THE EFFECT OF SOME MICRONUTRIENTS ON THE RESISTANCE OF HIGHLAND BENTGRASS TO FALL ARMYWORMS

by

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INTRODUCTION

The pesticide problem and re-evaluations

Many methods are now being examined in attempts to effectively deal with insect pests. Pesticides used alone may have some distinct and immediate advantages, but they are falling from favor, giving way to integrated pest control. Chemical control is a method which can be subjected to rational, scientific, and practical planning. It is mainly a matter of what chemical to use, when to use it, where to place it, and how to get it there. Except in rare cases, such as in the outbreak of a new pest, the problem to be dealt with can and must be handled in a matter of days at the most. As long as there is a pesticide registered to kill the pest and as long as there is a feasible way to do it, dealing with a pest problem in this way requires no great imagination or knowledge of the biology of the situation.

Integrated pest management is a more difficult method of handling pest populations. In dealing with the total biological situation in which the pest problem is occurring, it can develop into an almost insurmountable complex to understand. Predators, parasites, resistant varieties, soil conditions, crop conditions, and a host of environmental factors enter into this system of control. Shifting away from our dependence on chemical pest control will, therefore, occur slowly.

Recent EPA restrictions on the use and labeling of pesticides raise doubts about their future availability for the homeowner's or groundskeeper's use. When pesticide manufacturers have to do more intensive research for their labels, food and fiber crop research will take precedence over ornamental and turf research. Many chemicals, then, which formerly could be used on turf and ornamentals may soon no longer be registered for such use.

More generally, however, there are several problems with pesticides. These have been summarized by Adkisson (1972): insecticide resistant strains of most pests eventually appear, beneficial insects are destroyed which leads to a resurgence of the pest, secondary pests can be unleashed from their natural control, there may be residue hazards, there exist poison hazards to the workers, and ecosystems are simplified to create imbalances in food chains by disturbing the decomposers and earthworms.

It has been noted that even though more pesticides are being used, the pest problem keeps getting worse (Brannan 1952, Huffaker & Smith 1972). A good example of a pesticide syndrome is cotton (Adkisson 1972, van den Bosch 1971, Eveleens et al. 1973). Here pesticides used on boll weevils destroyed the natural enemies of the previously unimportant tobacco budworm. The budworm quickly developed resistance to all the insecticides applied against it. Other problems developed, including drifts over into fruit orchards which unleashed the brown soft scale there. Every year the tobacco budworm became an uncontrollable pest, nearly wiping out the crop in N.E. New Mexico. Overuse of pesticides leads to earlier development of insecticide resistance. It is commonly known, as another example, that spraying with sevin kills predatory mites while leaving phytophagus mites unaffected. Mite outbreaks thus may occur.

Dietrick (1972) explains that broad spectrum pesticides can have proportionally more effect on predators and parasites, which move around more, than on the more sedentary plant feeding pests.

Hostplant resistance

Hostplant resistance plays an important role in pest management. Its value has been widely recognized (Adkisson 1972, Brannan 1952, Dietrick 1972, Howard 1945, Huffaker and Smith 1972, Leuck 1972, Painter 1951). Some feel that resistant varieties are the ultimate solution to our pest problems. This may not be so, as there are problems with the practice.

First, breeding and selecting for resistance takes several years. Thus, the process is slow and costly. Second, there is the possibility that the pest can mutate and overcome the plant's resistance. The result is that races of a certain insect develop which can overcome the various genetic bases for resistance in its host (Painter 1951). This is an evolutionary must on the part of both the plant and the insect. The third point relates to the interesting fact that resistant varieties must be registered with the EPA. A problem may develop in genetically altering the plant in that high concentrations of plant toxicants, or new ones, may be selected for. The nutritional value of the food may also be adversely affected (Kehr 1973). Plant breeders should be aware of the quality of the resistant plants they produce.

Fertilizer induced resistance should be particularly examined on this point when it is applied to food crops. Abnormally high concentrations of any one element, while possibly imparting resistance to a pest, could be detrimental to animal health. When used as foliar sprays, however, micronutrients are considered to be nutritional plant sprays rather than pesticides according to The Pesticide Handbook -- Entoma, 24th ed. (Leuck et al. 1974). Registration with the EPA could be avoided.

Resistance, and induced resistance in the many cases where genetically resistant plants are not available, is probably one of the most important elements in integrated controls on home landscapes and public grounds. Here, populations of pests are usually not sizable enough or predictable enough to be able to use predators and parasites effectively. An adequate pest supply must be present to feed the enemies of the pest. Crop rotations, another method of non-chemical control, cannot easily be adapted to the domestic scenes either. Crop variability is also not a great issue on small landscapes (except in such situations as the American elm). Resistance seems to be the most viable alternative to pesticides in this context, then.

There are three types of resistance (Painter, 1951); antibiosis, tolerance, and nonpreference. This study will attempt to discover nonpreference only. Preference is especially relevant to the varied landscapes of golf courses and homes when an omnivorous pest such as the fall armyworm invades. Any nonpreferred hosts could be readily passed by. Variation in the crop community offers an omnivorous pest a wide choice, opening up the possibility of there being a highly susceptible "trap" crop somewhere in the community. On a golf course, the most favored crop unfortunately is the bentgrass on the greens.

Induced resistance in pest management

Induced resistance has been defined by Painter (1951) as being the temporarily increased resistance resulting from some condition of the plant or environment, such as changes in the amounts of water or in soil fertility. He further states that induced resistance may be of great value to horticulturalists. In home landscapes, where the total area is small, changes in soil fertility resulting in induced resistance can be easily and practically applied. It is then necessary to know how to fertilize for optimal resistance to any insect pests.

Manipulation of soil fertility can often alter the level of pest resistance or susceptibility in plants, as will be discussed later (pp. 15-19). It is a common assertion of organic gardeners and farmers, along with some soil scientists and entomologists (Dietrick 1972, Haseman 1946, Howard 1945, Rodale 1971), that soils treated with organic fertilizers are healthier and more resistant to pests than when chemical fertilizers are used. The theory is that the balance of nutrients in their total complex is important.

Organic gardening advocates maintain that chemical fertilizers throw the natural nutrient balance off. Just what this "balance" is would be difficult to determine and establish chemically. Furthermore, there would likely be a different optimal nutrient complex for each plant species. The many interactions of nutrients in their uptake by the plants are hard to sort out, particularly in view of all the micro-nutrients in the soil used by plants. It is generally known, however, that the concentration of some elements in the soil does affect the uptake of others. For example, high potassium levels inhibit magnesium uptake. It is plausable that natural fertilization and soil conditioning with compost, manure, or other organic materials helps create a favorable soil mineral balance for most plants. That a balanced nutrition can affect insect resistance is open to question, but should be studied. If it is so, this could be a general, practical method of inducing resistance on lawns, gardens, and grounds.

The use of organic methods by gardeners, farmers, and groundskeepers has collectively been called eco-agriculture. Eco-agriculture refers to agriculture practiced by the returning of natural substances (manure, compost, fish fertilizers, seaweed) to the soil rather than applying chemical substances devoid of organic origins. The claim is that naturally conditioned soils promote healthier, more resistant plants (Howard 1945, Hunter 1964, Rodale 1971).

Sir Albert Howard, in his research in India, provided a good example of how such theories develop. During his stay at the experimental farms in Pusa he began to feel that soil health had an immediate influence on plant health. Recognizing that crops were essentially free of pests and diseases in areas where peasants maintained a program of natural fertility without the use of chemical fertilizers and pesticides, he set about to test out the practice.

