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JOINT INFLUENCE OF HETERODERA GLYCINES AND CHENOPODIUM ALBUM ON EARLY DEVELOPMENT OF GLYCINE MAX

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JOINT INFLUENCE OF *HETERODERA GLYCINES* AND *CHENOPODIUM ALBUM* ON EARLY DEVELOPMENT OF *GLYCINE MAX*

By

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ABSTRACT

JOINT INFLUENCE OF HETERODERA GLYCINES AND CHENOPODIUM ALBUM ON EARLY DEVELOPMENT OF GLYCINE MAX

By

Jianjun Chen

The presence of H. glycines resulted in significantly less G. max dry weight than G. max grown in the absense of this nematode. The joint influence of Heterodera glycines and early colonization by Chenopodium album resulted in the lowest amount of Glycine max dry weight observed. Pod dry weight of G. max was significantly reduced by H. glycines, C. album and G. max competition. Competition also influenced the dry weight of C. album, and water utilization by G. max. On three harvest dates, the predicted joint impact of H. glycines and C. album on G. max dry weight and relative growth rate was the same as the measured impact of these organisms, indicating an additive response. There were no significant interactions among H. glycines and C. album in relation to the dry weight and relative growth rate of G. max; however, the interections between H. glycines and the population density of G. max resulted in significantly less pod dry weight than predicted for two weed planting dates.

DEDICATIONSTO MY WIFE

LING ZHANG

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I am also grateful to Mr. John Davenport for his kindness and help. All activities and experience at the PRC are worthy of memory. Many thanks go to all the "nematology people" for their friendship and help.

Should I give a special acknowledgement to the objects I studied? Yes. I am thankful for the soybean cyst nematodes' cooperation, with whom the Chinese people have had a "friendship" of 5,000 years. To common lambsquarters, I would quote a very famous Chinese poem of praise and respect to weeds:

"Couldn't be destroyed by wild fire;
Alive again with a spring wind blow."

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1.0 INTRODUCTION

Soybean cyst nematode (Heterodera glycines Ichinohe, 1952) was found in Michigan(MI) for the first time in April, 1987, and is currently known to exist in three locations in Michigan (Figure 1.1). Population densities as high as 1,300 viable units (eggs and second-stage juveniles) per 1.0 cm^3 soil have been recovered from soybean fields in MI. This nematode is a major limiting factor in the United States of America (USA) soybean production, and can also be a problem in the dry bean and snap bean production. Relatively little, however, is known about the soybean cyst nematode (SCN) in MI. Common lambsquarters, Chenopodium album, is a major weed pest of soybean in MI. It is a very strong competitor with soybean and causes considerable soybean yield losses.

The interaction and competition among organisms is a topic of both interest to scientists and of economic significance. They are very important to basic and applied sciences, such as ecology, crop management and pest management. There is extensive literature on interactions between Glycine max and H. glycines, and competition between G. max and C. album. There is no research base, however, on the joint interaction among these three organisms.

The availability of high quality water may will be a challenge on a long-term basis. On the one hand, if the climate becomes warmer because of "greenhouse effect", many meteologists believe there will be a tendency

for more droughts. On the other hand, water shortage for agriculture may worsen because of environment contamination and a large mount of water used in urban environment and industry. Many water resources are not available for US agriculture because of a lack of appropriate irrigation systems.

