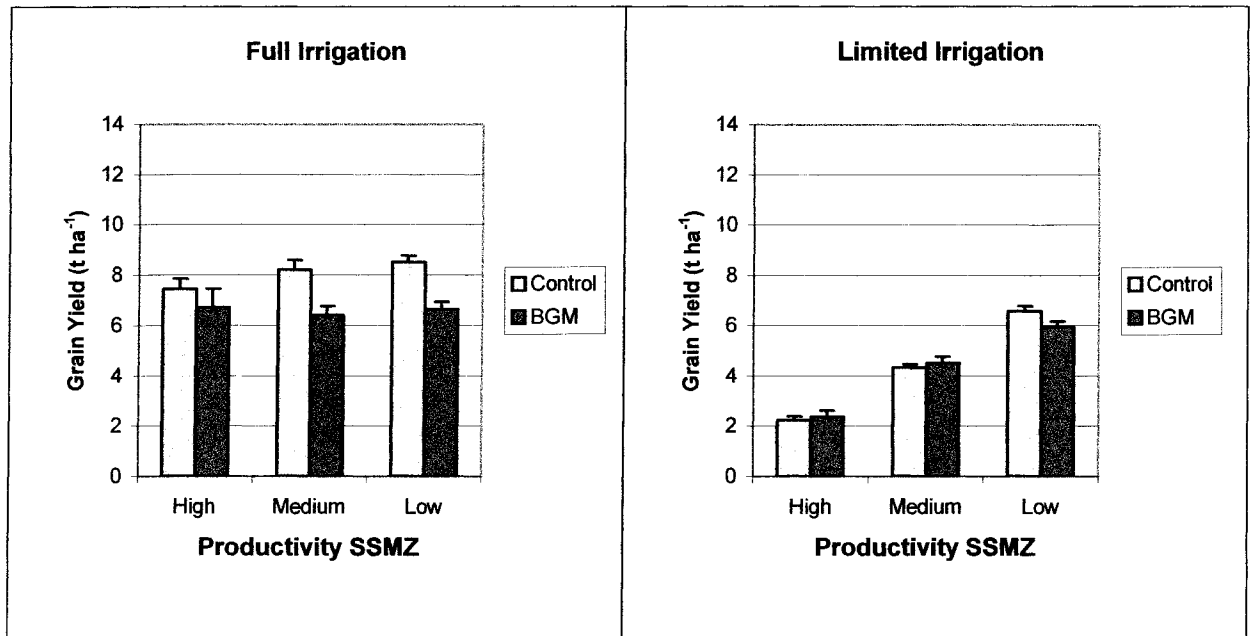


Fig. 4.3. Grain yield at ARDEC, Fort Collins, CO in 2003 separated by water level and site-specific management zone. Means are presented as ton ha^{-1} . (BGM = Banks grass mite treatments). Error bars represent standard error of means (SEM). high, medium, and low SSMZ respectively.

Discussion

The objective of this study was determine if Banks grass mite damage differed across SSMZ. The results of sampling artificially infested plots failed to show any differences in the subsequent densities of mites among SSMZ. Inferences about mite densities were difficult to interpret from the results. There were however more mites in the limited irrigated area than the fully irrigated area. The wide variance in mite densities is most likely due to the tendency of Banks grass populations to rapidly increase or decrease (Peairs and Archer 1999). It is also possible that mite densities in some plots had rapidly declined by the time sampling occurred.

Differences in Banks grass mite damage were observed. Yield losses caused by mites were greater in areas that had higher grain yields. The full irrigation strip had the highest grain yields, and also had greater yield reductions in Banks grass mite plots. In

the limited irrigation strip, the low productivity SSMZ had the highest yield and was the only SSMZ to have reduced yields. These results indicate that the full irrigation area suffered greater Banks grass mite damage than the limited irrigation area. The only SSMZ in the limited irrigation strip that had reduced grain yields in BGM plots was the low productivity SSMZ. In 2003, irrigation was not applied uniformly across the field. The west side of the field received more water than the east side. Because the low productivity SSMZ was located on the west side of the field (Fig. 4.1), it received more water than the other SSMZ. Yields were reversed from what was expected in the dryland area with the low productivity SSMZ having the highest yield and the high productivity SSMZ having the lowest yield (Fig. 4.3). In the irrigated area yield was similar among the three SSMZ.

Conclusions

In this study Banks grass mite densities were not consistent within any treatment, however damage was greater in fully irrigated areas. These results could prove useful in management programs for Banks grass mite. Banks grass mite infestations often begin in near the edges of fields where plants are water stressed (Wright et al. 1993, Peairs and Archer 1999). These areas have natural low yield potentials since they are consistently water stressed. The results in this study indicate that areas that have low yield potential will suffer less yield loss from Banks grass mite than more productive areas within a field. Management plans could be developed that tolerate mites in low yielding areas as long as mites do not move into high productivity areas of a field where yield losses would be expected to be much greater.

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General Discussion

This study compared arthropod damage and survival across four experimental units; water level, SSMZ, nitrogen level, and insect treatment. Of these four units, water level was the most significant. Pest survival was consistently greater in the fully irrigated strip for all pests, with the exception of Banks grass mite, where mite densities were greater in the limited irrigation strip. Damage caused by western corn rootworm and Banks grass mite were both greater in the fully irrigated strip than in the limited irrigation strip. Results pertaining to SSMZ showed that European corn borer larval survival differed among zones in 2002. Nitrogen level was not significant in any part of this study.

The experimental designs in the study limited the ways in which the data could be statistically analyzed. There were difficulties when evaluating the data pertaining to water levels and SSMZs because these two units were not properly replicated. Replication is the independent repetition of experimental units. It serves to provide an estimate of experimental error that is used to formally test statistical hypotheses to ensure that treatment effects are real and not due to chance alone (Gotway Crawford et al. 1997). In 2003 and 2004, water levels (full and limited irrigation) were created by watering one strip of rows at each water level. These strips were not replicated because they did not have a chance of receiving a water level other than what they were assigned. Without true replication, an error term of one was used to compare differences between the two strips. With an error term of one it is not possible to determine if differences between the two strips were due to treatment effects or merely to chance alone.

The fact that differences in water levels could not be compared with confidence is unfortunate because many of the most significant differences in grain yield and insect survival were between water levels. It seems most likely that the differences in grain yield and insect survival were not due to chance alone, but rather caused by water level, since similar results were seen each year. However, it is impossible to use statistical analysis to support this observation.

The reason that water levels were not replicated is due to the size of this experiment. If water levels would had been replicated while maintaining the other experimental units, the size of the experiment would have been so large that it would have been difficult to infest and harvest all plots in a reasonable amount of time. In retrospect, it would have been better if another factor, such as nitrogen level, would have been dropped. This would have allowed water levels to be replicated, while keeping the experiment a manageable size.

Site-specific management zones also were not properly replicated. The reason they could not be replicated is due to the method in which SSMZ are defined. Site-specific management zones are defined as areas within fields that have high, medium, or low productivity potential based on bare soil imagery, topography, and farmer experience (Fleming et al. 1999, Khosla et al. 2002). They describe certain areas within a field and cannot be randomly or independently assigned a treatment. Therefore, each SSMZ should be viewed as a single replication. In 2002, five insect study sites were selected within each SSMZ. The insect study sites would best be described as subsamples within SSMZ, because they all occurred within a single SSMZ replication (Gotway Crawford et al. 1997). When analyzed the insect study sites were treated as independent replications.

This was done so that SSMZ could be compared with one another. Without assuming the insect study sites represented true replications it would have been impossible to compare SSMZ.

An interesting result of this study was that SSMZ did not always differ in grain yield. The management zones used in this study are defined based on yield potential and in theory grain yield should match yield potential. This was the case in 2002 as the high productivity SSMZ had the greatest average yield and the low productivity SSMZ had the lowest average yield (Fig. 1.3). However, in 2003 and 2004 grain yields did not closely correlate with the yield potential of each SSMZ. One reason this might have happened is because more study sites were sampled per SSMZ in 2002 than in 2003 or 2004. More study sites could have given a more accurate representation of what the yield was within a SSMZ.

Another explanation for the differences in grain yield might be due to irregularities in irrigation. In 2003 and 2004, the furrow irrigation used to water the field did not appear to be applied evenly across the field (personal observation). The site-specific management zones used in this study were developed on fields irrigated by center-pivot irrigation (Fleming et al. 1999). It is likely that SSMZ will be less accurate in describing within-field variability when water is applied unevenly.

A third explanation could be that SSMZ more accurately describe the yield potential of some corn hybrids than other hybrids. In 2002, when the field was planted with Pioneer 37H26, grain yields matched expected yield potential among SSMZ (Fig 1.3). In 2003 and 2004 when the majority of the field was planted with Garst 8802, grain yields did not strongly differ among SSMZ. In 2004, it is interesting that grain yields for

Garst 8802 did not differ among SSMZ, because at the same locations Dekalb hybrids DKC46-24 and DKC46-28 were planted to measure western corn rootworm damage. These rootworm hybrids received the same amount of water as the Garst 8802 hybrid, but they differed in average grain yield among SSMZ and more closely matched yield potentials as designated by SSMZ (Fig. 2.7). It could be that SSMZ are better at describing yield potential for some hybrids than other hybrids.

General Conclusion

This study is the first to relate arthropod damage to management zones. Previous studies have delineated management zones based on insect distributions (Li et al. 2004, Park and Tollefson 2005), or related insect densities to productivity level management zones (Davidson 2003). Knowledge of where varying levels of damage will occur is important because the ultimate goal of managing insect pests is to prevent yield losses.

The results from this study showed that damage did differ within fields. Direct measures of yield loss were unable to be measured for European corn borer, although differential larval survival was observed. Differential survival of European corn borer will likely lead to different levels of damage. Western corn rootworm and Banks grass mite damage differed across water levels and SSMZ. For both pests, grain yields were reduced more in areas of high yield. No data about western bean cutworm damage was gathered due to a largely unsuccessful artificial infestation.

These results should prove useful to future studies that seek to implement site-specific management. One way in which site-specific management could be implemented would be to develop separate economic injury levels (EILs) for SSMZ. Economic injury levels define the level of pest injury that will economically justify the costs of management. In practice, management decisions are made before pest densities can exceed the break-even point of the EIL at a level known as the economic threshold (Pedigo et al. 1986). Using EILs to make decisions at the management zone level will allow the benefits of site-specific management to be realized. The site-specific management zones used in this study are suitable units for the development of EILs, because they are delineated according to yield potential. One of the factors used to

determine EILs is expected yield (Mason et al. 1996). Another factor used to determine EILs is yield loss. In this study differences in arthropod survival and damage were observed, indicating that yield losses might differ among SSMZ.

More research is needed before separate EILs can be used to practice pest management at the management zone level. The first step would be to calculate loss factors for individual insect pests among SSMZ. Loss factors are usually determined by infesting insect pests at different levels and then using a regression analysis to determine the amount of loss caused by a single insect or insect injury equivalent (Higley 2001). The ultimate goal would be understand expected loss factors at different yield potentials. These loss factors could then be used to develop separate EILs for individual SSMZ. Eventually, separate EILs would be evaluated at cooperator's farms so that the benefits and costs of sampling and treating individual SSMZs could be analyzed against whole-field management practices.

Two methods that have been proposed for managing insects in a site-specific manner are variable-rate applications of insecticides and the precision planting of resistant cultivars (Ellsbury et al. 1998, Pedigo 1999). Variable rate applicators of insecticide are currently commercially available and the technology to prescription plant seeds is currently being developed (Shanahan et al. 2004). The prescription planting of resistant hybrids is of interest to site-specific management because current guidelines require that certain percentages of fields that are planted with genetically modified hybrids be maintained as susceptible refuges (EPA 2004, Ostlie et al. 1997). Knowing which areas of a field are most susceptible to insect damage will allow producers to plant

those areas with resistant seeds. Areas of the field that will suffer less damage could then be maintained as refuges.

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Appendix

Presented are the raw data and the statistical input statements used in this study. For each comparison, SAS input statements are first presented, followed on the following page or pages by the data that was analyzed.