Feeling the experiment station at Pusa to be too confining, he established the Indore Institute of Plant Industry. Here he developed his Indore process of composting. Using only his compost and farmyard manure, he reported rather striking results. In eight years his crops and livestock proved to be considerably more healthy and free of pests than the surrounding areas, which depended on chemical fertilizers and pesticides. Three factors he considered essential to soil and plant health were earthworms, vigorous microbial populations, and my-corrhizal associations. He claimed all of these are deterred by either chemical pesticides or fertilizers, and encouraged by organic practices.

Although many practical results were reported by Howard and others using organic methods of soil maintenance, there are few reports of scientifically controlled experiments testing such conclusions (Howard 1945, Rodale 1971). Complicating matters is the fact that organic proponents rarely admit failures, which leaves one guessing at the true reliability of the methods. Nonetheless, the theory seems to have some merit. Recently (Dietrick 1972) the manager of a private enterprise based on biological controls stated that natural enemy complexes and food chains based on the decomposition of organic matter to humus are essential to the success of his firm's operation.

According to Hunter (1964) the balance of nutrients present is more important than the mere presence of them. Just what the proper balance may be for any particular crop or soil is largely unknown. Many experiments have been performed in this regard, as noted in a subsequent section. The tremendous variability noted in the effects of differing concentrations of the various elements tested may be due to nutrient antagonisms (e.g. Ca-K, N-Ca, N-P, P-Zn, and K-Mg interactions), creating differential uptake by the plants resulting in lesser or greater degrees of resistance to pests.

Again, the general idea is that chemical fertilizers, forcing greater growth from our crops, often create unfavorable balances of total soil nutrients, subjecting plants grown on them to greater degrees of insect damage. The thesis is that different crop and soil management practices can induce hostplant resistance or induce susceptibility of plants to pests.

Purpose and limitations of this study

This study was designed to examine how different levels of micronutrients applied to sand cultures of Highland bentgrass might affect the preference or nonpreference of fall armyworms to clippings of the variously treated grasses. No attempt was made to discover the physiological or anatomical basis for any nonpreference which might have occured, nor to determine the effects of the micronutrients on the physiology or anatomy of the grass. Any resistance noted was assumed to be caused by the higher rates of Mn, Zn, and Cu, or the lower rate of B.

Micronutrients were used in this study since much less work has previously been done with them than with nitrogen, phosphorus, and potassium as they affect insect feeding. It, in fact, is common knowledge that succulent tissue caused by excessive nitrogen, is often more susceptible to pests. There is very little, if any, knowledge as to the effects of micronutrients on plant resistance.

The experiment was not designed to prove or disprove the claims of eco-agriculturalists. Positive results would, however, indicate that there could be some scientific basis for contentions that high rates of nitrogen in particular, and chemical NPK fertilizers in general, may induce pest outbreaks by locking up some otherwise available micronutrients present in the soil. Natural fertilizers could not be used in this study due to their inherent variability. A well designed and controlled study in the scientific tradition would not have been possible.

The micronutrients used were selected more or less randomly, since the physiological basis for resistance is largly unknown. The four tested ($MnSO_4$, $ZnSO_4$, $CuSO_4$, and H_3BO_3) were selected so as to minimize any effects the carrier elements may have had.

No attempt has been made to claim that any results obtained from this greenhouse-culture solution study would be applicable to field situations. This study was simply to see if varying the levels of micronutrients applied to a sand culture of Highland bentgrass affects its resistance to fall armyworms.

THEORY AND EVIDENCE

The model

The theoretical basis for this study can be expressed in the following model:

A —affect→ B —affects→ C —affects→
(Soil management practices) (Micronutrient availability in soils) (Differing micronutrient levels in plants)

D —induces→ E —affects→ F
(Physiology of the plant) (Increased or decreased resistance to pests) (Pest outbreaks induced by soil management)

Evidence that steps A to B and to some extent, that C to E occur will be given in the following sections. It was shown (Table 13) that step B did affect step C. Step D will be left unknown, although the roles of Mn, Zn, Cu, and B in the physiology of the plant will be briefly discussed later. Step E to F may or may not occur, depending on various environmental factors. It is the intention of this experiment to help prove that steps C to E do or do not occur.

Most soils contain adequate levels of all the essential trace elements needed by plants. The actual availability of these elements to plants, however, is not assured. Chemical fertilizers, pesticides, soil compaction, and soil pH as affected by lime and acid fertilizer applications all play a role in whether or not all micronutrients present are available to plants. Only in severe cases will micronutrient deficiencies show up as actual physical deformities or discolorations in the leaves. Often these deficiencies go unnoticed as "hidden hunger". The plant may appear healthy, and have good growth or yield, yet still be deficient in one or more micronutrients. The "biological quality" (Voisin 1965) of the plant is affected.

Plants with poor biological quality, or hidden hunger, may have less resistance to environmental stresses such as drought, heat, cold, winds, diseases, and insect pests. It is interesting, therefore, to know how certain soil management practices may affect nutrient availability and biological quality of plants. And it is reasonable to speculate that both macronutrient and micronutrient availability in the soil will affect a plant's resistance to an environmental stress such as the fall armyworm.

Evidence: soil management affects micronutrient availability

The effect of soil pH on micronutrient availability is well known (Tisdale 1966). Other factors involved in micronutrient availability are not so well known.

Boron: It has been reported (Woodruff et al. 1960) that a potassium base saturation of anywhere from 4-20% will stunt soybeans due to an induced boron deficiency. When potassium was not added at such high rates, boron levels were adequate. Woodruff et al. (1960) further reports that alfalfa often develops boron deficiency when topdressed with K_2O. Chapman and Brown (1943) found that when orange and grapefruit seedlings were grown in solution cultures containing no potassium, the boron content of the leaves was 152-200 ppm. When grown in solutions containing potassium, the boron concentration was 20-40 ppm. No other micronutrient was so affected. They state that potassium deficiency favors boron accumulation.

Beckenbach (1944) reports that high applications of nitrogen and potassium will aggravate any boron deficiencies inherent in the soil. Nitrate levels of 9 and 16 M.E. NO_3^- could create boron deficiencies. He further states that when nitrate levels are high, the boron requirement is high.

Phosphorus fertilization at the rate of 900 pounds per acre reduced the boron content of sour orange leaves on a sandy loam soil in California (Bingham and Garber 1960). Liming at twice the recommended rate has been reported to fix boron in the soil (Midgley and Dunklee 1940).

Cooper et al. (1958) found that adding $Ca(NO_3)_2$ to boron contaminated well water at the rate of 3.6 grams per liter reduced the boron accumulation in grapefruit leaves grown under irrigation from the water. When no nitrogen was added, boron toxicity developed.

Copper: E. G. Mulder (1949) reports that as the ammonium nitrate applied per pot of rye-grass increased from 0.5 g to 4.0 g, the copper concentration of the plant tissue decreased from 8.8 ppm to 4.2 ppm.

High rates (360 and 900 lbs/acre) of monocalcium phosphate have been found to reduce copper availability in the soil (Bingham and Martin 1956). Likewise, Beeson et al. (1948) report that 40 ppm P_2O_5 reduced the copper uptake of soybeans. Bingham and Garber (1960) state that when phosphorus applications are increased from 100 lbs/acre to 900 lbs/acre, the copper concentration of sour orange leaves decreased from 5 ppm to 1 ppm.

Reuther and Smith (1954) state that liming reduces copper availability in the soil. As might be expected, prolonged use of bordeaux mixtures on Florida soils can produce copper toxicity (Reuther and Smith 1954).