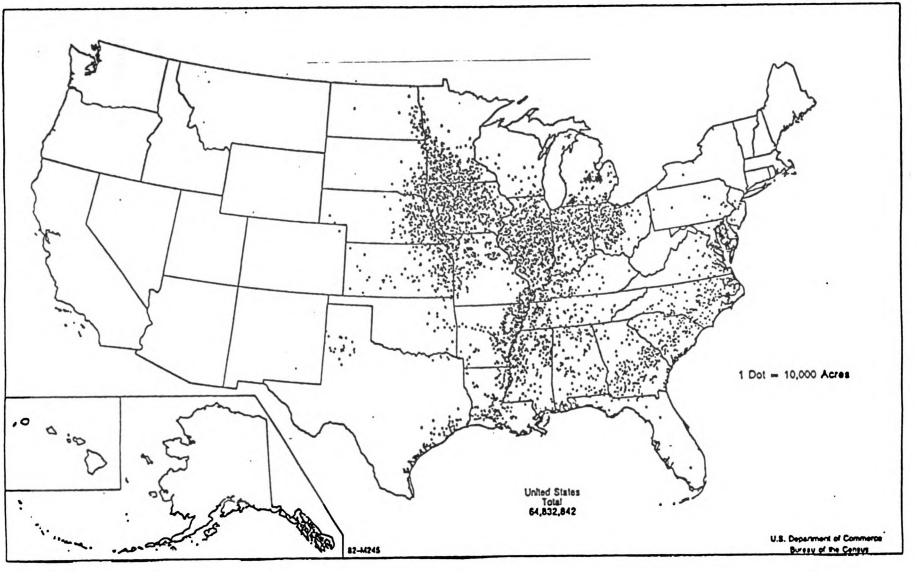
It is well known that 1987 was a drought year in MI. There are few irrigation systems available for most of the field crops grown in the Midwest. Yield losses of crops, such as soybeans and corn, were huge. In contrast, weeds, such as common lambsquarters, grew very well in the crop fields under drought conditions. A Gratiot population of soybean cyst nematode increased its population dramatically in 1987. The initial population density was 6,929 viable units/100 cm^3 and the final population density was 56,907 after the drought. How is water utilization by Glycine max influenced by weeds and pests? The uncertainty in water supply has created a risky situation for some American agricultural regions. Accurate calculation of soil water utilization is becoming increasingly important.

Information about the competition, joint action, and water relationships between SCN and lambsquarters is unknown. Because of the challenge sassociated with these pests in soybean production, the influence of H. glycines and C. album on early development of G. max was selected for this Master of Science Thesis. The research was initiated in September, 1987. The objectives of the study are to

1) Determine joint influence of soybean cyst nematode and common lambsquarters on early development oF soybean.
2) Study how water utilization is impacted by joint influences of soybean, common lambsquaters and soybean cyst nematode.
3) Report on current state of soybean cyst nematode in MI.

The thesis is divided into seven sections, with 47 tables, 9 figures and 8 fomula. The seven sections consist of an Introduction, Literature Review, Methods & Materials, Results, Discussion, Literature Cited sections, and an Appendix reporting observations on the current state of H. glycines in MI.

Fig.1.1 USA & MI soybean production in 1982 and the three known locations of Heterodera glycines in MI



2.0 LITERATURE REVIEWS

The literature review is divided into five sections, including: 1) Biology and ecology of Heterodera glycines, 2) Biology and ecology of Glycine max, 3) Biology and ecology of Chenopodium album, 4) Plant interactions, and 5) Water relationships of plants and soils.

2.1 BIOLOGY AND ECOLOGY OF HETERODERA GLYCINES

Heterodera glycines Ichinohe,1952 is currently known to exist in China, the USA, Japan, and Korea. It is present in 23 of 30 soybean-producing states in the US. H. glycines was first found in Korea in 1936 and in China in 1938. It was identified for the first time in the US in 1954. The soybean cyst nematode was described in 1952 by Ichinohe, 71 years after it was first noted causing a disease called "yellow dwarf", thought to be caused by Heterodera schachtii Schmidt (Riggs, 1977).

H. glycines has a life cycle consisting of 4 juvenile stages and an adult stage. The second-stage juvenile hatches and moves out of the cyst or gelatinous egg matrix and into the soil. Hatching occurs spontaneously when the egg is not in diapause, although there is some evidence of a hatching stimulant (Okada, 1972; Masamure, 1982). Glycinoeclepin A is a hatching stimulant extracted form kidney bean (Masamure et al., 1982).

H. glycines overwinters as a cyst in the upper 90 to 100 cm of soil (Agrios, 1978). The eggs contain fully developed second-stage juveniles. When temperature and moisture become favorable in the spring, the hatched second-stage juvenile moves through the soil and penetrates root tissue, generally well behind the zone of differentiation. Second-stage juveniles penetrate root tissues of resistant cultivars as readily as susceptible cultivars (Endo, 1965). The largest number of penetrations occur at 28C. The most rapid develop ment occurs at 28-31C, with little or no development at or below 15C and at or greater than 33C. H. glycines requires 7512 nematode degree hours (degrees above 10C multiplied by hours) to complete its life cycle (Ichinohe, 1950).