Yield for European Corn Borer Plots in 2003

```
data ecbyield2003;
input water $ zone $ N blk trt $ wt;
rtwt=sqrt(larvae+3/8);
lgwt=log(larvae+1);
datalines;

proc means;
var wt;
class water zone trt N;
proc mixed;
class water zone N blk trt;
model wt=water | zone | N | trt ;
random blk(water*zone*N);
lsmeans water | zone | N | trt /pdiff cl;
proc mixed;
class water zone N blk trt;
model rtwt=water | zone | N | trt ;
random blk(water*zone*N);
lsmeans water | zone | N | trt /pdiff cl;
run;
```

First Generation European Corn Borer Larval Survival in 2002

```
options nodate ls=74 ps=60;
options hpos=50 vpos=20;
data ecb2002;
input zone $ site larvae;
rtlarvae= sqrt(larvae+3/8);
datalines;

;
proc means;
var larvae;
class zone;
proc glm;
class zone;
model rtlarvae=zone site;
random site(zone);
means zone/lsd clm;
lsmeans zone/pdiff cl;
output out=out2 predicted=p2 student=s2;
proc gplot;
plot s2*p2;
symbol1 v=dot;
run;
```

Zone	Site	larvae
low	1	3
low	2	3
low	3	10
low	4	14
low	5	5
med	1	16
med	2	9
med	3	8
med	4	4
med	5	8
high	1	28
high	2	18
high	3	18
high	4	16
high	5	25

Yield for European Corn Borer Plots in 2002

```
options nodate ls=74 ps=60;
goptions hpos=50 vpos=60;
data yield2002;
input zone site plot $ wt ;
datalines;

proc means;
var wt;
class zone plot;
output out=out1 mean=;
proc gplot data=out1;
plot wt*zone=plot;
symbol1 v='A' line=1 i=join;
symbol2 v='B' line=2 i=join;
symbol3 v='C' line=3 i=join;
symbol3 v='D' line=4 i=join;
proc mixed data=yield2002;
class plot zone site;
model wt= plot zone zone*plot/ddfm=satterth;
random site(zone);
lsmeans zone/pdiff cl;
lsmeans plot/pdiff cl;
lsmeans zone*plot/pdiff cl slice=plot;

run;
```

Zone	Site	Plot	Grain wt
Low	1	ecb1	5544.703
Low	1	ecb2	3552.016
Low	1	control	5259.764
Low	2	ecb1	3715.373
Low	2	ecb2	2453.201
Low	2	control	2062.692
Low	3	ecb1	3244.823
Low	3	ecb2	3994.927
Low	3	control	4217.764
Low	4	ecb1	4370.78
Low	4	ecb2	4392.462
Low	4	control	5049.423
Low	5	ecb1	3711.494
Low	5	ecb2	5665.31
Low	5	control	4877.622
Med	1	ecb1	5400.257
Med	1	ecb2	5300.273
Med	1	control	4040.109
Med	2	ecb1	5353.333
Med	2	ecb2	5965.739
Med	2	control	4002.239
Med	3	ecb1	5635.746
Med	3	ecb2	3145.431
Med	3	control	4716.227
Med	4	ecb1	4164.054
Med	4	ecb2	5336.636
Med	4	control	4376.167
Med	5	ecb1	4112.736
Med	5	ecb2	4082.821
Med	5	control	5449.219
High	1	ecb1	4900.385
High	1	ecb2	4150.556
High	1	control	4867.81
High	2	ecb1	4252.167
High	2	ecb2	6021.031
High	2	control	4475.991
High	3	ecb1	3674.792
High	3	ecb2	4671.628
High	3	control	3864.667
High	4	ecb1	5234.073
High	4	ecb2	4704.706
High	4	control	4961.02
High	5	ecb1	5348.73
High	5	ecb2	6108.24
High	5	control	5450.074

First and Second Generation European Corn Borer Larval Survival in 2003

```
data ecb2003;
input water $ zone $ N blk trt $ larvae;
datalines;

proc means;
var larvae;
class water zone trt;
proc mixed;
class water zone N blk trt;
model larvae=water | zone | N | trt ;
random blk(water*zone*N);
lsmeans water | zone | N | trt /pdiff cl;
run;
```

Water	Zone	Nitrogen	row	trt	larvae						
full	high	1	1	ecb1	11	full	medium	1	6	ecb2	15
full	high	1	2	ecb1	7	full	medium	2	1	ecb1	0
full	high	1	3	ecb1	15	full	medium	2	2	ecb1	13
full	high	1	4	ecb1	6	full	medium	2	3	ecb1	8
full	high	1	5	ecb1	11	full	medium	2	4	ecb1	15
full	high	1	6	ecb1	9	full	medium	2	5	ecb1	10
full	high	1	1	ecb2	15	full	medium	2	6	ecb1	12
full	high	1	2	ecb2	19	full	medium	2	1	ecb2	10
full	high	1	3	ecb2	21	full	medium	2	2	ecb2	16
full	high	1	4	ecb2	20	full	medium	2	3	ecb2	7
full	high	1	5	ecb2	21	full	medium	2	4	ecb2	12
full	high	1	6	ecb2	.	full	medium	2	5	ecb2	14
full	high	2	1	ecb1	7	full	medium	2	6	ecb2	10
full	high	2	2	ecb1	7	full	medium	3	1	ecb1	4
full	high	2	3	ecb1	15	full	medium	3	2	ecb1	11
full	high	2	4	ecb1	4	full	medium	3	3	ecb1	11
full	high	2	5	ecb1	2	full	medium	3	4	ecb1	8
full	high	2	6	ecb1	5	full	medium	3	5	ecb1	14
full	high	2	1	ecb2	11	full	medium	3	6	ecb1	2
full	high	2	2	ecb2	15	full	medium	3	1	ecb2	14
full	high	2	3	ecb2	16	full	medium	3	2	ecb2	13
full	high	2	4	ecb2	5	full	medium	3	3	ecb2	5
full	high	2	5	ecb2	22	full	medium	3	4	ecb2	13
full	high	2	6	ecb2	25	full	medium	3	5	ecb2	17
full	high	3	1	ecb1	2	full	medium	3	6	ecb2	12
full	high	3	2	ecb1	2	full	low	1	1	ecb1	16
full	high	3	3	ecb1	9	full	low	1	2	ecb1	16
full	high	3	4	ecb1	15	full	low	1	3	ecb1	14
full	high	3	5	ecb1	18	full	low	1	4	ecb1	14
full	high	3	6	ecb1	14	full	low	1	5	ecb1	8
full	high	3	1	ecb2	15	full	low	1	6	ecb1	5
full	high	3	2	ecb2	18	full	low	1	1	ecb2	.
full	high	3	3	ecb2	8	full	low	1	2	ecb2	16
full	high	3	4	ecb2	25	full	low	1	3	ecb2	17
full	high	3	5	ecb2	12	full	low	1	4	ecb2	14
full	high	3	6	ecb2	18	full	low	1	5	ecb2	6
full	medium	1	1	ecb1	4	full	low	1	6	ecb2	13
full	medium	1	2	ecb1	7	full	low	2	1	ecb1	12
full	medium	1	3	ecb1	4	full	low	2	2	ecb1	2
full	medium	1	4	ecb1	9	full	low	2	3	ecb1	19
full	medium	1	5	ecb1	16	full	low	2	4	ecb1	8
full	medium	1	6	ecb1	11	full	low	2	5	ecb1	5
full	medium	1	1	ecb2	21	full	low	2	6	ecb1	5
full	medium	1	2	ecb2	22	full	low	2	1	ecb2	11
full	medium	1	3	ecb2	23	full	low	2	2	ecb2	16
full	medium	1	4	ecb2	18	full	low	2	3	ecb2	8
full	medium	1	5	ecb2	16	full	low	2	4	ecb2	7
full	medium	1	5	ecb2	16	full	low	2	5	ecb2	10

full	low	2	6	ecb2	7	limited	high	3	6	ecb2	2
full	low	3	1	ecb1	7	limited	medium	1	1	ecb1	3
full	low	3	2	ecb1	20	limited	medium	1	2	ecb1	8
full	low	3	3	ecb1	16	limited	medium	1	3	ecb1	5
full	low	3	4	ecb1	8	limited	medium	1	4	ecb1	12
full	low	3	5	ecb1	19	limited	medium	1	5	ecb1	5
full	low	3	6	ecb1	11	limited	medium	1	6	ecb1	7
full	low	3	1	ecb2	20	limited	medium	1	1	ecb2	3
full	low	3	2	ecb2	13	limited	medium	1	2	ecb2	5
full	low	3	3	ecb2	21	limited	medium	1	3	ecb2	11
full	low	3	4	ecb2	25	limited	medium	1	4	ecb2	5
full	low	3	5	ecb2	8	limited	medium	1	5	ecb2	4
full	low	3	6	ecb2	17	limited	medium	1	6	ecb2	5
limited	high	1	1	ecb1	8	limited	medium	2	1	ecb1	2
limited	high	1	2	ecb1	5	limited	medium	2	2	ecb1	7
limited	high	1	3	ecb1	8	limited	medium	2	3	ecb1	13
limited	high	1	4	ecb1	1	limited	medium	2	4	ecb1	3
limited	high	1	5	ecb1	4	limited	medium	2	5	ecb1	4
limited	high	1	6	ecb1	5	limited	medium	2	6	ecb1	4
limited	high	1	1	ecb2	7	limited	medium	2	1	ecb2	11
limited	high	1	2	ecb2	3	limited	medium	2	2	ecb2	10
limited	high	1	3	ecb2	7	limited	medium	2	3	ecb2	3
limited	high	1	4	ecb2	9	limited	medium	2	4	ecb2	1
limited	high	1	5	ecb2	8	limited	medium	2	5	ecb2	6
limited	high	1	6	ecb2	13	limited	medium	2	6	ecb2	9
limited	high	2	1	ecb1	6	limited	medium	3	1	ecb1	7
limited	high	2	2	ecb1	7	limited	medium	3	2	ecb1	8
limited	high	2	3	ecb1	9	limited	medium	3	3	ecb1	5
limited	high	2	4	ecb1	8	limited	medium	3	4	ecb1	2
limited	high	2	5	ecb1	10	limited	medium	3	5	ecb1	7
limited	high	2	6	ecb1	6	limited	medium	3	6	ecb1	13
limited	high	2	1	ecb2	5	limited	medium	3	1	ecb2	11
limited	high	2	2	ecb2	4	limited	medium	3	2	ecb2	16
limited	high	2	3	ecb2	5	limited	medium	3	3	ecb2	3
limited	high	2	4	ecb2	11	limited	medium	3	4	ecb2	3
limited	high	2	5	ecb2	10	limited	medium	3	5	ecb2	17
limited	high	2	6	ecb2	11	limited	medium	3	6	ecb2	12
limited	high	3	1	ecb1	7	limited	low	1	1	ecb1	4
limited	high	3	2	ecb1	3	limited	low	1	2	ecb1	5
limited	high	3	3	ecb1	3	limited	low	1	3	ecb1	11
limited	high	3	4	ecb1	7	limited	low	1	4	ecb1	7
limited	high	3	5	ecb1	7	limited	low	1	5	ecb1	2
limited	high	3	6	ecb1	11	limited	low	1	6	ecb1	7
limited	high	3	1	ecb2	6	limited	low	1	1	ecb2	12
limited	high	3	2	ecb2	6	limited	low	1	2	ecb2	9
limited	high	3	3	ecb2	3	limited	low	1	3	ecb2	4
limited	high	3	4	ecb2	4	limited	low	1	4	ecb2	7
limited	high	3	5	ecb2	11	limited	low	1	5	ecb2	7

limited	low	1	6	ecb2	3
limited	low	2	1	ecb1	7
limited	low	2	2	ecb1	8
limited	low	2	3	ecb1	7
limited	low	2	4	ecb1	8
limited	low	2	5	ecb1	1
limited	low	2	6	ecb1	8
limited	low	2	1	ecb2	0
limited	low	2	2	ecb2	7
limited	low	2	3	ecb2	1
limited	low	2	4	ecb2	7
limited	low	2	5	ecb2	9
limited	low	2	6	ecb2	4
limited	low	3	1	ecb1	6
limited	low	3	2	ecb1	4
limited	low	3	3	ecb1	11
limited	low	3	4	ecb1	2
limited	low	3	5	ecb1	8
limited	low	3	6	ecb1	7
limited	low	3	1	ecb2	5
limited	low	3	2	ecb2	8
limited	low	3	3	ecb2	4
limited	low	3	4	ecb2	10
limited	low	3	5	ecb2	9
limited	low	3	6	ecb2	2

Water	Zone	N	rep	trt	grain wt						
full	high	50	1	control	8.718013	full	low	100	4	control	7.369475
full	high	50	2	control	7.99132	full	low	100	5	control	7.465211
full	high	50	3	control	6.704593	full	low	100	6	control	8.596038
full	high	50	4	control	6.338191	full	low	200	1	control	8.691115
full	high	50	5	control	7.17449	full	low	200	2	control	8.538948
full	high	50	6	control	7.287024	full	low	200	3	control	9.882911
full	high	100	1	control	8.91212	full	low	200	4	control	9.162
full	high	100	2	control	8.38678	full	low	200	5	control	9.382676
full	high	100	3	control	8.181694	full	low	200	6	control	9.023483
full	high	100	4	control	6.30068	limit	high	50	1	control	2.743956
full	high	100	5	control	7.026056	limit	high	50	2	control	2.099385
full	high	100	6	control	7.19008	limit	high	50	3	control	2.297005
full	high	200	1	control	8.442773	limit	high	50	4	control	2.581907
full	high	200	2	control	7.498917	limit	high	50	5	control	3.081996
full	high	200	3	control	6.878353	limit	high	50	6	control	2.801156
full	high	200	4	control	5.989062	limit	high	100	1	control	1.936458
full	high	200	5	control	6.84139	limit	high	100	2	control	2.48716
full	high	200	6	control	7.915346	limit	high	100	3	control	2.053164
full	medium	50	1	control	6.55539	limit	high	100	4	control	2.389996
full	medium	50	2	control	7.418771	limit	high	100	5	control	2.515156
full	medium	50	3	control	8.643906	limit	high	100	6	control	1.750695
full	medium	50	4	control	8.817702	limit	high	200	1	control	1.674721
full	medium	50	5	control	7.452256	limit	high	200	2	control	1.860923
full	medium	50	6	control	8.210788	limit	high	200	3	control	1.581181
full	medium	100	1	control	6.814163	limit	high	200	4	control	1.885845
full	medium	100	2	control	8.167641	limit	high	200	5	control	2.37759
full	medium	100	3	control	8.90718	limit	high	200	6	control	2.36749
full	medium	100	4	control	8.153698	limit	medium	50	1	control	3.624903
full	medium	100	5	control	8.297741	limit	medium	50	2	control	3.843822
full	medium	100	6	control	7.646802	limit	medium	50	3	control	4.475438
full	medium	200	1	control	7.260126	limit	medium	50	4	control	4.093482
full	medium	200	2	control	8.850639	limit	medium	50	5	control	3.875844
full	medium	200	3	control	9.696563	limit	medium	50	6	control	4.364441
full	medium	200	4	control	9.881008	limit	medium	100	1	control	4.467204
full	medium	200	5	control	8.739862	limit	medium	100	2	control	4.370919
full	medium	200	6	control	8.38711	limit	medium	100	3	control	4.872435
full	low	50	1	control	7.896463	limit	medium	100	4	control	4.731136
full	low	50	2	control	7.768375	limit	medium	100	5	control	4.894393
full	low	50	3	control	8.854152	limit	medium	100	6	control	4.877924
full	low	50	4	control	8.986118	limit	medium	200	1	control	3.69934
full	low	50	5	control	9.073071	limit	medium	200	2	control	3.983364
full	low	50	6	control	9.092723	limit	medium	200	3	control	4.482904
full	low	100	1	control	8.008594	limit	medium	200	4	control	4.169456
full	low	100	2	control	7.204902	limit	medium	200	5	control	4.485539
full	low	100	3	control	8.332837	limit	medium	200	6	control	4.587203
						limit	low	50	1	control	6.989276
						limit	low	50	2	control	6.581081
						limit	low	50	3	control	6.861372