Manganese: Voisin (1965) found that increasing the applications of lime from 20g to 52g per pot of oatgrass decreased the manganese concentration of the tissue from 202 ppm to 59 ppm. High rates of P_2O_5 (40 ppm) reduce the manganese concentration in soybean leaves (Beeson et al. 1948). Phosphorus rates of 900 lbs P/acre were also found to reduce the manganese concentration in sour orange seedlings (Bingham and Garber 1960). Bradfield et al. (1934) state that waterlogging a New York soil increased manganese availability. Organic matter additions, through mulches, have been found to decrease manganese availability (Sherman and Fujimoto 1947).

Zinc: A study in Australia by Lonergan (1951) reveals that high rates of P_2O_5 (960 mg monosodium phosphate per pot) created zinc deficiency in flax. Bingham and Garber (1960) also report that high phosphorus rates (900 lbs P/acre) reduced zinc levels within sour orange seedlings. Chapman et al. (1937) found that when the nitrate concentration was increased tenfold from a low rate to a high rate, zinc deficiencies were more apt to occur in citrus species. Lott (1938) states that lime additions depress zinc availability in soils.

Millikan (1953) reveals that secretions from alfalfa roots make zinc more available in soils. Egalaby (1950) feels that soils with low Si/Mg ratios may fix zinc.

Iron: D. Mulder (1949) shows that potassium fertilizers increase iron uptake in some fruit trees. Both copper (Anne and Dupuis 1953) and zinc (Chapman et al. 1940) in excessive amounts have been found to reduce iron availability to plants. Martin et al. (1956) found that fumigation with carbon disulfide increases iron availability in soils. Poor soil aeration tends to decrease iron availability (Wallihan et al. 1961).

Molybdenum: Mulder (1954) reports that an excess of iron is an important character of soils on which plants suffer from molybdenum deficiencies. Stout et al. (1951) found that P_2O_5 at 400 lbs/acre increased molybdenum uptake, whereas $CaSO_4$ at 196, 784, and 3920 lbs/acre depressed the molybdenum content in tomatoes and peas.

These data are given to demonstrate that common management practices have an effect on micronutrient availability in the soil, and thus on the physiology of the plant.

Evidence: nutrient levels in plants affect insect feeding

It is widely accepted that environmental factors affect the expression of resistance in a plant (Dietrick 1972, Leuck et al. 1974, Painter, 1951, Wittwer and Haseman 1945). More importantly, the effects of fertilizers on resistance have been accepted.

Leuck et al. (1974) report that trace elements could produce some ecological and biological effects in crop plants, and that they can have an important effect on the management of insect populations in the field. They further contend that differential abilities of nutrient uptake may be a basis for resistance and should not be overlooked in breeding programs. Perhaps certain plants are more efficient in their uptake capabilities. These could then be demonstrating resistance by better utilizing their nutrients to create unfavorable environments for the insect.

Haseman (1946) states that though he expected to find plants grown on nutrient deficient media less preferred by insects, he found just the opposite to be true. Wittwer and Haseman (1945) suggest that the high value of crop rotation in pest management may be in part due to better maintenance of soil fertility. Babers (1952) states that it seems true that insects often develop better on plants with nutritional deficiencies.

A number of experiments have been performed along these lines, and the results appear to vary greatly (Dahms 1940, Dahms 1947, Djamin 1967, Garman 1949, Haseman 1946, LeRoux 1959, Leuck 1972, Leuck et al. 1974, McGarr 1942, Rodriguez 1951, Wiseman et al. 1974, Wittwer and Haseman 1945). The results vary, but the underlying principle that nutrition of the plant affects its resistance to insect pests is beginning to emerge. Induced resistance through fertilization may, in the future, play an important role in pest management.

Wittwer and Haseman (1945) worked with thrips on spinach. Using nitrogen (ammonium nitrate) and calcium (calcium acetate) levels of 5, 10, 20 and 40 meq. per gallon crock, they found that high nitrogen levels decreased thrip damage. They further found that low nitrogen and high calcium levels produced resistant plants while low nitrogen treatments alone rendered the plants susceptible to thrip damage. Rodriguez (1951) studied two-spotted mites on Globe tomatoes. He reported that number of mite progeny declined when calcium absorption by the tomatoes was high. However, high calcium and magnesium levels together increased the number of mite progeny. In general, doubling the fertilizer rates also doubled the number of mite progeny. LeRoux (1959) also worked with the two-spotted mite. He found that high levels of calcium reduced the mite populations on cucumbers in the greenhouse. His fertilizer variables were: 160, 240, 320 mg/l Ca; 28, 42, 56 mg/l Mg; and 192, 288, 384 mg/l S. Burpee hybrid cucumber plants were used. Increasing the magnesium level increased mite progeny. Sulfur had no effect. None of the Ca-Mg-S interactions was significant. Only the increase in calcium produced a linear decrease in the number of progeny.

Dahms (1940) researched the effect of fertilizers on chinch bug resistance in sorghum. He found that high nitrogen levels (sodium nitrate) increased the sorghum's susceptibility to chinch bugs. Atlas sorgo and Dwarf Yellow milo were used as hosts. Sodium nitrate, super-phosphate, and muriate of potash were used as fertilizers. Increased levels of super-phosphate increased resistance. Haseman (1946) reported opposite results, claiming that chinch bugs and thrips thrive better on sorghum grown in nitrogen deficient soils. Low nitrogen levels and high phosphorous levels attracted thrips to spinach. Djamin (1967) found that rice varieties with higher levels of silica present were more resistant to the Asiatic rice borer.

Of significant importance to the present study is the work of Leuck and his associates. His studies have been with fall armyworms. In Leuck and Hammons (1974a) the major nutrients N, P, and K were applied in differing ratios to an insect-resistant peanut cultivar, 'Southeastern runner 56-15'. Each medium was fertilized with 500 lb/acre equivalent of a complete (NPK 5-10-15) fertilizer. All components of the mixture were given to various groups of plants, too. Excised foliage of six week old plants was infested with first instar fall armyworms, and visual leaf damage observations were recorded. A rating of 1 was given to plants showing 0-10% damage. A rating of 9 meant 90-100% damage. Thus, those foliages rating between 1-3 were classified as being resistant. That rating 7-9 was classified as susceptible, and that rating 4-6 was intermediate.

In this manner a large number of plants can be rated in a short period of time, with practical impications in the results. The general conclusions of this experiment were that the most vigorous plants were the most susceptible to fall armyworm damage.

In a corresponding study Leuck and Hammons (1974b) tested micronutrients as foliar sprays, rather than the macronutrients. In this case an insect susceptible cultivar of peanut was used, 'Tifspan'. All plants were treated with 500 lb/acre of a 5-10-15. After six weeks the plants were atomized with mineral salt solutions. The following are the salts used and the elements intended for plant use (Leuck 1972): magnesium oxide (Mg), chelate iron (Fe), sodium molybdate (Mo), zinc sulfate (Zn), ammonium sulfate (S), chromic chloride (Cr), calcium sulfate (Ca), potassium iodide (I), potassium permanganate (Mn), and cobaltous sulfate (Co). The concentrations for each were 10,000, 1000, 100, 10, and 1.0 ppm per 25 gallons of water. Of these, zinc sulfate, potassium iodide, aluminum sulfate, magnesium oxide, and calcium sulfate imparted a significant degree of resistance to the cultivar. Cupric sulfate and potassium permanganate rendered the plants more susceptible. These conditions and results are given to suggest there may be a relationship of them to a study of fall armyworms on Highland bentgrass.

Wiseman et al. (1973) also did work with fall armyworms and induced resistance. They reported that plants fed with any nitrogen treatments were more susceptible. Zinc as a foliar treatment at 1.25 lb/acre in 25 gallons of water had a detrimental effect on larvae. The effect was nonpreference rather than antibiosis.