Cysts of H. glycines are lemon shaped, measuring 0.6 to 0.8 mm in length and 0.3 to 0.5 mm in diameter. The head of the female or cysts is embedded in root cortex tissue, and the rest of the body protrudes from the root surface. When first formed, the adult female is white or light yellow, the cuticle is thick, and after mating uteri contain fertilized eggs. Each female produces 300 to 600 eggs. When the female dies, the cuticle becomes brown and tough, and has a distinctive surface pattern of zig-zag lines or punctations. The dead female, with its contents of embryonated eggs, is called a "cyst". A gelatinous matrix is produced at the vulval cone, usually containing some eggs. The cyst consists of the female cuticle transformed through the secretions of the nematode into a tough, brown sac

that persists in the soil for many years and protects the eggs. The mechanism for egg hatch is unknown.

The adult male of H. glycines is vermiform, ca. 1.3 mm long by 30 to 40 um in diameter. Second-stage juveniles average 450 um in length. About half of the tail is hyaline.

Identification of H. glycines is dependented on using the characteristics of second-stage juveniles, males and cysts, especially on the structure of the cone top of cyst. A dichotomous key is used to separate H. glycines form other closely related species of Heterodera (Table 2.1).

Table 2.1 Dichotomous key

to three closely related species of Heterodera (Nemata)

(based on mature cysts, modified from Oostenbrink, 1960)

1. Cysts pear-shaped, i.e. with rounded posterior end of body ---------- some species in Heterodera
   Cysts lemon-shaped, (with cone-shaped posterior end) of body and valva on top of the cone ---------- 2
2. Cyst with pattern, including as basic element straight or wavy lines at right angles to axis of cyst, sometimes broken by short oblique or vertical lines ---------- some species in Heterodera
   Cyst with pattern, including as vatic element short zig-zag lines without regular transverse arrangement ---------- 3
3. Cyst without conspicuous bullae in posterior end, usually not large ---------- some species in Heterodera
   Cyst with conspicuous bullae in posterior end, usually large ---------- 4
4. Cyst broad with a low, tapering vulva cone and with an extremely short vulval split (12 um). bullae close to the vulva ----------H. avenae
   Cyst with a steep, slender vulva cone and with a vulval split of 40 um or more. Bullae well below the vulva ----------5
5. Average length of transparent patches on lip tops of the cyst cone at right angles of vulva split below 38.7 um ----------H. schachtii

Average patches on lip tops above 38.7 um. Dorsal gland orifice in larvae 3.0 - 5.2 um posterior to the stylet knobs ----------~~H.~~ glycines

H. glycines has rapidly developed races under field conditions (Price et al., 1978). Even different populations of the same race can have different indices of parasitism, an indication that qualitative and quantitative differences exist among populations of the same race (Triantaphyllou, 1975).

Four races of H. glycines were described in 1970(Golden et al., 1970) and a fifth race was proposed in 1978(Inagaki, 1979). The race scheme has been useful, largely because cultivars could be bred for resistance to designated races. The present race classification is largely qualitative. A quantitative scheme giving information on the percentage of control by resistant cultivars would enable decision-makers to determine if resistance was adequate or if additional control tactics would be required. Full expansion of race classification for H. glycines using the host differentials described by Golden et al. includes 16 races (Riggs et al., 1988)

Continuous or frequent use of the resistant cultivars results in race shifts that eventually renders resistant cultivars useless. Most field population of H. glycines are apparently mixtures of genotypes. Selection forces imposed by resistant soybean cultivars change the gene frequency (Triantaphyllou, 1975; McCann et al., 1982). Populations grown under greenhouse conditions retained the same gene frequency for parasitism when they were cultured on suscep- tible soybeans. Resistance genes, however, induced a change in the frequency of genes for parasitism (Triantaphyllou,

1975; Riggs et al., 1977). For example, the index of parasitism (reproduction on resistant line/reproduction on susceptible line x 100) of a population from Johnston County, North Carolina, following continuous propagation for seven generations on susceptible soybeans remained the same as the original population. The index of parasitism increased from 3 to 76 following propagation for seven generations on the resistant cultivar Peking (Triantaphyllou, 1975). This nematode apparently possesses as many as 10 genes for para- sitism (Thomas, 1974).