limit	low	50	4	control	6.345144	full	medium	200	4	ecb1	8.046215
limit	low	50	5	control	6.528199	full	medium	200	5	ecb1	8.477905
limit	low	50	6	control	6.412774	full	medium	200	6	ecb1	6.294422
limit	low	100	1	control	6.961829	full	low	50	1	ecb1	6.395428
limit	low	100	2	control	6.865324	full	low	50	2	ecb1	5.543904
limit	low	100	3	control	5.997003	full	low	50	3	ecb1	10.20554
limit	low	100	4	control	6.228329	full	low	50	4	ecb1	9.875738
limit	low	100	5	control	5.892484	full	low	50	5	ecb1	7.786234
limit	low	100	6	control	6.309243	full	low	50	6	ecb1	9.113364
limit	low	200	1	control	6.527504	full	low	100	1	ecb1	7.41383
limit	low	200	2	control	6.907703	full	low	100	2	ecb1	7.626382
limit	low	200	3	control	6.100315	full	low	100	3	ecb1	7.787552
limit	low	200	4	control	6.532774	full	low	100	4	ecb1	7.285158
limit	low	200	5	control	7.01332	full	low	100	5	ecb1	7.588614
limit	low	200	6	control	7.525046	full	low	100	6	ecb1	6.95623
full	high	50	1	ecb1	9.60434	full	low	200	1	ecb1	7.572805
full	high	50	2	ecb1	7.297015	full	low	200	2	ecb1	10.17217
full	high	50	3	ecb1	7.141554	full	low	200	3	ecb1	9.351825
full	high	50	4	ecb1	6.366004	full	low	200	4	ecb1	6.349316
full	high	50	5	ecb1	6.537275	full	low	200	5	ecb1	9.892426
full	high	50	6	ecb1	8.781801	full	low	200	6	ecb1	9.691293
full	high	100	1	ecb1	7.968045	limit	high	50	1	ecb1	3.083314
full	high	100	2	ecb1	8.711097	limit	high	50	2	ecb1	1.864656
full	high	100	3	ecb1	7.612768	limit	high	50	3	ecb1	2.321817
full	high	100	4	ecb1	9.505091	limit	high	50	4	ecb1	1.48259
full	high	100	5	ecb1	7.082707	limit	high	50	5	ecb1	2.706957
full	high	100	6	ecb1	6.138961	limit	high	50	6	ecb1	2.36222
full	high	200	1	ecb1	10.28152	limit	high	100	1	ecb1	2.347288
full	high	200	2	ecb1	8.774335	limit	high	100	2	ecb1	1.799661
full	high	200	3	ecb1	7.78316	limit	high	100	3	ecb1	2.360024
full	high	200	4	ecb1	7.045818	limit	high	100	4	ecb1	1.657374
full	high	200	5	ecb1	7.766472	limit	high	100	5	ecb1	2.215102
full	high	200	6	ecb1	6.192538	limit	high	100	6	ecb1	2.206758
full	medium	50	1	ecb1	8.25701	limit	high	200	1	ecb1	1.125996
full	medium	50	2	ecb1	7.817414	limit	high	200	2	ecb1	2.410966
full	medium	50	3	ecb1	5.620317	limit	high	200	3	ecb1	1.723248
full	medium	50	4	ecb1	9.596435	limit	high	200	4	ecb1	1.547585
full	medium	50	5	ecb1	8.15776	limit	high	200	5	ecb1	2.508019
full	medium	50	6	ecb1	8.255692	limit	high	200	6	ecb1	2.68983
full	medium	100	1	ecb1	7.019468	limit	medium	50	1	ecb1	2.935318
full	medium	100	2	ecb1	7.202596	limit	medium	50	2	ecb1	3.919027
full	medium	100	3	ecb1	8.098913	limit	medium	50	3	ecb1	3.59537
full	medium	100	4	ecb1	8.169178	limit	medium	50	4	ecb1	3.709111
full	medium	100	5	ecb1	10.38384	limit	medium	50	5	ecb1	5.377903
full	medium	100	6	ecb1	7.54382	limit	medium	50	6	ecb1	4.336665
full	medium	200	1	ecb1	8.427402	limit	medium	100	1	ecb1	4.053848
full	medium	200	2	ecb1	8.42872	limit	medium	100	2	ecb1	3.666513
full	medium	200	3	ecb1	7.618477	limit	medium	100	3	ecb1	3.830318

limit	medium	100	4	ecb1	6.235575	full	medium	50	4	ecb2	8.045776
limit	medium	100	5	ecb1	4.623873	full	medium	50	5	ecb2	7.919299
limit	medium	100	6	ecb1	4.306363	full	medium	50	6	ecb2	7.040548
limit	medium	200	1	ecb1	3.85535	full	medium	100	1	ecb2	7.05504
limit	medium	200	2	ecb1	4.021351	full	medium	100	2	ecb2	6.711181
limit	medium	200	3	ecb1	2.86681	full	medium	100	3	ecb2	6.717329
limit	medium	200	4	ecb1	4.290992	full	medium	100	4	ecb2	8.33474
limit	medium	200	5	ecb1	4.394633	full	medium	100	5	ecb2	8.175766
limit	medium	200	6	ecb1	3.935276	full	medium	100	6	ecb2	8.073442
limit	low	50	1	ecb1	6.549571	full	medium	200	1	ecb2	7.34093
limit	low	50	2	ecb1	5.925531	full	medium	200	2	ecb2	7.383089
limit	low	50	3	ecb1	6.310231	full	medium	200	3	ecb2	6.202638
limit	low	50	4	ecb1	7.220602	full	medium	200	4	ecb2	9.422529
limit	low	50	5	ecb1	5.71254	full	medium	200	5	ecb2	7.295258
limit	low	50	6	ecb1	5.722202	full	medium	200	6	ecb2	7.742319
limit	low	100	1	ecb1	6.01424	full	low	50	1	ecb2	7.484534
limit	low	100	2	ecb1	7.032643	full	low	50	2	ecb2	8.838891
limit	low	100	3	ecb1	5.529851	full	low	50	3	ecb2	8.533678
limit	low	100	4	ecb1	6.781446	full	low	50	4	ecb2	9.933707
limit	low	100	5	ecb1	5.870197	full	low	50	5	ecb2	9.327672
limit	low	100	6	ecb1	5.472322	full	low	50	6	ecb2	7.213575
limit	low	200	1	ecb1	5.125828	full	low	100	1	ecb2	6.786276
limit	low	200	2	ecb1	5.763921	full	low	100	2	ecb2	7.471799
limit	low	200	3	ecb1	6.095484	full	low	100	3	ecb2	6.028732
limit	low	200	4	ecb1	7.351909	full	low	100	4	ecb2	5.546978
limit	low	200	5	ecb1	7.190739	full	low	100	5	ecb2	5.83243
limit	low	200	6	ecb1	6.920658	full	low	100	6	ecb2	8.499424
full	high	50	1	ecb2	8.908278	full	low	200	1	ecb2	10.20247
full	high	50	2	ecb2	8.51172	full	low	200	2	ecb2	8.451116
full	high	50	3	ecb2	8.07476	full	low	200	3	ecb2	7.510445
full	high	50	4	ecb2	6.158283	full	low	200	4	ecb2	9.883204
full	high	50	5	ecb2	4.533846	full	low	200	5	ecb2	9.24555
full	high	50	6	ecb2		full	low	200	6	ecb2	8.347476
full	high	100	1	ecb2	6.874986	limit	high	50	1	ecb2	1.780777
full	high	100	2	ecb2	6.815261	limit	high	50	2	ecb2	1.478638
full	high	100	3	ecb2	3.677492	limit	high	50	3	ecb2	2.508898
full	high	100	4	ecb2	7.672932	limit	high	50	4	ecb2	2.918191
full	high	100	5	ecb2	6.951838	limit	high	50	5	ecb2	2.389887
full	high	100	6	ecb2	4.382776	limit	high	50	6	ecb2	2.700809
full	high	200	1	ecb2	10.97407	limit	high	100	1	ecb2	2.747799
full	high	200	2	ecb2	6.888161	limit	high	100	2	ecb2	2.033292
full	high	200	3	ecb2	8.031283	limit	high	100	3	ecb2	1.571739
full	high	200	4	ecb2	7.077437	limit	high	100	4	ecb2	1.884857
full	high	200	5	ecb2	5.80608	limit	high	100	5	ecb2	2.191827
full	high	200	6	ecb2	4.792509	limit	high	100	6	ecb2	2.123319
full	medium	50	1	ecb2	4.800413	limit	high	200	1	ecb2	1.538363
full	medium	50	2	ecb2	8.18938	limit	high	200	2	ecb2	1.001275
full	medium	50	3	ecb2	7.623308	limit	high	200	3	ecb2	2.465421

limit	high	200	4	ecb2	1.432527
limit	high	200	5	ecb2	1.714465
limit	high	200	6	ecb2	2.153621
limit	medium	50	1	ecb2	3.571655
limit	medium	50	2	ecb2	3.031493
limit	medium	50	3	ecb2	5.06215
limit	medium	50	4	ecb2	4.792509
limit	medium	50	5	ecb2	3.748635
limit	medium	50	6	ecb2	5.096404
limit	medium	100	1	ecb2	3.784646
limit	medium	100	2	ecb2	3.514565
limit	medium	100	3	ecb2	4.934356
limit	medium	100	4	ecb2	4.449528
limit	medium	100	5	ecb2	5.319496
limit	medium	100	6	ecb2	6.073966
limit	medium	200	1	ecb2	4.520232
limit	medium	200	2	ecb2	3.105711
limit	medium	200	3	ecb2	3.384575
limit	medium	200	4	ecb2	4.673058
limit	medium	200	5	ecb2	4.780651
limit	medium	200	6	ecb2	3.728873
limit	low	50	1	ecb2	6.148183
limit	low	50	2	ecb2	6.566698
limit	low	50	3	ecb2	6.877621
limit	low	50	4	ecb2	6.11305
limit	low	50	5	ecb2	7.4191
limit	low	50	6	ecb2	5.840774
limit	low	100	1	ecb2	6.125786
limit	low	100	2	ecb2	6.711181
limit	low	100	3	ecb2	5.924652
limit	low	100	4	ecb2	5.444655
limit	low	100	5	ecb2	6.250506
limit	low	100	6	ecb2	5.382734
limit	low	200	1	ecb2	5.66555
limit	low	200	2	ecb2	6.939542
limit	low	200	3	ecb2	7.139358
limit	low	200	4	ecb2	6.381814
limit	low	200	5	ecb2	5.485497
limit	low	200	6	ecb2	8.541143

First and Second Generation European Corn Borer Larval Survival in 2004

```
options ls=74 ps=55 nodate;
data ecbsurvival2004;
input water $ zone $ n trt $ blk larvae;
rtlarvae=sqrt(larvae + ½)
datalines;

proc means;
var larvae;
class water zone N trt;
proc mixed;
class water zone N blk trt;
model rtlarvae=water | zone | N | trt ;
random blk(water*zone*N)trt*blk(water*zone*N);
lsmeans water | zone | N | trt /pdiff cl;
run;
```