As can be seen, work with macronutrients has been more common. Those studies which have used micronutrients have utilized foliar sprays. It is not surprising that plants coated with various heavy metals from micronutrient foliar sprays were shown to be less preferred by the fall armyworm than plants left untreated. The present study is designed to examine the effects of plants grown in culture solution of varying micronutrient levels on fall armyworm feeding. It was felt that by demonstrating that bentgrass grown under different conditions has different degrees of resistance to the fall armyworm, a more basic principle (that micronutrient levels within the plant affect resistance) will have been proven.

MATERIALS

Highland bentgrass (*Agrostis tenuis*)

Highland bentgrass (*Agrostis tenuis*) is a colonial bentgrass (Roberts 1965). Madison (1971a) reports that Highland is a common, not a varietal name. He states that it is suited for Mediteranean climates and is not well adapted for use in the East although it is suitable in our western states. It is propagated from seeds. Roberts (1965) states that Highland forms tufts of foliage, and makes a tight, dense turf when mowed ½" high. It is fairly drought resistant. It will not spread from its original planting. Madison (1971b) reports that bentgrasses will live on soils ranging from a pH of 4.5-8.3. They are not very shade tolerant. They are moisture loving and slow growing.

DeFrance (1938) reports that high nitrogen and phosphorous fertilization will increase growth and color, but make the grass too spongy for use on golf greens. Therefore, he recommends using a 10-6-4 at 35 lbs per season. Sprague (1934) found Colonial bentgrass to be tolerant of deviations from the optimum nutrient solutions. He further reports nitrate to be preferred over ammonia as a source of nitrogen.

The grass was grown in a greenhouse in flats 0.2 sq. meters in area. The flats were lined with plastic through which a few drainage holes had been made. The flats were filled with sand which had been washed with 1.5N HNO_3. The acid was poured through until the sizzling was minimal, then rinsed with distilled water until a pH of 5.0 was reached. One gram of seed was sown into each flat. The seed emerged 7 days after planting and was watered with distilled water as necessary to prevent wilting.

Two separate tests were run, with Cu, Mn, Zn, and B being the variables. To briefly establish what is known about the physiological roles of these elements the following is given.

Copper: According to Mitchell (1970): "Copper-containing proteins are the enzymes which bring about certain oxidation reactions, like those which oxidize ascorbic acid and many phenolic compounds. Copper has been shown to facilitate the movement of calcium in barley and wheat." Tisdale (1966) adds that copper may be involved in the light reaction of plants.

Manganese: Mitchell (1970) lists several functions of manganese in plants. It plays a key role in nitrite assimilation and in the conversion of soluble nitrogen compounds to protein. It functions in the activation of numerous enzymes concerned with carbohydrate metabolism. It also functions in certain photochemical processes.

Zinc: Mitchell (1970) states that zinc is necessary for IAA and tryptophan synthesis, and that it is part of many of the enzymes that act in hydrogen transfer.

Boron: Beckenbach (1944) relates that boron functions in auxin formation and the utilization of sugars, and it may have a role in the early stages of nitrogen metabolism. Tisdale (1966) gives the following roles to boron: influences cell development by controlling polysaccharide formation, inhibition of the formation of starch, and facilitates the movement of sugars.

Mitchell (1970) adds that boron enhances ATP synthesis and plant reproduction, and that it may be needed in cell wall formation.

Fall armyworm (*Spodoptera frugiperda* (J. E. Smith))

It is essential to know the biology of the pest in an integrated system of pest management. The following information was taken mainly from Luginbill (1928) unless otherwise noted.

The fall armyworm, Spodoptera (Laphygma) frugiperda (J. E. Smith), (Wiseman 1967), is an insect which migrates northward every year. It perishes at the end of every growing season, surviving only in the deep South. Blanchard (1951) reports that the fall armyworm appears in Kansas in early August and may be present until early November. Outbreaks originate in Mexico, the West Indies, and Cuba. Although most damage is to the South, considerable damage occurs to the Midwest, East, and North, too. Probabilities of general invasions depend on the weather conditions where the worm is a permanent resident. Cool wet winters are conducive to outbreaks. This is due to unfavorable conditions for predators and parasites of the fall armyworm when it is cool and wet. Fall armyworms are almost omnivorous in their food habits, although they prefer plants of the family Poaceae. Hosts of ornamental interest are bentgrass, bermudagrass, bluegrass, crabgrass, and violets.

Eggs are laid anywhere, not necessarily on a host plant. Eggs are deposited within 4-5 days, a shorter period being required under higher temperatures. Each female lays up to 13 egg masses, averaging from 140-240 eggs per mass. More eggs are laid under caged conditions than in the wild. Practically all the eggs are fertile and do hatch, although initial larval mortality may be considerable. Egg masses are in layers or heaps, covered with wing scales. Oviposition occurs at night, with most of the eggs being laid early in the night. The average number of eggs laid by a female in her life is over 1000. Humidity plays a small role in

IDENTIFYING CHARACTERISTICS OF THE FALL ARMYWORM LARVAE

1. Caterpillar with five prolegs
2. Skin either smooth or granular, no tiny spines between setae
3. Body with several tubercles or spots
4. Crochets on prolegs in a half circle
5. Adfrontal sutures on head form Y shape
6. Mandible serrated, with more than one tooth
7. Prolegs without band
8. Dorsal sclerotized plates on eighth abdominal segment appear as four dots
9. Head with distinct reticulations or inverted Y dark colored

egg incubation. Average incubation period is 5 days. Warmer temperatures (80°F) will decrease incubation time, down to a minimum of 2 days.

Upon hatching, the larvae eat their egg shells, rest for several hours, then scatter out in search of tender host plants. The larvae will attack each other and other species of larvae. Therefore, a large amount of food plants are necessary in raising larvae in a cage. Larvae are most active in late evening and early morning, with some night feeding. They lay concealed on sunny days unless they need food. Newly hatched larvae can live up to a day without feeding.

The first three instars of the larvae mainly skeletonize leaves. In an experiment in South Carolina a first instar larva ate an average of 20.75 sq. mm of crabgrass, a second instar ate 82.25 sq. mm, a third ate 149 sq. mm, a fourth ate 644.5 sq. mm, a fifth ate 2,244.7 sq. mm, and a sixth instar ate 10,665.0 sq. mm of crabgrass. The total average eaten by one larva was 13,806 sq. mm of crabgrass. Sprague (1970) and Vance (1971) report that fall armyworms often devour grass down to the ground. Before reaching food larvae are phototrophic. Once on their host they are still slightly phototrophic.

A first instar will rarely eat through a leaf. It will skeletonize only. Few other lepidopterous larvae in their region have this habit. During the 2nd and 3rd instars they begin to make some holes, eating from the margins inward. Instars 4-6 may destroy small plants and strip larger ones. Larvae have longer lives in cooler weather. During July and August their average life is 12.5 days. During October they may live up to 29 days.

Pupation normally occurs in the soil. Humidity is not a factor. The average pupal stage lasts nine days.

The adult moth is inactive during the day, remaining concealed. They begin activity at sunset and are most active during the evening. Mating occurs and eggs are laid during this period. Hot sultry weather stimulates their activity, while cool days retard it. Adults feed on nectar of various plants. They enjoy sugar. Fed moths live 13-14 days, living longer in the fall than in the summer. Unfed moths live only 4-6 days and seldom oviposit. Mating occurs only on warm nights, two nights after males and females are placed with each other. Oviposition usually occurs 3-4 days after emergence and mating.

In the South there are about six generations per year. In Kansas there are usually only two. The fall armyworms in Kansas originate in southern Texas.

Rearing the fall armyworm

Fall armyworm pupae were received from the Southern Grain Insects Research Laboratory in Tifton, Georgia. Pupae were placed in glass cages. The cages were open on the top and bottom, They were set on food trays and filled with an inch of sand. After pupae were set in the sand, water was added until the sand was moist. Vermiculite was used at first, but it was found that vermiculite would stay wet too long, causing nearly 100% mortality of the pupae due to disease. Sand dries out better.