The occurrence of biotypes in most fields lead Riggs et al., (1981) to suggest that another system of classification be proposed. They recommend that "the best procedure for determining soybean cyst nematode races should be decided by a group of 5 to 7 nematologists and plant breeders who have been involved in soybean cyst nematode work." Unfortunately, the establishment of any H. glycines race classification system will probably break down over time because of its genetic diversity (Schmitt, et al., 1984).

Soybean plants infected by H. glycines appear stunted and have an unthrifty appearance. The foliage turns yellow prematurely and falls off early. The plants bear only a few flowers and form only a few small seeds. Infected plants growing on coarse-textured soils frequently die. Infected soybean plants growing on fine-textured soils with plenty of moisture exhibit only slight chlorosis of the older leaves, little or no stunting, and may produce close to a normal yield for a year or two. In subsequent years,

however, nematode population densities increase and plants in these areas become severely chlorotic and dwarfed. In heavily infested fields, yield is reduced 30-75%.

The root systems of infected plants appear smaller than those of healthy plants, but no macroscopic lesions, galls, or other type of abnormalities are evident on infected roots. The roots of infected plants usually have fewer nitrogen fixing bacterial nodules than those of healthy plants. The most characteristic sign of this disease is the presence of female nematodes in varying stages of development and cysts attached on soybean roots. Young females are small, white, and partly buried in the root, with their posterior region protruding. Older females are larger, almost completely on the surface of the root, and appear yellowish or brown depending on maturity. Brown cysts also appear on roots.

Systems used throughout the USA to predict crop damage are based on cyst, egg, or second-stage juvenile population density estimates. More research is necessary, however, to determine which parameters are best for predicting crop loss (Schmitt and Noel, 1984). The influence of soil texture is important in this relationships because of a tendency toward linear population density slopes in sandy soil and quadratic relationships in other soil textures (Schmitt & Noel, 1984).

Crop rotation is an effective and practical means of control. Resistance to H. glycines is a type of hypersen- sitive reaction in which the

tissue affected by the nematode deteriorates and the nematodes fail to develop.

2.2 BIOLOGY AND ECOLOGY OF GLYCINE MAX

The soybean [Glycine max (L.) Merrill], is an important crop in both China and the USA. The origin of the cultivated form of the soybean was described in the writings of the Chinese Emperor Shen Nung 4,000 years ago. Soybeans were first imported to the USA less than 200 years ago. In the US, soybeans were used as a hay crop in the early years of the production. Up to 1941, over half of the soybean acreage was for hay, grazing, or green manure. The trend toward soybean production for processing has increased because of the demand of soybean oil and meal. In 1961, the production in the USA was 558.8 million bushels of beans, and 751,000 tons of hay. Morse (1950) presented a detailed account of the modern history of the soybean and recorded that the first published account of soybeans in the United States. The first soybeans came to the United States by Clippership in 1804. According to Morse, not more than eight varieties of soybeans were grown in the United States prior to the numerous introductions by the US Department of Agriculture beginning in 1898. Introductions from China, Korea and Japan played a predominant role in the

soybean industry. The early varieties and germplasm used in soybean breeding came from these introductions.