Water	Zone	N	trt	rep	larvae	limit	low	100	ecb1	4	2
limit	high	50	ecb1	1	3	limit	low	100	ecb1	5	0
limit	high	50	ecb1	2	0	limit	low	100	ecb1	6	0
limit	high	50	ecb1	3	0	limit	low	200	ecb1	1	1
limit	high	50	ecb1	4	0	limit	low	200	ecb1	2	1
limit	high	50	ecb1	5	6	limit	low	200	ecb1	3	1
limit	high	50	ecb1	6	3	limit	low	200	ecb1	4	0
limit	high	100	ecb1	1	2	limit	low	200	ecb1	5	3
limit	high	100	ecb1	2	3	limit	low	200	ecb1	6	1
limit	high	100	ecb1	3	.	limit	high	50	ecb2	1	3
limit	high	100	ecb1	4	1	limit	high	50	ecb2	2	3
limit	high	100	ecb1	5	3	limit	high	50	ecb2	3	1
limit	high	100	ecb1	6	14	limit	high	50	ecb2	4	1
limit	high	200	ecb1	1	1	limit	high	50	ecb2	5	0
limit	high	200	ecb1	2	5	limit	high	50	ecb2	6	2
limit	high	200	ecb1	3	9	limit	high	100	ecb2	1	0
limit	high	200	ecb1	4	3	limit	high	100	ecb2	2	0
limit	high	200	ecb1	5	7	limit	high	100	ecb2	3	1
limit	high	200	ecb1	6	3	limit	high	100	ecb2	4	1
limit	med	50	ecb1	1	7	limit	high	100	ecb2	5	0
limit	med	50	ecb1	2	12	limit	high	100	ecb2	6	0
limit	med	50	ecb1	3	2	limit	high	200	ecb2	1	3
limit	med	50	ecb1	4	11	limit	high	200	ecb2	2	0
limit	med	50	ecb1	5	9	limit	high	200	ecb2	3	2
limit	med	50	ecb1	6	2	limit	high	200	ecb2	4	1
limit	med	100	ecb1	1	5	limit	high	200	ecb2	5	0
limit	med	100	ecb1	2	2	limit	high	200	ecb2	6	.
limit	med	100	ecb1	3	1	limit	med	50	ecb2	1	3
limit	med	100	ecb1	4	1	limit	med	50	ecb2	2	9
limit	med	100	ecb1	5	8	limit	med	50	ecb2	3	1
limit	med	100	ecb1	6	1	limit	med	50	ecb2	4	2
limit	med	200	ecb1	1	3	limit	med	50	ecb2	5	2
limit	med	200	ecb1	2	3	limit	med	50	ecb2	6	0
limit	med	200	ecb1	3	2	limit	med	100	ecb2	1	.
limit	med	200	ecb1	4	6	limit	med	100	ecb2	2	3
limit	med	200	ecb1	5	3	limit	med	100	ecb2	3	0
limit	med	200	ecb1	6	2	limit	med	100	ecb2	4	1
limit	low	50	ecb1	1	0	limit	med	100	ecb2	5	1
limit	low	50	ecb1	2	0	limit	med	100	ecb2	6	0
limit	low	50	ecb1	3	1	limit	med	200	ecb2	1	1
limit	low	50	ecb1	4	1	limit	med	200	ecb2	2	2
limit	low	50	ecb1	5	0	limit	med	200	ecb2	3	2
limit	low	50	ecb1	6	3	limit	med	200	ecb2	4	0
limit	low	100	ecb1	1	4	limit	med	200	ecb2	5	2
limit	low	100	ecb1	2	1	limit	med	200	ecb2	6	0
limit	low	100	ecb1	3	2	limit	low	50	ecb2	1	0
						limit	low	50	ecb2	2	0
						limit	low	50	ecb2	3	1

limit	low	50	ecb2	4	2	full	med	200	ecb1	4	9
limit	low	50	ecb2	5	2	full	med	200	ecb1	5	3
limit	low	50	ecb2	6	0	full	med	200	ecb1	6	10
limit	low	100	ecb2	1	0	full	low	50	ecb1	1	5
limit	low	100	ecb2	2	1	full	low	50	ecb1	2	11
limit	low	100	ecb2	3	0	full	low	50	ecb1	3	8
limit	low	100	ecb2	4	0	full	low	50	ecb1	4	14
limit	low	100	ecb2	5	0	full	low	50	ecb1	5	9
limit	low	100	ecb2	6	0	full	low	50	ecb1	6	9
limit	low	200	ecb2	1	0	full	low	100	ecb1	1	9
limit	low	200	ecb2	2	0	full	low	100	ecb1	2	6
limit	low	200	ecb2	3	1	full	low	100	ecb1	3	10
limit	low	200	ecb2	4	0	full	low	100	ecb1	4	16
limit	low	200	ecb2	5	0	full	low	100	ecb1	5	4
limit	low	200	ecb2	6	0	full	low	100	ecb1	6	7
full	high	50	ecb1	1	14	full	low	200	ecb1	1	4
full	high	50	ecb1	2	8	full	low	200	ecb1	2	8
full	high	50	ecb1	3	6	full	low	200	ecb1	3	5
full	high	50	ecb1	4	11	full	low	200	ecb1	4	8
full	high	50	ecb1	5	24	full	low	200	ecb1	5	9
full	high	50	ecb1	6	15	full	low	200	ecb1	6	9
full	high	100	ecb1	1	4	full	high	50	ecb2	1	5
full	high	100	ecb1	2	11	full	high	50	ecb2	2	10
full	high	100	ecb1	3	12	full	high	50	ecb2	3	2
full	high	100	ecb1	4	11	full	high	50	ecb2	4	3
full	high	100	ecb1	5	10	full	high	50	ecb2	5	3
full	high	100	ecb1	6	9	full	high	50	ecb2	6	9
full	high	200	ecb1	1	10	full	high	100	ecb2	1	1
full	high	200	ecb1	2	16	full	high	100	ecb2	2	10
full	high	200	ecb1	3	4	full	high	100	ecb2	3	4
full	high	200	ecb1	4	10	full	high	100	ecb2	4	2
full	high	200	ecb1	5	9	full	high	100	ecb2	5	5
full	high	200	ecb1	6	14	full	high	100	ecb2	6	4
full	med	50	ecb1	1	5	full	high	200	ecb2	1	4
full	med	50	ecb1	2	2	full	high	200	ecb2	2	3
full	med	50	ecb1	3	4	full	high	200	ecb2	3	1
full	med	50	ecb1	4	3	full	high	200	ecb2	4	0
full	med	50	ecb1	5	5	full	high	200	ecb2	5	4
full	med	50	ecb1	6	14	full	high	200	ecb2	6	4
full	med	100	ecb1	1	16	full	med	50	ecb2	1	1
full	med	100	ecb1	2	18	full	med	50	ecb2	2	2
full	med	100	ecb1	3	11	full	med	50	ecb2	3	0
full	med	100	ecb1	4	15	full	med	50	ecb2	4	0
full	med	100	ecb1	5	14	full	med	50	ecb2	5	4
full	med	100	ecb1	6	6	full	med	50	ecb2	6	0
full	med	200	ecb1	1	4	full	med	100	ecb2	1	1
full	med	200	ecb1	2	17	full	med	100	ecb2	2	4
full	med	200	ecb1	3	10	full	med	100	ecb2	3	1

full	med	100	ecb2	4	0
full	med	100	ecb2	5	1
full	med	100	ecb2	6	3
full	med	200	ecb2	1	0
full	med	200	ecb2	2	2
full	med	200	ecb2	3	2
full	med	200	ecb2	4	1
full	med	200	ecb2	5	1
full	med	200	ecb2	6	2
full	low	50	ecb2	1	2
full	low	50	ecb2	2	1
full	low	50	ecb2	3	0
full	low	50	ecb2	4	2
full	low	50	ecb2	5	2
full	low	50	ecb2	6	1
full	low	100	ecb2	1	2
full	low	100	ecb2	2	4
full	low	100	ecb2	3	1
full	low	100	ecb2	4	2
full	low	100	ecb2	5	1
full	low	100	ecb2	6	0
full	low	200	ecb2	1	0
full	low	200	ecb2	2	2
full	low	200	ecb2	3	4
full	low	200	ecb2	4	2
full	low	200	ecb2	5	1
full	low	200	ecb2	6	0

Yield for European Corn Borer Plots in 2004

```
data ecbyield2004;
input water $ zone $ trt $ blk wt;
rtwt=sqrt(larvae+3/8);
lgwt=log(larvae+1);
datalines;

proc means;
var wt;
class water zone trt ;
proc mixed;
class water zone blk trt;
model wt=water | zone | trt ;
random blk(water*zone);
lsmeans water | zone | trt /pdiff cl;
proc mixed;
class water zone blk trt;
model rtwt=water | zone | trt ;
random blk(water*zone);
lsmeans water | zone | trt /pdiff cl;
run;
```

Water	Zone	N	Trt	rep	Grain wt	limit	high	100	ecb1	4	6.507914
limit	low	50	ecb1	1	6.878664	limit	high	100	ecb1	5	7.522322
limit	low	50	ecb1	2	6.255949	limit	high	100	ecb1	6	6.497116
limit	low	50	ecb1	3	6.792995	limit	high	200	ecb1	1	4.123839
limit	low	50	ecb1	4	10.13622	limit	high	200	ecb1	2	8.021672
limit	low	50	ecb1	5	7.118031	limit	high	200	ecb1	3	6.324339
limit	low	50	ecb1	6	7.074422	limit	high	200	ecb1	4	5.717683
limit	low	100	ecb1	1	5.357179	limit	high	200	ecb1	5	6.765279
limit	low	100	ecb1	2	7.236455	limit	high	200	ecb1	6	6.437724
limit	low	100	ecb1	3	6.485597	full	low	50	ecb1	1	7.270383
limit	low	100	ecb1	4	9.242102	full	low	50	ecb1	2	8.964392
limit	low	100	ecb1	5	7.779441	full	low	50	ecb1	3	7.810233
limit	low	100	ecb1	6	6.063975	full	low	50	ecb1	4	8.096494
limit	low	200	ecb1	1	7.483382	full	low	50	ecb1	5	8.387028
limit	low	200	ecb1	2	5.611963	full	low	50	ecb1	6	6.991041
limit	low	200	ecb1	3	7.192476	full	low	100	ecb1	1	7.895684
limit	low	200	ecb1	4	6.893782	full	low	100	ecb1	2	7.431806
limit	low	200	ecb1	5	7.392286	full	low	100	ecb1	3	7.567954
limit	low	200	ecb1	6	7.619443	full	low	100	ecb1	4	6.699368
limit	med	50	ecb1	1	8.05374	full	low	100	ecb1	5	5.999674
limit	med	50	ecb1	2	7.56737	full	low	100	ecb1	6	7.454936
limit	med	50	ecb1	3	7.600966	full	low	200	ecb1	1	5.2091
limit	med	50	ecb1	4	4.837742	full	low	200	ecb1	2	7.414879
limit	med	50	ecb1	5	9.636289	full	low	200	ecb1	3	6.454708
limit	med	50	ecb1	6	6.727484	full	low	200	ecb1	4	6.25075
limit	med	100	ecb1	1	.	full	low	200	ecb1	5	7.04497
limit	med	100	ecb1	2	5.486553	full	low	200	ecb1	6	7.592943
limit	med	100	ecb1	3	6.129638	full	med	50	ecb1	1	4.994618
limit	med	100	ecb1	4	7.407792	full	med	50	ecb1	2	8.234381
limit	med	100	ecb1	5	5.568442	full	med	50	ecb1	3	5.719529
limit	med	100	ecb1	6	6.601502	full	med	50	ecb1	4	7.339031
limit	med	200	ecb1	1	5.756447	full	med	50	ecb1	5	5.4552
limit	med	200	ecb1	2	5.326555	full	med	50	ecb1	6	7.638431
limit	med	200	ecb1	3	9.254013	full	med	100	ecb1	1	7.868699
limit	med	200	ecb1	4	6.40451	full	med	100	ecb1	2	8.032406
limit	med	200	ecb1	5	8.772283	full	med	100	ecb1	3	8.293256
limit	med	200	ecb1	6	5.614636	full	med	100	ecb1	4	10.62035
limit	high	50	ecb1	1	7.270356	full	med	100	ecb1	5	7.163503
limit	high	50	ecb1	2	3.081181	full	med	100	ecb1	6	9.311474
limit	high	50	ecb1	3	7.128339	full	med	200	ecb1	1	7.321812
limit	high	50	ecb1	4	2.284489	full	med	200	ecb1	2	7.649225
limit	high	50	ecb1	5	5.488271	full	med	200	ecb1	3	9.487516
limit	high	50	ecb1	6	5.601392	full	med	200	ecb1	4	10.33301
limit	high	100	ecb1	1	6.835142	full	med	200	ecb1	5	8.728832
limit	high	100	ecb1	2	7.934629	full	med	200	ecb1	6	8.237488
limit	high	100	ecb1	3	.	full	high	50	ecb1	1	7.259073
						full	high	50	ecb1	2	7.844413
						full	high	50	ecb1	3	8.387028