After about three days, the moths emerged. At this time a paper towel was laid over the tops of the cages, and a screened lid set over the towel. The moths were fed on beer, set daily into their cages in a small vial lid. Beer was found to be a very adequate food. After three days the moths would begin to lay eggs. Most of the eggs were laid on the paper towels lining the top of their glass cages. Those eggs laid on the glass sides were left to hatch out. The paper towel was changed daily.

Egg clusters came in groups of 100-1000. Each cluster was cut out of the paper towel and set in a separate plastic petri dish, lined with paper. The petri dish was kept moist. On the third day the eggs would hatch. At this time the larvae were used for testing. It was necessary to leave some grass clippings in the petri dishes since the larvae would leave the dish if they had no food to keep them there.

The larvae hatching from the glass sides of the cages were left in the cages for rearing as the next generation.

Grass clippings were taken from unsprayed areas and set into each cage daily. After feeding for 20 days the larvae would burrow into the sand and pupate. The moisture level was not found to be a factor in larval development or pupation. After 5-6 days the pupae emerged as moths.

Rearing was done under a temperature of 80°F and a relative humidity of 50%.

Other methods of rearing the fall armyworm have been described by Burton (1967), Revelo and Raun (1964), and Wiseman (1967). Revelo and Raun (1964) state that the fall armyworm is good for lab studies in that it has a high reproductive rate, lacks diapause in a short life cycle, and can be reared in a greenhouse. This was found to be true. Problems include larval cannibalism and the pupal susceptibility to disease if they are kept too wet.

METHODS

Nutrient levels used on the grass

Two separate tests were run, using the standard Hoaglands solution shown as Table I (Treatment I) (Hoagland and Arnon 1938). Treatment I, the normal nutrient solution, was used in both sets of trials. The first set of grass trials were grown using treatments I, II, III, and IV, as defined by tables 1-3.

The standard, normal nutrient solution was prepared as follows. The micronutrient solution was prepared once, and kept in a washed acid bottle for further use every week. The mg listed under "mg per liter of stock solution" were dissolved in one liter of double distilled water. The Fe-EDTA was prepared as per instructions and kept in one liter of double distilled water in a washed acid bottle.

Once per week the macronutrient solutions were made up. This was done by dissolving 505.5 mg KNO_3, 1181.0 mg $Ca(NO_3)_2 \cdot 4H_2O$, 493.0 mg $MgSO_4 \cdot 7H_2O$, and 136.1 mg KH_2PO_4 in one liter of double distilled water.

First trials

As was stated, the first treatments tried were normal, 3N-zinc, 3N-manganese, and 3N-copper. These first trials were done in two different ways, necessitating two sets of data which must be analysed separately.

The first tests were done using 200 mg (fresh weight) of grass clippings per square. Ten first instar larvae were placed on each sample.

The grass was clipped, placed in a plastic bag, and sprayed. The 200 mg samples were weighed and four replications of each treatment were placed randomly on a sheet of newsprint containing 16 squares (Figure 1). The newsprint was set on wet sand inside a glass cage. The cage stood on a food tray, allowing watering to be done from below. This glass cage was covered with a white cloth sheet to block out light.

Ten first instar larvae were dropped onto each square. Thus, 160 larvae were used per test. After 60 hours the larvae were removed. The eaten grass, and the larval frass, were placed in separate petri dishes to dry for 48 hours. The frass was removed and the remaining grass placed in small brown paper bags. These, then, were oven dried at 70°C for 72 hours. Dry weights were then recorded.

The second set of tests, using grasses of the same treatments (I, II, III, IV) were conducted slightly differently. It was thought that larger larvae and larger grass samples would elicit better results. Therefore, 500 mg (fresh weight)

To each liter of macronutrient solution was added one ml micronutrient stock solution and one ml Fe-EDTA solution. This liter of total nutrient solution was then applied to the grass. One liter per week was added to each flat.

Four flats of grass treatments were grown in each of the two sets of tests. For the first trials, treatments I, II, III, and IV were used. This corresponds to a normal solution, a solution containing three times the recommended rate of zinc, a solution containing three times the recommended rate of manganese, and solution containing three times the recommended rate of copper.

The second set of trials utilized treatments I, V, VI and VII. This corresponds to the same normal solution, a solution containing ten times the recommended rate of manganese, a solution containing ten times the recommended rate of zinc, and a solution containing one tenth the recommended rate of boron.

THIS BOOK CONTAINS NUMEROUS PAGES WITH DIAGRAMS THAT ARE CROOKED COMPARED TO THE REST OF THE INFORMATION ON THE PAGE.

THIS IS AS RECEIVED FROM CUSTOMER.

Figure 1.

Design for first trials

3"

4"

IV	II	III	I
III	IV	I	II
I	III	II	IV
II	I	IV	III

Figure 2.