Soybean appeared in Michigan as early as 1902 (Megee, 1937). Mr. E. E. Evans of West Branch, took an active part in introducing, breeding, and distributing varieties of soybeans for almost 20 years. The Ogemaw is an introduction of Mr. Evans and is the result of a cross between his No. 6 Early Black and Dwarf Browm. Since 1918, the MI Agricultural Experiment Station has conducted numerous variety tests of both hay and seed production in East Lansing and at various locations throughout the state. The adaptation of soybeans in MI is usually limited to areas and soils upon which corn can be grown. Before World War II, soybeans had been used primarily by farmers as an emergency or short-season hay crop, or as a supplementary dairy feed. The soybean seed was ground with oats and barley, or the seed, stems and leaves were run through a hammer mill and fed as a roughage. They had also been used to a limited extent as a soil improvement and green manure crop (Megee, 1936). The soybean acreage planted increased to 1.21 million acres in MI in 1988, a crop of value at $254 million (Michigan Agricultural Statistics, 1989, Michigan Department of Agriculture).

In 1930s, Herry Ford of Ford Motor Company became interested in soybeans and began growing them on a large scale (Smith, 1936). Windish states that "The industrial giant, Henry Ford, was among the soybean's strongest supporters." "He envisioned an immense future potential for

soybeans, but in industry rather than in food or feed." Mr. Henry "wore a handsome suit ..... made entirely of soybean, at a whispered cost of $40,000 in scientific research." "The Ford Motor Co. at that time made 20 automobile parts and all of its car enamel of soybeans."

G. max is known to have 40 chromosomes and behaves as a diploid. Norman (1963) listed the genes reported for G. max, including a description of phenotypes and references establishing the mode of inheritance and assigning the symbols. Resistance to H. glycines was reported by Caldwell et al. (1960) to be due to the complementary action of three recessive genes (rhg1 rhg2 rhg3). There is a predominance of Manchurian germplasm in northern soybean varieties and this is understandable because such a large number of the early introductions adapted in maturity to northern States were from Manchuria.

In its flowering response, G. max is an example of a short-day plant. But varieties differ in numerical length of their effective short days. For example, plants of many varieties are incapable of flowering unless they receive 10 or more hours of darkness daily (Bortywick and Parker,1939). The characteristic of flowering response has been used by plant breeders as the basis for classification of soybean lines, first into eight and currently into ten maturity groups; ranging form Group 00 for Canadian latitudes to Group VIII for Gulf Coast areas. Group 0 and 00 were added to the original numbering scheme with the development of increasingly early varieties and the movement of soybean production northward.

Growth of G. max from germination to maturity is in general proportional to the available moisture supply, although a precise mathematical description of available moisture is difficult to make (Norman, 1961). Soil-moisture relationships are of practical interest when the moisture extremes occur, such as drought or excessively wet condi- tions. The soybean plant possesses an adaptive morphological mechanism that may limit its use of water. Clark and Levitt (1956) found that rates of water loss were inversely corre- lated with surface-lipid concentration. Hunter and Erickson (1952) reported that a moisture content of about 50% was required for germination of seeds.

Growth of soybean roots as well as of the rest of the plant is affected by soil-moisture conditions. Both deficient and excessive moisture during the preflowering period retard vegetative growth and reduces the number of flowers. When either deficient or excessive moisture prevailed during flowering, the shedding percentage increases (Fukui and Ojima, 1957).

G. max succeeds on nearly all soil types except extremely deep sands. Earley and Cartter (1945) found that under greenhouse gravelculture conditions, temperature variations between 54 and 99 F, had only a slight effect on root dry weight. Most of the normal respiration of roots can be accounted for in mitochondria, using a conventional Krebs cycle type of metabolic system (Key et al., 1960), and thus require a supply of oxygen. Hopkins et al. (1950) found that restriction of oxygen supply to roots

reduced shoot system growth as much or more than root growth, although the plants exhibited a "remarkable tendency to maintain growth processes" at oxygen levels in the root medium as low as 1.5%.

Light saturation of photosynthesis in individual soybean leaves is at about 2,200 foot-candles (Bohning and Burnside, 1956). This is about 20% of the intensity of sunlight at midday in the central part of the USA.

Nodes on the main axis are rapidly differentiated, and only 4 or 5 weeks is required for complete differentiation (Johnson et al., 1960). Plants increase in dry weight slowly at first, and then more rapidly (Borst and Thatcher, 1931). Vegetative growth ceases at the time seed enlargement starts. The dry wights of leaves, and to a smaller extent the dry weight of stems and roots decrease thereafter; so that the total weight of the plant at maturity, including seed, is slightly less than the maximum attained 3 or 4 weeks earlier.