full	high	50	ecb1	4	6.461733	limit	med	200	ecb2	4	6.271656
full	high	50	ecb1	5	8.343628	limit	med	200	ecb2	5	5.43574
full	high	50	ecb1	6	6.325394	limit	med	200	ecb2	6	5.575314
full	high	100	ecb1	1	10.21768	limit	high	50	ecb2	1	6.887063
full	high	100	ecb1	2	8.650283	limit	high	50	ecb2	2	6.626698
full	high	100	ecb1	3	8.153177	limit	high	50	ecb2	3	4.296015
full	high	100	ecb1	4	8.705961	limit	high	50	ecb2	4	6.819872
full	high	100	ecb1	5	6.196427	limit	high	50	ecb2	5	5.923132
full	high	100	ecb1	6	9.648653	limit	high	50	ecb2	6	5.181331
full	high	200	ecb1	1	7.003885	limit	high	100	ecb2	1	3.930665
full	high	200	ecb1	2	7.685718	limit	high	100	ecb2	2	7.49178
full	high	200	ecb1	3	6.571191	limit	high	100	ecb2	3	5.790172
full	high	200	ecb1	4	7.536789	limit	high	100	ecb2	4	7.296207
full	high	200	ecb1	5	10.31273	limit	high	100	ecb2	5	7.437188
full	high	200	ecb1	6	10.4877	limit	high	100	ecb2	6	6.55569
limit	low	50	ecb2	1	6.517513	limit	high	200	ecb2	1	6.780168
limit	low	50	ecb2	2	7.513617	limit	high	200	ecb2	2	6.349536
limit	low	50	ecb2	3	8.104133	limit	high	200	ecb2	3	7.520207
limit	low	50	ecb2	4	6.458721	limit	high	200	ecb2	4	4.640368
limit	low	50	ecb2	5	8.021672	limit	high	200	ecb2	5	7.421535
limit	low	50	ecb2	6	8.138492	limit	high	200	ecb2	6	
limit	low	100	ecb2	1	5.452538	full	low	50	ecb2	1	8.789258
limit	low	100	ecb2	2	8.380379	full	low	50	ecb2	2	9.819555
limit	low	100	ecb2	3	6.425126	full	low	50	ecb2	3	7.573411
limit	low	100	ecb2	4	6.314261	full	low	50	ecb2	4	11.04291
limit	low	100	ecb2	5	5.376561	full	low	50	ecb2	5	8.643381
limit	low	100	ecb2	6	6.582604	full	low	50	ecb2	6	10.10032
limit	low	200	ecb2	1	7.27677	full	low	100	ecb2	1	5.817512
limit	low	200	ecb2	2	8.090899	full	low	100	ecb2	2	7.797415
limit	low	200	ecb2	3	7.352817	full	low	100	ecb2	3	7.075353
limit	low	200	ecb2	4	7.2108	full	low	100	ecb2	4	6.692172
limit	low	200	ecb2	5	7.211818	full	low	100	ecb2	5	10.15843
limit	low	200	ecb2	6	8.718013	full	low	100	ecb2	6	5.058706
limit	med	50	ecb2	1	7.922522	full	low	200	ecb2	1	7.182777
limit	med	50	ecb2	2	7.189422	full	low	200	ecb2	2	8.842971
limit	med	50	ecb2	3	8.534766	full	low	200	ecb2	3	9.718641
limit	med	50	ecb2	4	9.300334	full	low	200	ecb2	4	7.253851
limit	med	50	ecb2	5	7.000447	full	low	200	ecb2	5	6.972812
limit	med	50	ecb2	6	7.341893	full	low	200	ecb2	6	7.531763
limit	med	100	ecb2	1		full	med	50	ecb2	1	6.530745
limit	med	100	ecb2	2	5.464056	full	med	50	ecb2	2	6.384148
limit	med	100	ecb2	3	6.076573	full	med	50	ecb2	3	5.177199
limit	med	100	ecb2	4	5.349426	full	med	50	ecb2	4	4.896799
limit	med	100	ecb2	5	6.845068	full	med	50	ecb2	5	6.76247
limit	med	100	ecb2	6	5.558364	full	med	50	ecb2	6	4.853624
limit	med	200	ecb2	1	6.509878	full	med	100	ecb2	1	7.699146
limit	med	200	ecb2	2	6.922185	full	med	100	ecb2	2	11.0955
limit	med	200	ecb2	3	8.440851	full	med	100	ecb2	3	8.676576

full	med	100	ecb2	4	9.198813	limit	med	50	control	4	7.979754
full	med	100	ecb2	5	9.929421	limit	med	50	control	5	6.700188
full	med	100	ecb2	6	9.530649	limit	med	50	control	6	7.49166
full	med	200	ecb2	1	7.583177	limit	med	100	control	1	6.503595
full	med	200	ecb2	2	9.000852	limit	med	100	control	2	7.466584
full	med	200	ecb2	3	7.595655	limit	med	100	control	3	5.915086
full	med	200	ecb2	4	9.331263	limit	med	100	control	4	4.831033
full	med	200	ecb2	5	8.396327	limit	med	100	control	5	6.141664
full	med	200	ecb2	6	7.196883	limit	med	100	control	6	5.281201
full	high	50	ecb2	1	7.861503	limit	med	200	control	1	7.424799
full	high	50	ecb2	2	9.401634	limit	med	200	control	2	6.578505
full	high	50	ecb2	3	8.545112	limit	med	200	control	3	8.207439
full	high	50	ecb2	4	9.19717	limit	med	200	control	4	6.560271
full	high	50	ecb2	5	5.626956	limit	med	200	control	5	7.606005
full	high	50	ecb2	6	12.30496	limit	med	200	control	6	6.56726
full	high	100	ecb2	1	8.009019	limit	high	50	control	1	7.256612
full	high	100	ecb2	2	8.843742	limit	high	50	control	2	8.196775
full	high	100	ecb2	3	5.937632	limit	high	50	control	3	4.023052
full	high	100	ecb2	4	11.9818	limit	high	50	control	4	6.966661
full	high	100	ecb2	5	8.09393	limit	high	50	control	5	5.027491
full	high	100	ecb2	6	7.009621	limit	high	50	control	6	5.178386
full	high	200	ecb2	1	10.42732	limit	high	100	control	1	5.890238
full	high	200	ecb2	2	8.738802	limit	high	100	control	2	7.129255
full	high	200	ecb2	3	9.015596	limit	high	100	control	3	8.74657
full	high	200	ecb2	4	10.6643	limit	high	100	control	4	7.398629
full	high	200	ecb2	5	7.758962	limit	high	100	control	5	6.578243
full	high	200	ecb2	6	5.623823	limit	high	100	control	6	6.358635
limit	low	50	control	1	6.789331	limit	high	200	control	1	7.702102
limit	low	50	control	2	7.263484	limit	high	200	control	2	7.05504
limit	low	50	control	3	5.646911	limit	high	200	control	3	6.008413
limit	low	50	control	4	6.329346	limit	high	200	control	4	6.993017
limit	low	50	control	5	7.120292	limit	high	200	control	5	6.752681
limit	low	50	control	6	6.519128	limit	high	200	control	6	8.007928
limit	low	100	control	1	6.214154	full	low	50	control	1	8.188683
limit	low	100	control	2	4.781049	full	low	50	control	2	8.033687
limit	low	100	control	3	6.482026	full	low	50	control	3	7.09833
limit	low	100	control	4	5.901397	full	low	50	control	4	8.718343
limit	low	100	control	5	6.902601	full	low	50	control	5	7.804452
limit	low	100	control	6	6.654766	full	low	50	control	6	7.852768
limit	low	200	control	1	6.950894	full	low	100	control	1	7.495284
limit	low	200	control	2	5.976987	full	low	100	control	2	8.21877
limit	low	200	control	3	6.882443	full	low	100	control	3	7.782935
limit	low	200	control	4	8.581478	full	low	100	control	4	6.380725
limit	low	200	control	5	8.976978	full	low	100	control	5	7.123585
limit	low	200	control	6	8.158227	full	low	100	control	6	7.248869
limit	med	50	control	1	6.726339	full	low	200	control	1	7.894745
limit	med	50	control	2	7.226306	full	low	200	control	2	8.745448
limit	med	50	control	3	7.918419	full	low	200	control	3	7.875176

full	low	200	control	4	7.7141
full	low	200	control	5	7.848686
full	low	200	control	6	7.663257
full	med	50	control	1	6.615125
full	med	50	control	2	5.883059
full	med	50	control	3	7.404888
full	med	50	control	4	6.71125
full	med	50	control	5	9.986388
full	med	50	control	6	6.522829
full	med	100	control	1	8.994341
full	med	100	control	2	9.465723
full	med	100	control	3	9.926002
full	med	100	control	4	8.839109
full	med	100	control	5	10.51049
full	med	100	control	6	7.686638
full	med	200	control	1	9.642142
full	med	200	control	2	7.820487
full	med	200	control	3	8.931483
full	med	200	control	4	8.196606
full	med	200	control	5	8.662407
full	med	200	control	6	8.957863
full	high	50	control	1	8.390044
full	high	50	control	2	8.257341
full	high	50	control	3	8.245412
full	high	50	control	4	8.074561
full	high	50	control	5	8.737377
full	high	50	control	6	9.619375
full	high	100	control	1	8.981218
full	high	100	control	2	8.727769
full	high	100	control	3	8.537137
full	high	100	control	4	9.112508
full	high	100	control	5	8.330111
full	high	100	control	6	8.022009
full	high	200	control	1	10.23483
full	high	200	control	2	8.926306
full	high	200	control	3	9.940956
full	high	200	control	4	10.64151
full	high	200	control	5	9.212694
full	high	200	control	6	9.433301

Yield for Western Corn Rootworm Plots in 2002

```
options nodate ls=74 ps=60;
goptions hpos=50 vpos=60;
data wcryield2002;
input zone $ rep trt $ wt;
datalines;

;
proc means;
var wt;
class zone trt;
output out=out1 mean=;
proc gplot data=out1;
plot wt*zone=trt;
symbol1 v='A' line=1 i=join;
symbol2 v='B' line=2 i=join;
symbol3 v='C' line=3 i=join;
symbol3 v='D' line=4 i=join;
proc mixed data=wcryield2002;
class trt;
model wt= trt /ddfm=satterth;
lsmeans trt/pdiff cl;
proc print;
run;
```

zone	rep	trt	wt
medium	1	untreated	3288.56
medium	2	treated	4101.977
medium	3	untreated	2021.683
medium	4	treated	2798.865
medium	5	treated	1815.896
medium	6	untreated	2931.02
medium	7	untreated	3227.647
medium	8	treated	3300.269
medium	9	treated	3870.32
medium	10	untreated	2827.185
medium	11	untreated	2180.969
medium	12	treated	3096.66
medium	13	untreated	3489.009
medium	14	treated	3145.729
medium	15	treated	3116.797
medium	16	untreated	3735.196
medium	17	treated	3344.222
medium	18	treated	2826.058
medium	19	treated	4287.089
medium	20	untreated	3769.615
high	1	treated	2060.17
high	2	treated	3853.15
high	3	untreated	2247.25
high	4	treated	4398.356
high	5	untreated	2128.365
high	6	treated	2482.917
high	7	treated	3257.25
high	8	untreated	3590.76
high	9	treated	3203.944
high	10	untreated	3436.104
high	11	treated	3385.696
high	12	untreated	3847.712
high	13	treated	3430.115
high	14	untreated	3409.848
high	15	untreated	3797.787
high	16	untreated	3425.884
high	17	untreated	3052.22
high	18	treated	2760.667
high	19	treated	3145.567
high	20	untreated	1954.13

Densities of Western Corn Rootworm Larvae in 2002

```
data fromm2002;
input trt $ zone $ larvae;
rtlarvae= sqrt(larvae+3/8);
cards;

;
proc glm;
class zone;
model larvae=zone;
means zone/lsd clm;
lsmeans zone/pdiff cl;
output out=out1 predicted=p1 student=s1;
proc gplot;
plot s1*p1;
symbol1 v=dot;
proc glm;
class zone;
model rtlarvae=zone;
means zone/lsd clm;
lsmeans zone/pdiff cl;
output out=out2 predicted=p2 student=s2;
proc gplot;
plot s2*p2;
symbol1 v=dot;
proc print;
run;
```

Treatment	Zone	larvae
untreated	medium	4
untreated	medium	1
untreated	medium	2
untreated	medium	1
untreated	medium	0
untreated	medium	1
untreated	medium	0
untreated	medium	2
untreated	medium	4
untreated	high	7
untreated	high	4
untreated	high	1
untreated	high	5
untreated	high	1
treated	medium	1
treated	medium	1
treated	medium	2
treated	medium	0
treated	medium	0
treated	medium	0
treated	medium	6
treated	medium	2
treated	medium	0
treated	medium	0
treated	medium	1
treated	high	1
treated	high	3
treated	high	5
treated	high	0
treated	high	1
treated	high	2
treated	high	2

Densities of Western Corn Rootworm Larvae in 2003

```
data wcr2003;  
input water $ zone $ N blk larvae;  
rtlarvae= sqrt(larvae+3/8);  
datalines;
```

```
proc means;  
var larvae;  
class water ;  
proc mixed;  
class water zone N blk ;  
model rtlarvae=water ;  
random blk(water*zone*N);  
lsmeans water /pdiff cl;  
run;
```

Water	Zone	Nitrogen	rep	larvae					
					full	low	100	4	2
					full	low	100	5	2
					full	low	100	6	2
					full	low	200	1	0
					full	low	200	2	0
					full	low	200	3	1
					full	low	200	4	0
					full	low	200	5	2
					full	low	200	6	0
					limit	high	50	1	1
					limit	high	50	2	2
					limit	high	50	3	1
					limit	high	50	4	4
					limit	high	50	5	3
					limit	high	50	6	1
					limit	high	100	1	1
					limit	high	100	2	0
					limit	high	100	3	0
					limit	high	100	4	9
					limit	high	100	5	0
					limit	high	100	6	1
					limit	high	200	1	0
					limit	high	200	2	0
					limit	high	200	3	0
					limit	high	200	4	0
					limit	high	200	5	0
					limit	high	200	6	2
					limit	medium	50	1	12
					limit	medium	50	2	0
					limit	medium	50	3	2
					limit	medium	50	4	0
					limit	medium	50	5	1
					limit	medium	50	6	0
					limit	medium	100	1	5
					limit	medium	100	2	0
					limit	medium	100	3	4
					limit	medium	100	4	1
					limit	medium	100	5	3
					limit	medium	100	6	1
					limit	medium	200	1	2
					limit	medium	200	2	7
					limit	medium	200	3	2
					limit	medium	200	4	3
					limit	medium	200	5	0
					limit	medium	200	6	0
					limit	low	50	1	0
					limit	low	50	2	0
					limit	low	50	3	0

limit	low	50	4	2
limit	low	50	5	3
limit	low	50	6	0
limit	low	100	1	0
limit	low	100	2	0
limit	low	100	3	1
limit	low	100	4	3
limit	low	100	5	0
limit	low	100	6	1
limit	low	200	1	0
limit	low	200	2	0
limit	low	200	3	0
limit	low	200	4	0
limit	low	200	5	1
limit	low	200	6	1