Design of second trials

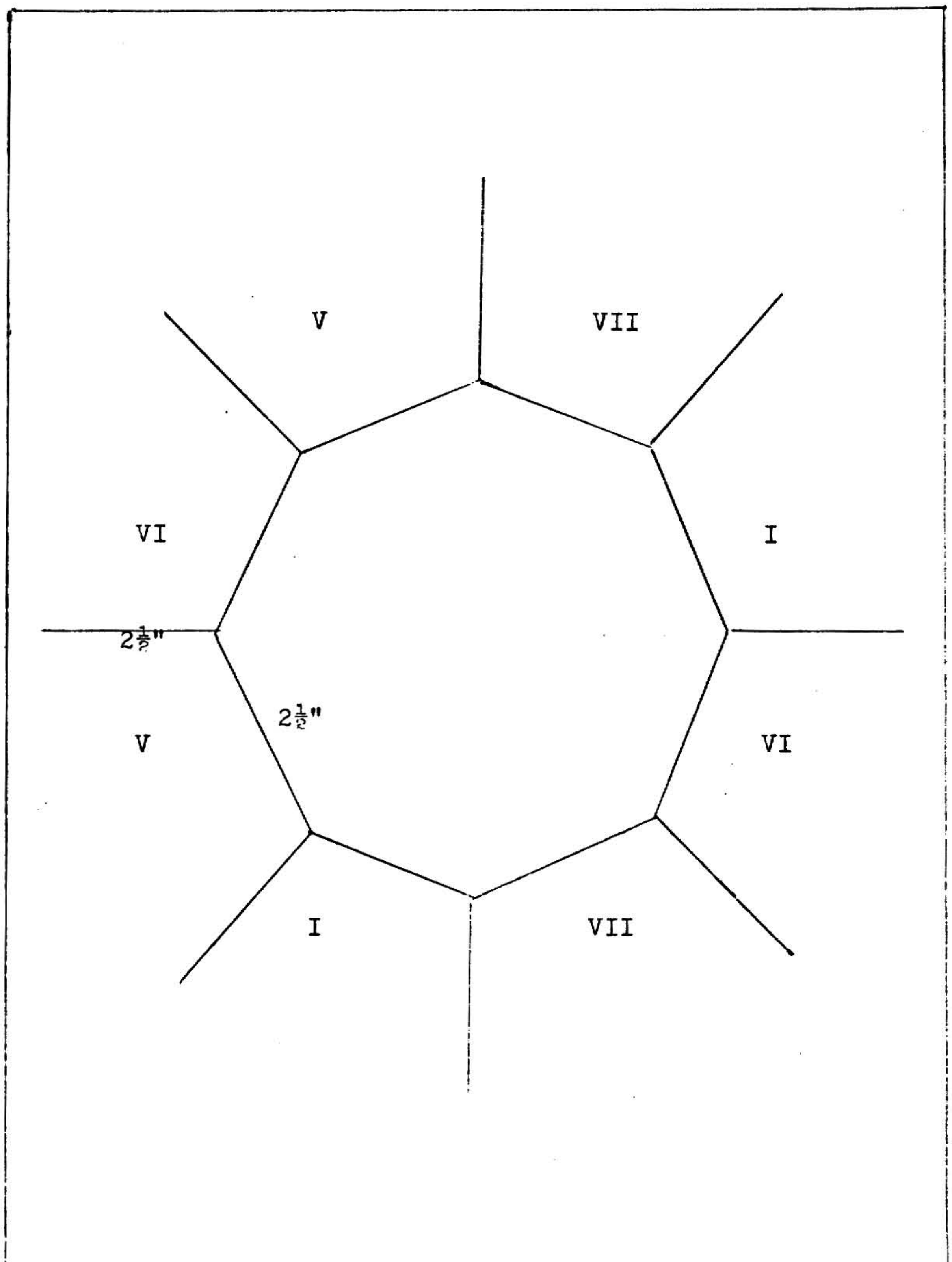

Table 1.

MACRONUTRIENT SALTS USED FOR SOLUTION CULTURE

TREATMENT I (NORMAL)

Macronutrient Solutions

Specific salts used		
Compounds	Ml. molar stock soln. per liter culture solution	Mol. wt.
KNO_3	5.0	101.1
$Ca(NO_3)_2 \cdot 4H_2O$	5.0	236.2
$MgSO_4 \cdot 7H_2O$	2.0	246.5
KH_2PO_4	1.0	136.1

Conc. of individual elements in final sol.		
Elements	ug atoms per liter	p.p.m.
N	15000	210
K	6000	234
Ca	5000	200
P	1000	31
S	2000	64
Mg	2000	48

Table 2.

MICRONUTRIENT SALTS USED FOR SOLUTION CULTURE

TREATMENT I (NORMAL)

Micronutrient Solutions

Specific salts used			
Compounds	Ml. stock sol. per liter culture sol.	Mol. wt.	Mg. per liter of stock sol.
KCl	1	74.6	3728
H_3BO_3	1	61.8	1546
$MnSO_4 \cdot H_2O$	1	169.0	845
$ZnSO_4 \cdot 7H_2O$	1	287.6	575
$CuSO_4 \cdot 5H_2O$	1	249.7	125
$(NH_4)_6Mo_7O_{24} \cdot 4H_2O$	1	1236	18.4

Elements	Conc. of individual elements in final solution: ug atoms per liter	p.p.m.
Cl	50	1.77
B	25	0.27
Mn	5.0	0.27
Zn	2.0	0.13
Cu	0.5	0.03
Mo	0.1	0.01

$FeSo_4$-EDTA. Prepared by dissolving 3.72g Na_2EDTA and 2.78g $FeSO_4 \cdot 7H_2O$ in 1000 ml of double distilled water and heated to 80 C. One ml added per liter of nutrient solution weekly.

Table 3.

TREATMENTS II-VII AS VARIATIONS OF NORMAL TREATMENT (I)

Treatments	Specific compound used	Mg. per liter of stock sol.	Conc. of individual elements in final solution		
			Elements	ug atoms per liter	p.p.m.
II (3N-Zn)	$ZnSO_4 \cdot 7H_2O$	1725	Zn	6.0	0.39
III (3N-Mn)	$MnSO_4 \cdot H_2O$	1535	Mn	15	0.81
IV (3N-Cu)	$CuSO_4 \cdot 5H_2O$	249.7	Cu	1.5	0.09
V (10N-Mn)	$MnSO_4 \cdot H_2O$	8458	Mn	50	2.70
VI (10N-Zn)	$ZnSO_4 \cdot 7H_2O$	5750	Zn	20	1.30
VII (0.1N-B)	H_3BO_3	154.6	B	2.5	0.03

of grass, and 3rd instar larvae were used. Again, ten larvae were placed on each of 16 squares (4 treatments X 4 reps per treatment), and left for 48 hours. All other procedures were identical with the first tests.

Second trials

For these trials, treatments I, V, VI, and VII were used. The grass previously used was discarded, new sand was washed, and new treatments begun. Treatment I is the standard, normal nutrient solution. Treatment V contains ten times the recommended rate of manganese. Treatment VI contains ten times the recommended rate of zinc. Treatment VII contains one tenth the recommended rate of boron.

These trials used 500 mg (fresh weight) samples. The design differed from the design of the first trials, as can be seen in figure 2. Two hundred first instar larvae were placed in the center circle, leaving the larvae freer, hopefully, to choose their hosts. The larve were left on for 72 hours. All other procedures are identical with those used for the first trials.

RESULTS

First trials

Results of the first trials showed no differences in preference among treatments I, II, III, and IV. Physically, the grass appeared equally vigorous, and of uniform color.

Several problems developed which had to be overcome. The first attempts were not laid on wet sand, resulting in dried up grass by morning and worthless results. It was hoped, initially, that the grass could be grown in pots and left intact while the larvae fed. However, this would have required a value judgement as to how severe the feeding damage was. By using dry weights of clippings, a more objective evaluation of results could be obtained.

One set of tests was allowed to run 4 days. This resulted in the clippings being completely covered by frass, which caused the larvae to leave the grass.

Thus, two reliable tests were recorded (8 replications of each treatment). Along with the test data, a similar sample size of grass was taken with both tests (200 mg or 500 mg) and was dried without having been eaten. This served as the control.

The second tests used 3rd instar larvae and 500 mg of grass. The first set of these tests were allowed to go on 12 hours too long. The large larvae, it was found, would drag grass clippings around with them as they moved. Naturally, results of those tests were impossible to take. Again, two tests (8 reps of each treatment) gave accurate results which could be analysed.

Visually, no difference in insect feeding could be noticed in any of the tests.

Data are provided in the following tables.

Data used for analysis are found in tables 6 and 9. Since the dry weights of the control groups of the four treatments varied, it was thought that this should be taken into consideration when comparing the dry weights of the experimental grasses. No significant difference at any level was found between the treatments I, II, III, and IV.

Table 4.

First trials: Test 1

200 mg fresh weight, 1st instar larvae

Treatments	Control oven dry weight(mg)	Oven dry weight (mg) of bentgrass remaining after larval feeding damage: Test A (4 reps/treatment)	Test B (4 reps/treatment)
	31.0 mg	14.7 mg	21.0 mg
I (Normal)	31.0	19.4	17.4
	31.5	14.8	14.9
	33.0	17.4	15.5
average	31.6 mg	16.6 mg	17.2 mg
	32.0 mg	15.4 mg	16.5 mg
II (3N-Zn)	30.5	18.0	19.0
	29.5	13.8	13.1
	29.0	14.5	18.5
average	30.3 mg	15.2 mg	16.8 mg
	30.5 mg	----	13.4 mg
III (3N-Mn)	27.0	21.0 mg	13.0
	27.0	22.0	20.9
	27.5	16.2	22.1
average	28.0 mg	19.7 mg	17.4 mg
	30.5 mg	16.0 mg	21.0 mg
IV (3N-Cu)	32.0	23.4	15.6
	32.0	17.5	19.0
	32.0	18.5	22.5
average	31.6 mg	18.9 mg	19.5 mg

Table 5.