Three distinct growth stages were recognized by Hsmmonf and Kirkham (1949) in both greenhouse and field studies: 1) preflowering; 2) flowering and pod set; and 3) seed development. Within each stage a plot of the logarithm of weight against time gave a straight line. Relative growth rates (grams per gram per day) were about 0.085 in first period, 0.045 in second period, and 0.02 in third period (Norman, 1961). Brown (1960) and Chapman (1960, 1961) developed a Soybean Development Unit (SDU) system based on the equation: SDU = 4.39T - 0.0256T* - 155.18) which

indicates a requirement for less than 1,900 to more than 5,000 SDU for maturity of soybeans growing in the Great Lakes Region.

2.3 BIOLOGY AND ECOLOGY OF CHENOPODIUM ALBUM

Chenopodium album L. (common lambsquarters) is native to Europe. It is one of the most widely distributed weed species in the USA, and in the world. It can be a serious weed problems in soybean production and in a wide range of other agronomic crops in MI. The discovery of triazine resistant common lambsquarters in European countries and the USA has created new challenges for controlling this weed in agronomic crops (Crook, unpublished).

C. album is a hexaploid 2n=54, with 34 subspecies. The plant is an erect pale green summer annual having alternate leaves with a mealy white appearance of the flowers and leaves, especially in young plants.

C. album is a highly competitive colonizer occurring in habitats that have been opened by disturbance. The plant is extremely tolerant to wide variations in pH and grows well in most soils, except those with very high acidity (William, 1963). Plants have different metabolic pathways for fixing carbon dioxide into organic carbon structures. The type of metabolism may influence the optimum environment in which a plant performs. Plants are designated as C3 or C4 plants. The C4 pathway provides more efficient

water usage (Harper, 1977). G. album is a C3 plant, performing better in lower temperatures and higher relative humidity (Brunce, 1983). Germination, growth, exchange of carbon dioxide and light utilization are more efficient at lower temperatures early in the season when cooler air and soil temperatures prevail (Tenhumen, 1982). These lower temperatures may give C. album a competitive advantage compared to a C4 plant which germinates later when the soil and air temperatures are warmer.

C. album requires 658 grams of water to produce 1.0 gram of dry matter (Black, 1969). The density increases to 576 plants/m^2, at which yield plateaus because of increasing intraspecific competition. Competition from other plants, either inter or intraspecific may also delay flowering of C. album (Pickett, 1978). The amount and duration of shade influence the growth of C. album. Branch and tiller number decrease under shaded conditions. Main stem length is inhibited under 84% shade, and shade results in shorter plants (Crook, unpublished). Shade has to be greater than 90% to diminish its overall growth (Noguchi, 1978). Shade also delays heading and flowering of the mother plant, and seed ripening. Competition encountered by one individual plant is dependent on the density, distribution, duration, and species of competitor plants. Plants can compete for a supply of nutrients, light, or water simultaneously or in rapid succession. Plant growth therefore, integrates the situation of justifying the use of plant weight as an index of competition. Plant size, weight and

height suggest that the potential for the capture of light, although climatic conditions have a modifying effect on these results.

C. album has "somatic polymorphism", a condition where a plant produces more than one seed type in terms of morphology or behavior (Holzner, Williams and Harper, 1965, Williams, 1962). Brown seeds germinate immediately, while black seeds remain dormant (Williams, 1962, Williams and Harper 1965). C. album has epigeal germination from an optimum soil depth of 2.0 to 2.5 cm (Williams, 1963). Seedlings that germinate accounted for less than 5% of the total viable seeds in the top 10 cm of soil (Roberts and Ricketts, 1979). Fourteen hours of daylight is required by mother plants before induction of flowers (Holzner, 1982). C. album does not germinate in darkness at any temperature (Baskin, 1977). Germination of the plant is prevented at soil depths where light penetration is not sufficient to change phytochrome red (Pr) to phytochrome far-red (Pfr) (Gutterman, 1985), and is stimulated by alternating temperatures which increase the sensitivity to light (Hension, 1970).