Yield for Western Corn Rootworm Plots in 2003

```
options ls=74 ps=55 nodate;
data wcrYIELD2003;
input water $ zone $ trt $ blk $ rep $ y;
sqrty=sqrt(y +.1);
datalines;

proc means;
var y;
class zone water trt;
proc glm;
class zone;
model y=zone;
means zone / lsd;
means zone/ tukey pdiff cl;
output out=out1 predicted= p1 student=s1;
proc gplot data=out1;
plot s1*p1;
symbol1 v=dot;
proc glm;
class zone;
model sqrty=zone;
means zone / lsd;
means zone/ tukey pdiff cl;
output out=out2 predicted= p2 student=s2;
proc gplot data=out2;
plot s2*p2;
symbol1 v=dot;
proc mixed;
class water zone blk trt rep;
model sqrty= water|zone|trt;
random blk(water*zone) rep(water*zone*blk) trt*rep(water*zone);
lsmeans water | zone | trt /pdiff cl;
run;
```

Water	Zone	N	rep	trt	grain wt								
						full	low	100	4	wcr	6.416507		
						full	low	100	5	wcr	7.25793		
						full	low	100	6	wcr	5.725276		
						full	low	200	1	wcr	7.449402		
						full	low	200	2	wcr	8.686065		
						full	low	200	3	wcr	7.59608		
						full	low	200	4	wcr	6.979944		
						full	low	200	5	wcr	10.41985		
						full	low	200	6	wcr	6.884647		
						limit	high	50	1	wcr	2.666116		
						limit	high	50	2	wcr	3.740291		
						limit	high	50	3	wcr	3.388966		
						limit	high	50	4	wcr	3.028858		
						limit	high	50	5	wcr	2.999435		
						limit	high	50	6	wcr	3.128986		
						limit	high	100	1	wcr	1.7272		
						limit	high	100	2	wcr	1.670988		
						limit	high	100	3	wcr	1.209875		
						limit	high	100	4	wcr	2.517681		
						limit	high	100	5	wcr	2.125954		
						limit	high	100	6	wcr	1.770238		
						limit	high	200	1	wcr	1.618729		
						limit	high	200	2	wcr	1.907254		
						limit	high	200	3	wcr	2.186557		
						limit	high	200	4	wcr	1.640247		
						limit	high	200	5	wcr	2.44522		
						limit	high	200	6	wcr	2.102679		
						limit	medium	50	1	wcr	3.808799		
						limit	medium	50	2	wcr	3.922541		
						limit	medium	50	3	wcr	4.053848		
						limit	medium	50	4	wcr	4.496078		
						limit	medium	50	5	wcr	3.991927		
						limit	medium	50	6	wcr	4.554047		
						limit	medium	100	1	wcr	3.857106		
						limit	medium	100	2	wcr	4.550094		
						limit	medium	100	3	wcr	4.495639		
						limit	medium	100	4	wcr	6.062987		
						limit	medium	100	5	wcr	5.878541		
						limit	medium	100	6	wcr	5.31203		
						limit	medium	200	1	wcr	3.76137		
						limit	medium	200	2	wcr	4.182521		
						limit	medium	200	3	wcr	5.367364		
						limit	medium	200	4	wcr	4.678767		
						limit	medium	200	5	wcr			
						limit	medium	200	6	wcr	5.723519		
						limit	low	50	1	wcr	5.75426		
						limit	low	50	2	wcr	6.996632		
						limit	low	50	3	wcr	5.973399		
full	high	50	1	wcr	9.079109								
full	high	50	2	wcr	8.556953								
full	high	50	3	wcr	7.379576								
full	high	50	4	wcr	5.999309								
full	high	50	5	wcr	6.442417								
full	high	50	6	wcr	6.075283								
full	high	100	1	wcr	10.51691								
full	high	100	2	wcr	9.476546								
full	high	100	3	wcr	9.563498								
full	high	100	4	wcr	6.13413								
full	high	100	5	wcr	6.599196								
full	high	100	6	wcr	7.427444								
full	high	200	1	wcr	7.694012								
full	high	200	2	wcr	8.911791								
full	high	200	3	wcr	8.911352								
full	high	200	4	wcr	5.73889								
full	high	200	5	wcr	4.381459								
full	high	200	6	wcr	4.076245								
full	medium	50	1	wcr	6.808673								
full	medium	50	2	wcr	5.431041								
full	medium	50	3	wcr	5.470126								
full	medium	50	4	wcr	5.829795								
full	medium	50	5	wcr	8.148099								
full	medium	50	6	wcr	8.513477								
full	medium	100	1	wcr	7.089733								
full	medium	100	2	wcr	6.977309								
full	medium	100	3	wcr	9.169576								
full	medium	100	4	wcr	7.833663								
full	medium	100	5	wcr	8.252618								
full	medium	100	6	wcr	8.473953								
full	medium	200	1	wcr	8.446725								
full	medium	200	2	wcr	7.897341								
full	medium	200	3	wcr	9.306592								
full	medium	200	4	wcr	7.614085								
full	medium	200	5	wcr	6.424412								
full	medium	200	6	wcr	6.039272								
full	low	50	1	wcr	9.232814								
full	low	50	2	wcr	9.773415								
full	low	50	3	wcr	7.093686								
full	low	50	4	wcr	7.228506								
full	low	50	5	wcr	8.577593								
full	low	50	6	wcr	9.043099								
full	low	100	1	wcr	5.424015								
full	low	100	2	wcr	7.006733								
full	low	100	3	wcr	6.31111								

limit	low	50	4	wcr	6.645307	full	medium	200	4	control	9.881008
limit	low	50	5	wcr	5.584746	full	medium	200	5	control	8.739862
limit	low	50	6	wcr	5.380099	full	medium	200	6	control	8.38711
limit	low	100	1	wcr	6.317258	full	low	50	1	control	7.896463
limit	low	100	2	wcr	6.674731	full	low	50	2	control	7.768375
limit	low	100	3	wcr	6.425729	full	low	50	3	control	8.854152
limit	low	100	4	wcr	5.754699	full	low	50	4	control	8.986118
limit	low	100	5	wcr	6.33175	full	low	50	5	control	9.073071
limit	low	100	6	wcr	6.335702	full	low	50	6	control	9.092723
limit	low	200	1	wcr	7.449841	full	low	100	1	control	8.008594
limit	low	200	2	wcr	6.510486	full	low	100	2	control	7.204902
limit	low	200	3	wcr	6.520587	full	low	100	3	control	8.332837
limit	low	200	4	wcr	7.149898	full	low	100	4	control	7.369475
limit	low	200	5	wcr	.	full	low	100	5	control	7.465211
limit	low	200	6	wcr	6.492481	full	low	100	6	control	8.596038
full	high	50	1	control	8.718013	full	low	200	1	control	8.691115
full	high	50	2	control	7.99132	full	low	200	2	control	8.538948
full	high	50	3	control	6.704593	full	low	200	3	control	9.882911
full	high	50	4	control	6.338191	full	low	200	4	control	9.162
full	high	50	5	control	7.17449	full	low	200	5	control	9.382676
full	high	50	6	control	7.287024	full	low	200	6	control	9.023483
full	high	100	1	control	8.91212	limit	high	50	1	control	2.743956
full	high	100	2	control	8.38678	limit	high	50	2	control	2.099385
full	high	100	3	control	8.181694	limit	high	50	3	control	2.297005
full	high	100	4	control	6.30068	limit	high	50	4	control	2.581907
full	high	100	5	control	7.026056	limit	high	50	5	control	3.081996
full	high	100	6	control	7.19008	limit	high	50	6	control	2.801156
full	high	200	1	control	8.442773	limit	high	100	1	control	1.936458
full	high	200	2	control	7.498917	limit	high	100	2	control	2.48716
full	high	200	3	control	6.878353	limit	high	100	3	control	2.053164
full	high	200	4	control	5.989062	limit	high	100	4	control	2.389996
full	high	200	5	control	6.84139	limit	high	100	5	control	2.515156
full	high	200	6	control	7.915346	limit	high	100	6	control	1.750695
full	medium	50	1	control	6.55539	limit	high	200	1	control	1.674721
full	medium	50	2	control	7.418771	limit	high	200	2	control	1.860923
full	medium	50	3	control	8.643906	limit	high	200	3	control	1.581181
full	medium	50	4	control	8.817702	limit	high	200	4	control	1.885845
full	medium	50	5	control	7.452256	limit	high	200	5	control	2.37759
full	medium	50	6	control	8.210788	limit	high	200	6	control	2.36749
full	medium	100	1	control	6.814163	limit	medium	50	1	control	3.624903
full	medium	100	2	control	8.167641	limit	medium	50	2	control	3.843822
full	medium	100	3	control	8.90718	limit	medium	50	3	control	4.475438
full	medium	100	4	control	8.153698	limit	medium	50	4	control	4.093482
full	medium	100	5	control	8.297741	limit	medium	50	5	control	3.875844
full	medium	100	6	control	7.646802	limit	medium	50	6	control	4.364441
full	medium	200	1	control	7.260126	limit	medium	100	1	control	4.467204
full	medium	200	2	control	8.850639	limit	medium	100	2	control	4.370919
full	medium	200	3	control	9.696563	limit	medium	100	3	control	4.872435

limit	medium	100	4	control	4.731136
limit	medium	100	5	control	4.894393
limit	medium	100	6	control	4.877924
limit	medium	200	1	control	3.69934
limit	medium	200	2	control	3.983364
limit	medium	200	3	control	4.482904
limit	medium	200	4	control	4.169456
limit	medium	200	5	control	4.485539
limit	medium	200	6	control	4.587203
limit	low	50	1	control	6.989276
limit	low	50	2	control	6.581081
limit	low	50	3	control	6.861372
limit	low	50	4	control	6.345144
limit	low	50	5	control	6.528199
limit	low	50	6	control	6.412774
limit	low	100	1	control	6.961829
limit	low	100	2	control	6.865324
limit	low	100	3	control	5.997003
limit	low	100	4	control	6.228329
limit	low	100	5	control	5.892484
limit	low	100	6	control	6.309243
limit	low	200	1	control	6.527504
limit	low	200	2	control	6.907703
limit	low	200	3	control	6.100315
limit	low	200	4	control	6.532774
limit	low	200	5	control	7.01332
limit	low	200	6	control	7.525046

Densities of Western Corn Rootworm Larvae in 2003

```
options ls=74 ps=55 nodate;
data wcrlarvae2004;
input water $ zone $ gene $ side $ blk y;
sqrty=sqrt(y +.5);
datalines;

proc means;
var y;
class zone water;
proc mixed;
class water zone blk;
model sqrty= water|zone|gene;
random side(water*zone) blk(water*zone*side);
lsmeans water | zone /pdiff cl;
run;
```


full	med	susc	south	15	.	full	med	res	north	8	0
full	med	res	south	1	1	full	med	res	north	9	0
full	med	res	south	2	0	full	med	res	north	10	0
full	med	res	south	3	0	full	med	res	north	11	0
full	med	res	south	4	0	full	med	res	north	12	0
full	med	res	south	5	0	full	med	res	north	13	0
full	med	res	south	6	0	full	med	res	north	14	0
full	med	res	south	7	0	full	med	res	north	15	0
full	med	res	south	8	0	full	low	susc	south	1	1
full	med	res	south	9	1	full	low	susc	south	2	2
full	med	res	south	10	0	full	low	susc	south	3	0
full	med	res	south	11	0	full	low	susc	south	4	0
full	med	res	south	12	0	full	low	susc	south	5	1
full	med	res	south	13	0	full	low	susc	south	6	3
full	med	res	south	14	0	full	low	susc	south	7	1
full	med	res	south	15	0	full	low	susc	south	8	6
full	med	susc	north	1	0	full	low	susc	south	9	0
full	med	susc	north	2	0	full	low	susc	south	10	1
full	med	susc	north	3	2	full	low	susc	south	11	2
full	med	susc	north	4	1	full	low	susc	south	12	3
full	med	susc	north	5	2	full	low	susc	south	13	2
full	med	susc	north	6	1	full	low	susc	south	14	0
full	med	susc	north	7	1	full	low	susc	south	15	0
full	med	susc	north	8	5	full	low	res	south	1	0
full	med	susc	north	9	2	full	low	res	south	2	0
full	med	susc	north	10	3	full	low	res	south	3	0
full	med	susc	north	11	1	full	low	res	south	4	0
full	med	susc	north	12	5	full	low	res	south	5	0
full	med	susc	north	13	3	full	low	res	south	6	0
full	med	susc	north	14	1	full	low	res	south	7	0
full	med	susc	north	15	1	full	low	res	south	8	0
full	med	res	north	1	0	full	low	res	south	9	0
full	med	res	north	2	0	full	low	res	south	10	1
full	med	res	north	3	0	full	low	res	south	11	0
full	med	res	north	4	0	full	low	res	south	12	0
full	med	res	north	5	0	full	low	res	south	13	0
full	med	res	north	6	0	full	low	res	south	14	0
full	med	res	north	7	0	full	low	res	south	15	0