First trials: Test 1

200 mg fresh weight, 1st instar larvae

Treatments		Oven dry weight of control as % fresh weight	Oven dry weight of bentgrass remaining after larval feeding damage as % fresh weight: Test A	Test B
		15.50	7.35	10.50
I (Normal)		15.50	9.70	8.70
		15.75	7.40	7.45
		16.50	8.70	7.75
	average	15.81	8.28	8.60
		16.00	7.70	8.25
II (3N-Zn)		15.25	9.00	9.50
		14.75	6.90	6.55
		14.50	7.25	9.15
	average	15.12	7.58	8.39
		15.25	----	6.70
III (3N-Mn)		13.50	10.50	6.50
		13.50	11.00	10.45
		13.75	8.10	11.05
	average	14.00	9.86	8.67
		15.25	8.00	10.50
IV (3N-Cu)		16.00	11.70	7.80
		16.00	8.75	9.50
		16.00	9.25	11.25
	average	15.81	9.42	9.76

Table 6.

First trials: Test 1

200 mg fresh weight, 1st instar larvae

Treatments	Ave. oven dry weight of control	Oven dry weight of bentgrass remaining after larval feeding damage as % of average control dry weight: Test A	Test B
I (Normal)	31.6 mg	46.5	66.4
		61.3	55.1
		46.8	47.2
		55.1	49.0
II (3N-Zn)	30.2 mg	51.0	54.6
		59.6	62.9
		45.7	43.4
		48.0	61.2
III (3N-Mn)	28.0 mg	----	47.8
		75.0	46.4
		78.6	74.6
		57.8	78.9
IV (3N-Cu)	31.6 mg	50.6	66.4
		74.0	49.4
		55.4	60.1
		58.5	71.2

Table 7.

First Trials: Test 2

500 mg fresh weight, 3rd instar larvae

Treatments	Control oven dry weight(mg)	Oven dry weight (mg) of bentgrass remaining after larval feeding damage: Test A (4 reps/treatment)	Test B (4 reps/treatment)
	103.5 mg	39.5 mg	74.1 mg
I (Normal)	110.0	45.5	54.0
	107.0	34.0	51.5
	115.0	53.5	40.0
average	108.9 mg	43.1 mg	54.9 mg
	118.5 mg	70.0 mg	63.5 mg
II (3N-Zn)	131.1	47.0	53.7
	123.0	54.8	71.0
	120.3	73.2	46.3
average	123.2 mg	61.2 mg	58.6 mg
	116.5 mg	47.5 mg	49.0 mg
III (3N-Mn)	110.3	50.5	68.4
	119.4	60.9	60.5
	112.5	46.2	73.5
average	114.7 mg	51.3 mg	62.8 mg
	110.1 mg	29.2 mg	49.0 mg
IV (3N-Cu)	123.5	55.1	51.0
	111.0	46.9	40.5
	118.8	47.1	58.8
average	115.5 mg	44.6 mg	49.8 mg

Table 8.

First trials: Test 2

500 mg fresh weight, 3rd instar larvae

Treatments		Oven dry weight of control as % fresh weight	Oven dry weight of bentgrass remaining after larval feeding damage as % fresh weight: Test C	Oven dry weight of bentgrass remaining after larval feeding damage as % fresh weight: Test D
I (Normal)		20.70	7.90	14.82
		22.00	9.10	10.80
		21.40	6.80	10.30
		23.00	10.70	8.00
	average	21.78	8.63	10.98
II (3N-Zn)		23.70	14.00	12.70
		26.22	9.40	10.74
		24.60	10.96	14.20
		24.06	14.64	9.26
	average	24.64	12.25	11.72
III (3N-Mn)		23.30	9.50	9.80
		22.06	10.10	13.68
		23.88	12.18	12.10
		22.50	9.24	14.70
	average	22.94	10.26	12.57
IV (3N-Cu)		22.02	5.84	9.80
		24.70	11.02	10.20
		22.20	9.38	8.10
		23.76	9.42	11.76
	average	23.10	8.92	9.96

Table 9.

First trials: Test 2

500 mg fresh weight, 3rd instar larvae

Treatments	Ave. oven dry weight of control	Oven dry weight of bentgrass remaining after larval feeding damage as % of average control dry weight: Test C	Test D
I (Normal)	108.9 mg	36.3	68.0
		41.8	49.6
		31.2	47.3
		49.1	36.7
II (3N-Zn)	123.2 mg	56.8	51.5
		38.2	43.6
		44.5	57.6
		59.4	37.6
III (3N-Mn)	114.7 mg	41.4	42.7
		44.0	59.6
		53.1	52.7
		40.3	64.1
IV (3N-Cu)	115.5 mg	25.3	42.4
		47.7	44.2
		40.6	35.1
		40.8	50.9

Second trials

Results of the second trials did reveal a difference both in the physical appearance of the differently treated grasses and in the preference of fall armyworms for the grasses.

Physically, the grass receiving normal treatment (I) and that receiving 10N-Mn treatment (V) were equally vigorous. The grass receiving the 10N-Zn treatment (VI) was less vigorous. Treatment VII (0.1N-B) was only about half as tall as the most vigorous grasses. This is in keeping with the findings by Beckenbach (1944) that boron deficiency will result in reduced plant vigor. The boron deficient grass also proved to be more glossy in color than the others. Treatments I and V would consistantly show more signs of water stress after similar periods of time than VI or VII.

Table 10 sets forth the results of 10 tests, with two replications of each treatment per test. These figures represent the dry weight in milligrams of each set of clippings after being devoured by fall armyworm larvae for 72 hours. The larvae, set on the test plots approximately 12 hours after hatching, had become 2nd instars by the time of their removal. The grass was oven dried at 70°C for five days.

Clippings of 500 mg fresh weight were taken from each treatment and dried, without having been subjected to the larvae. These serve as the control dry weights for each treatment of grass. Table 11 exhibits the results of five replications from each treatment as milligrams of dry weight. The average dry weight was computed for each treatment.

Table 12 represents the data used for analysis. These data are expressed as the experimental dry weights as percentages of the average control dry weight for each treatment. For example, each figure under treatment I (76.2, 71.6 ... 68.0 mg) was divided by the average control dry weight for treatment I found in Table 11 (120.0 mg). It was felt this was necessary to better correlate the data. To take an example, again, if the average control dry weight of the 10N-Mn grass had been 90 mg, obviously the significance of the figures recorded in Table 10 would be much greater than would be apparent. In actuality, in that case, the normally treated grass would have been significantly destroyed, while the 10N-Mn grass would have shown almost total resistance. For this reason, the data originally recorded in Table 10 could be misleading, therefore the data in Table 12 were used for analysis.

Table 10.

Second trials: Oven dry weight (mg) of bentgrass remaining after 72 hrs. of feeding damage by 1st instar larvae (from 500 mg fresh weight)

Test/Replicate	I (Normal)	V (10N-Mn)	VI (10N-Zn)	VII (0.1N-B)
	Treatments			
I/1	76.2 mg	60.5 mg	69.8 mg	69.5 mg
I/2	71.6	69.8	74.0	70.5
II/3	70.0	72.2	68.0	69.0
II/4	64.1	63.9	77.9	82.0
III/5	82.9	77.0	77.9	83.4
III/6	65.0	88.3	75.7	81.6
IV/7	78.4	74.4	66.2	80.1
IV/8	77.6	78.8	70.7	85.6
V/9	81.1	84.5	83.6	86.5
V/10	90.0	76.0	82.2	90.0
VI/11	68.1	82.5	92.6	91.6
VI/12	86.1	84.6	82.2	87.8
VII/13	81.5	80.8	90.3	88.0
VII/14	81.0	80.0	74.8	90.5
VIII/15	72.2	39.0	90.0	65.9
VIII/16	61.1	60.0	71.7	76.8
IX/17	88.1	81.2	86.6	92.0
IX/18	88.0	80.0	88.1	90.0
X/19	78.2	72.1	82.7	66.2
X/20	68.0	65.7	66.4	77.8
average	76.6 mg	74.6 mg	78.6 mg	81.2 mg

Table 11.