Many competitive weeds are the earliest to emerge. This indicates that the timing of emergence of a seeding population may be more important than the spacial arrangement of the seedlings. Early germination may be an important determinant for C. album in competitive interactions, primarily through events prior to the actual initiation of competition under the field conditions (Pearcy, 1981). The growth rate of individual plants may be directly related to the time at which the individual plants emerge,

rather than the absolute time of each plant's emergence. An individual plant's potential for capturing resources is dictated by the number and proximity of neighbors already capturing the resources (Ross, 1972).

2.4 PLANT INTERACTIONS

Interactions among plants can be divided into three categories: competition, allelomediation, and allelopathy.

Competition is a mutually adverse impact of an organism which utilizes a resource in shout supply (Radosevich and Holt, 1986). It can be divided into two categories: intraspecific and interspecific competition. Intraspecific competition is the negative interaction between plants of the same species. Interspecific competition is the adverse interaction between different species.

Several methods are used to study relationships between plants growing in mixed cultures. These include additive, substitution, and sysmatic interaction analysis procedures. The additive method involves growing two plant species together, where the density of one species is the varied, while the density of the other species is held constant (Radosevich, 1987). In most experiments, the crop density is held constant and the weed density varied. As weed density increases, crop productivity decreases

curvilinearly to a point at which crop yield no longer decreases as weed population increases.

The substitutive or replacement method is used to predict the competitiveness of one species with another, and total plant density is held as a constant. The law of constant, final yield compared to total plant yield is independent of density, is applied in the replacement method (Radosevich, 1987). With this procedure the total plant density remains constant while the proportion of the two species to each other is varied (Roush and Radosevich,1985). The replacement method is valuable in assessing the competitive ability of plants at a constant total plant density (Radosevich, 1987). The systematic method utilizes a parallel row or fan design with introspecific competition pertaining to crop yields.

C. album ranks third in relative competitive index after barnyardgrass and redroot pigweed, which are C4 plants being more competitive in the warmer climate. As a C3 plant, C. album has better germination, general growth, and higher photosynthetic rate at lower temperatures (Chu, 1978, and Aldrich, Pearcy, 1981). Under cool wet spring conditions, common lambsquarters emerges early and establishes a dominant population (Chu, 1978). This competitive advantage, therefore, is gained primarily through events that take place prior to the actual initiation of competition (Pearcy, 1981). The vegetative development of C. album is maximum 42 to 49 days after emergence (Williams, 1964). Plant size, weight and height provide C.

album a potential advantage for light capture (Roush, Williams, 1964). Its aggressiveness in competition is also attributed to its ability to compete strongly for nutrients (William, 1964). Holm reported that C. album competes strongly with corn for nitrogen, potassium, calcium, and magnesium. At a density of one plant per 0.625 m^2 of row, competition from C. album decreases soybean yield 15% (Shurtlwff, 1985).

In greenhouse studies, soybean dry matter production was reduced when C. album was planted two weeks before soybeans (Shurtleff, 1985). The observed growth stimulation of C. album when planted prior to soybeans suggested that this species competes well with soybeans for available resources provided that the root system is established prior to the soybean (Shurtleff, 1985).

Resources such as light, water, and nitrogen can be limiting factors in plant growth and crop production. Since soybean are legumes, competition with weeds for nitrogen is usually not a limiting factor for soybeans. Weed control is essential in soybean production, however, as weeds compete for light and moisture with soybeans (Crook, unpublished).

Moisture is a critical factor in soybean growth. Soybean yields were reduced more by weed competition under water stress (Hagood, 1981) than under higher soil moisture conditions. Adequate soil moisture is critical during the podfilling stage of soybean development, emphasing the detrimental effect of weed competition on plant moisture stress when soil moisture was limiting (Webber, 1987).