full	low	susc	north	1	0	limit	high	susc	south	9	.
full	low	susc	north	2	0	limit	high	susc	south	10	.
full	low	susc	north	3	0	limit	high	susc	south	11	.
full	low	susc	north	4	1	limit	high	susc	south	12	.
full	low	susc	north	5	5	limit	high	susc	south	13	.
full	low	susc	north	6	2	limit	high	susc	south	14	.
full	low	susc	north	7	0	limit	high	susc	south	15	.
full	low	susc	north	8	1	limit	high	res	south	1	0
full	low	susc	north	9	0	limit	high	res	south	2	0
full	low	susc	north	10	1	limit	high	res	south	3	1
full	low	susc	north	11	1	limit	high	res	south	4	0
full	low	susc	north	12	2	limit	high	res	south	5	0
full	low	susc	north	13	0	limit	high	res	south	6	0
full	low	susc	north	14	0	limit	high	res	south	7	.
full	low	susc	north	15	0	limit	high	res	south	8	.
full	low	res	north	1	0	limit	high	res	south	9	.
full	low	res	north	2	0	limit	high	res	south	10	.
full	low	res	north	3	0	limit	high	res	south	11	.
full	low	res	north	4	0	limit	high	res	south	12	.
full	low	res	north	5	0	limit	high	res	south	13	.
full	low	res	north	6	0	limit	high	res	south	14	.
full	low	res	north	7	0	limit	high	res	south	15	.
full	low	res	north	8	0	limit	high	susc	north	1	0
full	low	res	north	9	0	limit	high	susc	north	2	1
full	low	res	north	10	0	limit	high	susc	north	3	0
full	low	res	north	11	0	limit	high	susc	north	4	2
full	low	res	north	12	0	limit	high	susc	north	5	2
full	low	res	north	13	0	limit	high	susc	north	6	3
full	low	res	north	14	0	limit	high	susc	north	7	2
full	low	res	north	15	0	limit	high	susc	north	8	3
limit	high	susc	south	1	2	limit	high	susc	north	9	4
limit	high	susc	south	2	0	limit	high	susc	north	10	0
limit	high	susc	south	3	2	limit	high	susc	north	11	5
limit	high	susc	south	4	4	limit	high	susc	north	12	.
limit	high	susc	south	5	4	limit	high	susc	north	13	.
limit	high	susc	south	6	1	limit	high	susc	north	14	.
limit	high	susc	south	7	.	limit	high	susc	north	15	.
limit	high	susc	south	8	.	limit	high	res	north	1	0

limit	high	res	north	2	0	limit	med	res	south	10	0
limit	high	res	north	3	0	limit	med	res	south	11	0
limit	high	res	north	4	0	limit	med	res	south	12	0
limit	high	res	north	5	0	limit	med	res	south	13	0
limit	high	res	north	6	0	limit	med	res	south	14	0
limit	high	res	north	7	0	limit	med	res	south	15	0
limit	high	res	north	8	0	limit	med	susc	north	1	1
limit	high	res	north	9	0	limit	med	susc	north	2	2
limit	high	res	north	10	0	limit	med	susc	north	3	3
limit	high	res	north	11	0	limit	med	susc	north	4	.
limit	high	res	north	12	0	limit	med	susc	north	5	.
limit	high	res	north	13	.	limit	med	susc	north	6	.
limit	high	res	north	14	.	limit	med	susc	north	7	.
limit	high	res	north	15	.	limit	med	susc	north	8	.
limit	med	susc	south	1	1	limit	med	susc	north	9	.
limit	med	susc	south	2	0	limit	med	susc	north	10	.
limit	med	susc	south	3	0	limit	med	susc	north	11	.
limit	med	susc	south	4	2	limit	med	susc	north	12	.
limit	med	susc	south	5	2	limit	med	susc	north	13	.
limit	med	susc	south	6	5	limit	med	susc	north	14	.
limit	med	susc	south	7	1	limit	med	susc	north	15	.
limit	med	susc	south	8	2	limit	med	res	north	1	0
limit	med	susc	south	9	1	limit	med	res	north	2	0
limit	med	susc	south	10	0	limit	med	res	north	3	0
limit	med	susc	south	11	4	limit	med	res	north	4	.
limit	med	susc	south	12	5	limit	med	res	north	5	.
limit	med	susc	south	13	2	limit	med	res	north	6	.
limit	med	susc	south	14	2	limit	med	res	north	7	.
limit	med	susc	south	15	7	limit	med	res	north	8	.
limit	med	res	south	1	0	limit	med	res	north	9	.
limit	med	res	south	2	0	limit	med	res	north	10	.
limit	med	res	south	3	0	limit	med	res	north	11	.
limit	med	res	south	4	0	limit	med	res	north	12	.
limit	med	res	south	5	1	limit	med	res	north	13	.
limit	med	res	south	6	0	limit	med	res	north	14	.
limit	med	res	south	7	0	limit	med	res	north	15	.
limit	med	res	south	8	0	limit	low	susc	south	1	0
limit	med	res	south	9	0	limit	low	susc	south	2	0

limit	low	susc	south	3	0	limit	low	susc	north	11	0
limit	low	susc	south	4	2	limit	low	susc	north	12	1
limit	low	susc	south	5	2	limit	low	susc	north	13	.
limit	low	susc	south	6	0	limit	low	susc	north	14	.
limit	low	susc	south	7	2	limit	low	susc	north	15	.
limit	low	susc	south	8	0	limit	low	res	north	1	0
limit	low	susc	south	9	2	limit	low	res	north	2	0
limit	low	susc	south	10	0	limit	low	res	north	3	0
limit	low	susc	south	11	0	limit	low	res	north	4	0
limit	low	susc	south	12	1	limit	low	res	north	5	0
limit	low	susc	south	13	2	limit	low	res	north	6	0
limit	low	susc	south	14	3	limit	low	res	north	7	1
limit	low	susc	south	15	1	limit	low	res	north	8	0
limit	low	res	south	1	0	limit	low	res	north	9	0
limit	low	res	south	2	0	limit	low	res	north	10	0
limit	low	res	south	3	0	limit	low	res	north	11	0
limit	low	res	south	4	0	limit	low	res	north	12	0
limit	low	res	south	5	0	limit	low	res	north	13	.
limit	low	res	south	6	2	limit	low	res	north	14	.
limit	low	res	south	7	0	limit	low	res	north	15	.
limit	low	res	south	8	0						
limit	low	res	south	9	0						
limit	low	res	south	10	0						
limit	low	res	south	11	0						
limit	low	res	south	12	0						
limit	low	res	south	13	0						
limit	low	res	south	14	0						
limit	low	res	south	15	0						
limit	low	susc	north	1	1						
limit	low	susc	north	2	0						
limit	low	susc	north	3	0						
limit	low	susc	north	4	0						
limit	low	susc	north	5	0						
limit	low	susc	north	6	0						
limit	low	susc	north	7	0						
limit	low	susc	north	8	0						
limit	low	susc	north	9	1						
limit	low	susc	north	10	0						

Yield for Western Corn Rootworm Plots in 2004

```
data wcryield2004;
input water $ zone $ blk $ trt $ rep wt;
rtwt=sqrt(larvae+3/8);
lgwt=log(larvae+1);
datalines;

proc means;
var wt;
class water zone trt ;
proc mixed;
class water zone blk trt rep;
model wt=water | zone | trt ;
random blk(water*zone) blk*rep(water*zone);
lsmeans water | zone | trt /pdiff cl;

run;
```

water	zone	blk	trt	rep	mt wt						
						full	low	south	susc	1	3.725799
						full	low	south	susc	2	3.637265
						full	low	south	susc	3	4.933302
						full	low	south	susc	4	4.53244
						full	low	south	susc	5	5.626817
						full	low	north	res	1	5.946522
						full	low	north	res	2	6.895802
						full	low	north	res	3	8.18938
						full	low	north	res	4	6.667089
						full	low	north	res	5	8.486952
						full	low	north	susc	1	7.98526
						full	low	north	susc	2	4.798042
						full	low	north	susc	3	5.850611
						full	low	north	susc	4	5.284978
						full	low	north	susc	5	4.470959
						limit	high	south	res	1	.
						limit	high	south	res	2	7.977882
						limit	high	south	res	3	.
						limit	high	south	res	4	5.971115
						limit	high	south	res	5	.
						limit	high	south	susc	1	6.453133
						limit	high	south	susc	2	.
						limit	high	south	susc	3	.
						limit	high	south	susc	4	9.158333
						limit	high	south	susc	5	.
						limit	high	north	res	1	.
						limit	high	north	res	2	7.68031
						limit	high	north	res	3	7.360605
						limit	high	north	res	4	8.86322
						limit	high	north	res	5	.
						limit	high	north	susc	1	6.876128
						limit	high	north	susc	2	4.473418
						limit	high	north	susc	3	5.066103
						limit	high	north	susc	4	5.929308
						limit	high	north	susc	5	.
						limit	med	south	res	1	7.763925
						limit	med	south	res	2	.
						limit	med	south	res	3	.
						limit	med	south	res	4	7.03844
						limit	med	south	res	5	.
						limit	med	south	susc	1	.
						limit	med	south	susc	2	10.74456
						limit	med	south	susc	3	.
						limit	med	south	susc	4	8.929621
						limit	med	south	susc	5	.
						limit	med	north	res	1	4.505388
						limit	med	north	res	2	5.995708
						limit	med	north	res	3	4.217653

limit	med	north	res	4	4.849687
limit	med	north	res	5	.
limit	med	north	susc	1	9.362453
limit	med	north	susc	2	7.434383
limit	med	north	susc	3	7.363064
limit	med	north	susc	4	8.644345
limit	med	north	susc	5	.
limit	low	south	res	1	7.272071
limit	low	south	res	2	6.317873
limit	low	south	res	3	5.432534
limit	low	south	res	4	6.713816
limit	low	south	res	5	7.011388
limit	low	south	susc	1	6.101457
limit	low	south	susc	2	7.281908
limit	low	south	susc	3	5.710432
limit	low	south	susc	4	5.371053
limit	low	south	susc	5	7.358145
limit	low	north	res	1	6.777757
limit	low	north	res	2	4.739019
limit	low	north	res	3	5.009539
limit	low	north	res	4	6.389192
limit	low	north	res	5	.
limit	low	north	susc	1	5.575172
limit	low	north	susc	2	6.101457
limit	low	north	susc	3	7.188455
limit	low	north	susc	4	6.246554
limit	low	north	susc	5	.

Survival of Western Bean Cutworm Larvae in 2004

```
options ls=74 ps=55 nodate;
data wclarvae2003;
input water $ zone $ blk y;
sqrty=sqrt(y+.5);
datalines;

proc means;
var y;
class zone water;
proc glm;
class zone;
model y=zone;
means zone / lsd;
means zone/ tukey pdiff cl;
output out=out1 predicted= p1 student=s1;
proc gplot data=out1;
plot s1*p1;
symbol1 v=dot;
proc glm;
class zone;
model sqrty=zone;
means zone / lsd;
means zone/ tukey pdiff cl;
output out=out2 predicted= p2 student=s2;
proc gplot data=out2;
plot s2*p2;
symbol1 v=dot;
proc mixed;
class water zone blk;
model sqrty= water|zone;
random blk(water*zone);
lsmeans water | zone /pdiff cl;
run;
```

Water	Zone	Rep	larvae
Full	High	1	0
Full	High	2	3
Full	High	3	3
Full	High	4	0
Full	High	5	15
Full	High	6	1
Full	Medium	1	0
Full	Medium	2	0
Full	Medium	3	3
Full	Medium	4	0
Full	Medium	5	0
Full	Medium	6	5
Full	Low	1	0
Full	Low	2	0
Full	Low	3	0
Full	Low	4	5
Full	Low	5	.
Full	Low	6	1
Limited	High	1	0
Limited	High	2	1
Limited	High	3	0
Limited	High	4	6
Limited	High	5	0
Limited	High	6	1
Limited	Medium	1	0
Limited	Medium	2	0
Limited	Medium	3	0
Limited	Medium	4	0
Limited	Medium	5	0
Limited	Medium	6	0
Limited	Low	1	0
Limited	Low	2	0
Limited	Low	3	0
Limited	Low	4	2
Limited	Low	5	5
Limited	Low	6	0

Yield of Western Bean Cutworm Plots in 2004

```
data ecbyield2004;
input water $ zone $ trt $ blk wt;
datalines;

proc means;
var wt;
class water zone trt ;
proc mixed;
class water zone blk trt;
model wt=water | zone | trt ;
random blk(water*zone);
lsmeans water | zone | trt /pdiff cl;
run;
```