Second trials: Oven dry weight (mg) of undamaged bentgrass, 500 mg fresh weight

Treatments

	I (Normal)	V (10N-Mn)	VI (10N-Zn)	VII (0.1N-B)
	121.5 mg	110.5 mg	112.5 mg	114.0 mg
	115.5	105.8	123.5	105.5
	119.6	114.0	114.8	114.0
	122.0	115.5	120.0	109.0
	120.0	118.4	113.8	116.5
average—	120.0 mg	113.0 mg	117.0 mg	111.8 mg

Table 12.

Second trials: Oven dry weight (mg) of bentgrass remains (Table 10) as % of average control dry weight (Table 11)

Test/Replicate	I (Normal)	V (10N-Mn)	VI (10N-Zn)	VII (0.1N-B)
	Treatments			
I/1	63.5	53.5	59.7	62.3
I/2	59.7	61.8	63.2	63.1
II/3	58.3	63.9	58.1	61.7
II/4	53.5	56.5	66.5	73.3
III/5	69.8	68.1	66.5	74.6
III/6	54.2	78.2	64.8	73.0
IV/7	65.3	65.8	56.6	71.7
IV/8	64.7	69.7	60.5	76.6
V/9	67.5	74.7	71.4	77.3
V/10	75.0	67.3	70.3	80.5
VI/11	56.8	73.1	79.1	81.9
VI/12	71.8	74.9	70.3	78.5
VII/13	67.8	71.5	77.3	78.7
VII/14	67.5	70.8	63.9	81.0
VIII/15	60.2	52.2	76.9	58.9
VIII/16	51.0	53.1	61.2	68.7
IX/17	73.3	71.9	74.0	82.3
IX/18	73.3	70.8	75.4	80.5
X/19	65.2	61.7	70.6	59.2
X/20	56.7	58.2	56.8	69.5
average	63.8%[a]	66.0%[a]	67.2%[a]	72.6%[b]

Means followed by the same letter are not significantly significantly different at the 5% level of probability.

$LSD_{.05} = 4.61$

Table 13.

TISSUE ANALYSIS OF TREATMENTS

I, V, VI, and VII

Treatment	Mn (ppm)	Zn (ppm)
I	147.6	19.3
V	212.0	19.8
VI	180.5	86.5
VII	183.6	36.8

Boron concentrations as % of treatment V

Treatment	% of treatment V
I	89.7
V	100.0
VI	82.6
VII	23.2

CONCLUSIONS

The first trials revealed no significant differences in selectivity by the fall armyworm. The second trials revealed that boron deficient grass was significantly more resistant to fall armyworm damage than the other grasses. An average of 72.6% of the boron deficient grass was left uneaten, whereas an average of 63.8% of the grass receiving the standard, normal treatment was left uneaten.

It is clear that different levels of micronutrients can induce a degree of resistance in Highland bentgrass to fall armyworms. This is demonstrated by the significant difference between treatment VII and treatments I, V, and VI.

It is equally clear that, in most cases, differing micronutrient levels in the nutrient solutions had no effect on the preference of the larvae for the grass. This is in contrast to the results of Leuck et al. (1974) in which several foliar nutrient sprays, externally applied to coastal bermudagrass, Antigua corn, and sorghum, adversely affected the preferential feeding of the fall armyworm.

The method by which a given micronutrient level may confer resistance to a plant is not explained. When clipped into two inch segments for the tests, the treated grasses had no observable morphological differences. Physiological or anatomical changes may have occurred in the boron deficient grass which made it relatively less palatable than the other grasses. The roles of boron, manganese, and zinc in plant physiology may be briefly reviewed.

Boron was the only element tested not listed as a heavy metal. Boron functions in sugar translocation, auxin formation, and inhibition of starch formation among others (Mitchell 1970). This could indicate a role of sugars and starchs in fall armyworm preference. Or possibly some factor associated with slow growth, such as thicker cell walls or increased silica content per unit area of the cell wall, may have been responsible for the degree of induced resistance noted in this grass. As Leuck and Hammonds (1974a) noted, less vigorous plants are normally less preferred by fall armyworm larvae.

Zinc and manganese function as enzyme activators, and are associated with electron transfer (Mitchell 1972). Neither zinc nor manganese, applied at ten times the normal rate, were phytotoxic to the grasses. When phytotoxicity does occur, it is presumed to be due to heavy metal precipitation of proteins. Either the rates used were not high enough to cause protein precipitation, or the process has very little effect on fall armyworm preference.

Fertilizer applications, as well as other management practices, can affect the availability of these micro-nutrients in the soil. As noted previously, potassium fertilizers applied at the rate of 250 lbs per acre induced boron deficiency in soybeans (Woodruff et al. 1960). Cooper et al. (1958) also report that $CaNC_3$ may depress boron availability.

It is possible that potassium fertilizers, by reducing the boron content within the plant (Bingham and Garber 1960, Chapman and Brown 1943, Woodruff et al. 1960), may be able to decrease the feeding preference of fall armyworms for Highland bentgrass. Any such conclusions, of course, are strictly hypothetical, but merit further investigation.

Manganese, zinc, and copper excesses were not found to influence the preference of fall armyworms for the grass. Therefore, reports of management practices which influence their availability to plants are not as significant to the present study as are those practices affecting boron availability.

Although micronutrients do play a role in fall armyworm preference for Highland bentgrass, the roles discovered in the present study are of questionable practical application. The economic injury level on golf greens is extremely low. That is, very little damage can be tolerated. Boron deficiency results in a difference of grass being 27.4% destroyed and 36.2% destroyed by fall armyworms. Such a level of resistance, although visually noticeable, is not of interest to a golf course superintendant. For different crops under different economic injury levels, such a difference in larval feeding preference could have much greater practical significance.

It would be difficult, under field conditions, to intentionally manage for induced resistance based on any certain micronutrient. Unintentionally, as a side effect, the preference of an insect for a crop may be affected by management practices which affect micronutrient availability in the soil. If the matter were to be pursued further, actual fertilizer products and foliar sprays could be tested in the field for induced resistance of value.

It must be concluded that the proposed model (p. 10) does work. Although most of the results were negative, the fact that positive results did occur enhances the hypothesis of Leuck et al. (1974) that trace elements could have an effect on the management of insect populations in the field. The present study has shown that micronutrient manipulation through nutrient solutions can affect the feeding preference of fall armyworm larvae for Highland bentgrass.

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THE EFFECT OF SOME MICRONUTRIENTS ON THE RESISTANCE OF HIGHLAND BENTGRASS TO FALL ARMYWORMS

by

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Highland bentgrass (*Agrostis tenuis*) was grown in the greenhouse at different nutrient levels. The preference of fall armyworms (*Spodoptera frugiperda* (J.E.Smith)) for the grass grown under these treatments was determined.

The first trials compared four nutrient treatments. Treatment I was grown with the standard Hoagland's solution (Hoagland and Arnon 1938). Treatment II tripled the zinc concentration of the standard. Treatment III tripled the manganese concentration of the standard. Treatment IV tripled the copper concentration of the standard. Grass clippings in a series of randomized designs of these four treatments were subjected to fall armyworm larvae. No measurable degree of preference by the fall armyworm for any of these grasses was noted.

The second trials compared a different set of four treatments. Treatment I was again used as the standard. Treatment V increased the manganese concentration of the standard tenfold. Treatment VI increased the zinc concentration of the standard tenfold. Treatment VII reduced the boron concentration of the standard to one tenth. The grass clippings were subjected to fall armyworm larvae. The boron deficient grass proved to be more resistant, by being less preferred, than the other three treatments.