Water	Zone	Trt	rep	Grain wt					
limit	low	wbc	1	4.77055	limit	med	control	4	6.56027
limit	low	wbc	2	5.31648	limit	med	control	5	7.606
limit	low	wbc	3	5.30291	limit	med	control	6	6.56726
limit	low	wbc	4	5.27965	limit	high	control	1	7.7021
limit	low	wbc	5	5.46346	limit	high	control	2	7.05504
limit	low	wbc	6	7.66816	limit	high	control	3	6.00841
limit	med	wbc	1	8.02625	limit	high	control	4	6.99302
limit	med	wbc	2	9.94425	limit	high	control	5	6.75268
limit	med	wbc	3	5.11261	limit	high	control	6	8.00793
limit	med	wbc	4	7.43019	full	low	control	1	7.89474
limit	med	wbc	5	5.56844	full	low	control	2	8.74545
limit	med	wbc	6	4.76215	full	low	control	3	7.87518
limit	high	wbc	1	4.78735	full	low	control	4	7.7141
limit	high	wbc	2	7.95372	full	low	control	5	7.84869
limit	high	wbc	3	6.10837	full	low	control	6	7.66326
limit	high	wbc	4	6.28474	full	med	control	1	9.64214
limit	high	wbc	5	6.10477	full	med	control	2	7.82049
limit	high	wbc	6	7.68724	full	med	control	3	8.93148
full	low	wbc	1	8.22284	full	med	control	4	8.19661
full	low	wbc	2	5.83078	full	med	control	5	8.66241
full	low	wbc	3	6.2856	full	med	control	6	8.95786
full	low	wbc	4	7.07108	full	high	control	1	10.2348
full	low	wbc	5	7.78912	full	high	control	2	8.92631
full	low	wbc	6	5.60901	full	high	control	3	9.94096
full	med	wbc	1	9.48752	full	high	control	4	10.6415
full	med	wbc	2	7.74757	full	high	control	5	9.21269
full	med	wbc	3	8.41751	full	high	control	6	9.4333
full	med	wbc	4	10.9757					
full	med	wbc	5	8.80247					
full	med	wbc	6	8.80488					
full	high	wbc	1	6.88926					
full	high	wbc	2	8.57619					
full	high	wbc	3	8.38105					
full	high	wbc	4	8.55					
full	high	wbc	5	7.97088					
full	high	wbc	6	7.20524					
limit	low	control	1	6.95089					
limit	low	control	2	5.97699					
limit	low	control	3	6.88244					
limit	low	control	4	8.58148					
limit	low	control	5	8.97698					
limit	low	control	6	8.15823					
limit	med	control	1	7.4248					
limit	med	control	2	6.5785					
limit	med	control	3	8.20744					

Density of Banks Grass Mites in 2003

```
options ls=74 ps=55 nodate;  
data bgm2003;  
input water $ zone $ blk N $ mites;  
sqrtmite= sqrt (mites + .5);  
datalines;
```

```
proc means;  
var wt;  
class water zone N ;  
proc mixed;  
class water zone N blk ;  
model sqrtmite=water | zone | N ;  
random blk(water*zone*N);  
lsmeans water | zone | N /pdiff cl;  
run;
```

water	zone	row	N	mites	water	zone	row	N	mites
full	high	1	50	59	full	low	4	50	93
full	high	2	50	154	full	low	5	50	130
full	high	3	50	83.5	full	low	6	50	102.5
full	high	4	50	168	full	low	1	100	27
full	high	5	50	63	full	low	2	100	18
full	high	6	50	91	full	low	3	100	145
full	high	1	100	366.5	full	low	4	100	46
full	high	2	100	360.5	full	low	5	100	63.5
full	high	3	100	364	full	low	6	100	113.5
full	high	4	100	669.5	full	low	1	200	124
full	high	5	100	217.5	full	low	2	200	606
full	high	6	100	719.5	full	low	3	200	22
full	high	1	200	405.5	full	low	4	200	161.5
full	high	2	200	489.5	full	low	5	200	78
full	high	3	200	328	full	low	6	200	513.5
full	high	4	200	813.5	limit	high	1	50	167
full	high	5	200	1347.5	limit	high	2	50	507.5
full	high	6	200	142.5	limit	high	3	50	623
full	medium	1	50	40.5	limit	high	4	50	243.5
full	medium	2	50	102.5	limit	high	5	50	80.5
full	medium	3	50	156	limit	high	6	50	471
full	medium	4	50	65	limit	high	1	100	379
full	medium	5	50	78	limit	high	2	100	92.5
full	medium	6	50	52	limit	high	3	100	131
full	medium	1	100	148.5	limit	high	4	100	471.5
full	medium	2	100	467.5	limit	high	5	100	134.5
full	medium	3	100	127.5	limit	high	6	100	109.5
full	medium	4	100	208.5	limit	high	1	200	181
full	medium	5	100	185	limit	high	2	200	111.5
full	medium	6	100	180.5	limit	high	3	200	57
full	medium	1	200	77	limit	high	4	200	125
full	medium	2	200	54.5	limit	high	5	200	927.5
full	medium	3	200	31.5	limit	high	6	200	1129.5
full	medium	4	200	55.5	limit	medium	1	50	112
full	medium	5	200	45.5	limit	medium	2	50	161
full	medium	6	200	89	limit	medium	3	50	295
full	low	1	50	324	limit	medium	4	50	78
full	low	2	50	89.5	limit	medium	5	50	153.5
full	low	3	50	90.5	limit	medium	6	50	35
					limit	medium	1	100	196.5
					limit	medium	2	100	662.5

limit	medium	3	100	234.5
limit	medium	4	100	886
limit	medium	5	100	1148
limit	medium	6	100	802
limit	medium	1	200	246
limit	medium	2	200	350.5
limit	medium	3	200	199.5
limit	medium	4	200	148
limit	medium	5	200	114.5
limit	medium	6	200	199.5
limit	low	1	50	48
limit	low	2	50	77
limit	low	3	50	85
limit	low	4	50	91.5
limit	low	5	50	39.5
limit	low	6	50	186
limit	low	1	100	911.5
limit	low	2	100	783.5
limit	low	3	100	1842.5
limit	low	4	100	555.5
limit	low	5	100	1861
limit	low	6	100	807
limit	low	1	200	224.5
limit	low	2	200	889.5
limit	low	3	200	381.5
limit	low	4	200	1413
limit	low	5	200	750
limit	low	6	200	510

Yield of Banks Grass Mite Plots in 2003

```
data BGMyield2003;
input water $ zone $ N blk trt $ wt;
rtwt=sqrt(larvae+.5);
lgwt=log(larvae+1);
datalines;

proc means;
var wt;
class water zone trt N;
proc mixed;
class water zone N blk trt;
model wt=water | zone | N | trt ;
random blk(water*zone*N);
lsmeans water | zone | N | trt /pdiff cl;
run;
```

Water	Zone	N	rep	trt	grain wt								
						full	low	100	4	bgm	4.82281		
						full	low	100	5	bgm	5.090695		
						full	low	100	6	bgm	4.852673		
						full	low	200	1	bgm			
						full	low	200	2	bgm	7.398899		
						full	low	200	3	bgm	8.252618		
						full	low	200	4	bgm	7.754176		
						full	low	200	5	bgm	6.792425		
						full	low	200	6	bgm	7.676006		
						limit	high	50	1	bgm	3.035885		
						limit	high	50	2	bgm	2.627909		
						limit	high	50	3	bgm	3.088584		
						limit	high	50	4	bgm	2.944101		
						limit	high	50	5	bgm	2.338505		
						limit	high	50	6	bgm	3.075409		
						limit	high	100	1	bgm	1.533532		
						limit	high	100	2	bgm	1.201091		
						limit	high	100	3	bgm	2.143959		
						limit	high	100	4	bgm	1.647274		
						limit	high	100	5	bgm	2.224764		
						limit	high	100	6	bgm	2.328844		
						limit	high	200	1	bgm	0.974487		
						limit	high	200	2	bgm	2.039879		
						limit	high	200	3	bgm	2.082477		
						limit	high	200	4	bgm	2.747799		
						limit	high	200	5	bgm	3.578242		
						limit	high	200	6	bgm	3.011731		
						limit	medium	50	1	bgm	3.909366		
						limit	medium	50	2	bgm	4.672619		
						limit	medium	50	3	bgm	3.994562		
						limit	medium	50	4	bgm	4.174616		
						limit	medium	50	5	bgm	3.936154		
						limit	medium	50	6	bgm	4.507496		
						limit	medium	100	1	bgm	3.812752		
						limit	medium	100	2	bgm	3.404776		
						limit	medium	100	3	bgm	5.107383		
						limit	medium	100	4	bgm	4.63046		
						limit	medium	100	5	bgm	5.215855		
						limit	medium	100	6	bgm	4.817101		
						limit	medium	200	1	bgm	19.82965		
						limit	medium	200	2	bgm	3.25678		
						limit	medium	200	3	bgm	3.502708		
						limit	medium	200	4	bgm	4.263326		
						limit	medium	200	5	bgm	4.199648		
						limit	medium	200	6	bgm	6.086701		
						limit	low	50	1	bgm	6.331311		
						limit	low	50	2	bgm	6.904848		
						limit	low	50	3	bgm	5.708149		

limit	low	50	4	bgm	5.43148	full	medium	200	4	control	9.881008
limit	low	50	5	bgm	6.13413	full	medium	200	5	control	8.739862
limit	low	50	6	bgm	5.475835	full	medium	200	6	control	8.38711
limit	low	100	1	bgm	4.911959	full	low	50	1	control	7.896463
limit	low	100	2	bgm	6.612371	full	low	50	2	control	7.768375
limit	low	100	3	bgm	5.786758	full	low	50	3	control	8.854152
limit	low	100	4	bgm	6.34712	full	low	50	4	control	8.986118
limit	low	100	5	bgm	5.622952	full	low	50	5	control	9.073071
limit	low	100	6	bgm	4.966414	full	low	50	6	control	9.092723
limit	low	200	1	bgm	5.974277	full	low	100	1	control	8.008594
limit	low	200	2	bgm	5.897864	full	low	100	2	control	7.204902
limit	low	200	3	bgm	6.062987	full	low	100	3	control	8.332837
limit	low	200	4	bgm	6.422655	full	low	100	4	control	7.369475
limit	low	200	5	bgm	5.607582	full	low	100	5	control	7.465211
limit	low	200	6	bgm	6.48765	full	low	100	6	control	8.596038
full	high	50	1	control	8.718013	full	low	200	1	control	8.691115
full	high	50	2	control	7.99132	full	low	200	2	control	8.538948
full	high	50	3	control	6.704593	full	low	200	3	control	9.882911
full	high	50	4	control	6.338191	full	low	200	4	control	9.162
full	high	50	5	control	7.17449	full	low	200	5	control	9.382676
full	high	50	6	control	7.287024	full	low	200	6	control	9.023483
full	high	100	1	control	8.91212	limit	high	50	1	control	2.743956
full	high	100	2	control	8.38678	limit	high	50	2	control	2.099385
full	high	100	3	control	8.181694	limit	high	50	3	control	2.297005
full	high	100	4	control	6.30068	limit	high	50	4	control	2.581907
full	high	100	5	control	7.026056	limit	high	50	5	control	3.081996
full	high	100	6	control	7.19008	limit	high	50	6	control	2.801156
full	high	200	1	control	8.442773	limit	high	100	1	control	1.936458
full	high	200	2	control	7.498917	limit	high	100	2	control	2.48716
full	high	200	3	control	6.878353	limit	high	100	3	control	2.053164
full	high	200	4	control	5.989062	limit	high	100	4	control	2.389996
full	high	200	5	control	6.84139	limit	high	100	5	control	2.515156
full	high	200	6	control	7.915346	limit	high	100	6	control	1.750695
full	medium	50	1	control	6.55539	limit	high	200	1	control	1.674721
full	medium	50	2	control	7.418771	limit	high	200	2	control	1.860923
full	medium	50	3	control	8.643906	limit	high	200	3	control	1.581181
full	medium	50	4	control	8.817702	limit	high	200	4	control	1.885845
full	medium	50	5	control	7.452256	limit	high	200	5	control	2.37759
full	medium	50	6	control	8.210788	limit	high	200	6	control	2.36749
full	medium	100	1	control	6.814163	limit	medium	50	1	control	3.624903
full	medium	100	2	control	8.167641	limit	medium	50	2	control	3.843822
full	medium	100	3	control	8.90718	limit	medium	50	3	control	4.475438
full	medium	100	4	control	8.153698	limit	medium	50	4	control	4.093482
full	medium	100	5	control	8.297741	limit	medium	50	5	control	3.875844
full	medium	100	6	control	7.646802	limit	medium	50	6	control	4.364441
full	medium	200	1	control	7.260126	limit	medium	100	1	control	4.467204
full	medium	200	2	control	8.850639	limit	medium	100	2	control	4.370919
full	medium	200	3	control	9.696563	limit	medium	100	3	control	4.872435

limit	medium	100	4	control	4.731136
limit	medium	100	5	control	4.894393
limit	medium	100	6	control	4.877924
limit	medium	200	1	control	3.69934
limit	medium	200	2	control	3.983364
limit	medium	200	3	control	4.482904
limit	medium	200	4	control	4.169456
limit	medium	200	5	control	4.485539
limit	medium	200	6	control	4.587203
limit	low	50	1	control	6.989276
limit	low	50	2	control	6.581081
limit	low	50	3	control	6.861372
limit	low	50	4	control	6.345144
limit	low	50	5	control	6.528199
limit	low	50	6	control	6.412774
limit	low	100	1	control	6.961829
limit	low	100	2	control	6.865324
limit	low	100	3	control	5.997003
limit	low	100	4	control	6.228329
limit	low	100	5	control	5.892484
limit	low	100	6	control	6.309243
limit	low	200	1	control	6.527504
limit	low	200	2	control	6.907703
limit	low	200	3	control	6.100315
limit	low	200	4	control	6.532774
limit	low	200	5	control	7.01332
limit	low	200	6	control	7.525046