Soybeans have the ability to compensate when planted under stress. The time when weeds are competing is a critical factor in the degree of competition the soybean plant experiences. Yield reduction may be due to a combined effect of light and moisture competition (Webber, 1987). Weed control during the first month after planting is most critical to obtain maximum yields, regardless of planting date (Burnside, 1979, Murphy, 1981). An inverse relationship exists between soybean stand and the production of shoot system growth (Burnside, 1979). The weight of weeds at harvest is inversely correlated to soybean yield (Thurlow, 1972). As weed growth increased, the soybean seed weight and numbers of seed per plant decreased (Burnside, 1979). Other soybean growth parameters such as dry weight of the leaves, stems, roots, pods seeds and pod number, and leaf area index are also reduced by weed competition (Hagood, 1980).

Cultivars of G. max vary in their ability to compete with weeds (Burnside, 1972). Wild oat competition decreased the number of soybean pods per plant and the number of seeds per pod or seed weight (Rathmann, 1981). Shading by the soybean canopy suppresses late germinating weeds (Murphy, Bloomberg, 1982). Weeds germinating 20 to 40 days after soybeans were greatly suppressed due to canopy closure, therefore reducing their effect on soybean yield (Eaton, 1976). Competition within the row is studied more frequently because weeds are believed to be more competitive for light and moisture in the soybean row, and weeds cannot be removed from within the row by cultivation.

On a global basis, H. glycines parasitizes a wide range of common weeds. While most crops grown in MI are not hosts of H. glycines. A few of the weeds these crops foster may be hosts of this nematode. Herbicide and alternative weed management tactics in MI could be affected by H. glycines. Most major weeds in MI soybean production are not recorded as hosts of H. glycines.

Weed science is placing increasing emphasis on the importance of competition thresholds. Few of these thresholds, however, have been developed for use in the presence of a concomitant pest species such as H. glycines. Soybean competition thresholds have been developed in MI for giant foxtail and fall panicum. Theoretically, the competition threshold for G. max should be lower in the presence of H. glycines than in the presence of this nematode. There is a need to develop appropriate joint action thresholds that account for both the competition of weed and impact of H. glycines. Future weed and nematode control procedures will most likely require information on the effect of weed stress on economic thresholds for H. glycines. Giant foxtail competition thresholds for soybean plants were shown to be influenced by soil texture and annual environmental conditions. Nothing is known, however, about the impact of H. glycines induced physiological changes of the soybean plant in relation to weed competition thresholds. Information about the influence of H. glycines on weed competition thresholds is needed for proper timing of post-emergence herbicides and other soybean management decisions.

2.5 THE WATER RELATIONSHIPS OF PLANTS AND SOILS

Water is essential for the development of green plants, accounting for 70-90% of the fresh weight of most non-woody species. Most of this water is contained in cell contents (85-90% water) where it provides a suitable medium for biochemical reactions. Water also has many other roles to play in the physiology of plants. Water functions as a soluent for three groups of biologically important solutes, which are 1) organic solutes, 2) charged ions, and 3) small molecules (Fitter and Hay, 1987).

Water moves from the soil through the root and stem, to a transpiring leaf only if there is continuity of liquid throughout the pathway. Thus, in addition to continuous columns of water in xylem, plants also requires continuity of water in the capillaries of the soil and the apoplasts of both root and leaf. The pathway of water movement from the root surface to the site of evaporation in the leaf is predominantly extracellular.

Most of the plant's water supply is derived though the functional activity of young roots. In the meristematic region just behind the tip, the uptake of water is impeded by the presence of dense protoplasm and the absence of xylem vessels. Maximum absorption occurs some distance back in the zone where xylem is well differentiated and epidermis has not become so impregnated with suberin that its permeability is drastically reduced. Root hairs, by extending the surface exposed to the external

liquids, will facilitate absorption. It should be noted that there are marked differences in root hair development between the different plant species. Angiosperms develop more root hairs than gymnosperms (Thomas et al., 1973). As the available water surrounding roots is reduced by absorption, more water may move towards the roots by capillarity. If toot extension stops for only a few days, a serious water deficit develops in rapidly transpiring plants rooted in soil drier than field capacity (Kramer, 1969). Many temperate weeds produce very small seeds which are able to lodge in cracks in the soil surface where better contact can be made with soil moisture, and evaporative loss from the seed is reduced by an undisturbed, humid, boundary layer (Harper et al., 1965).

Furr and Reeve (1945) used the terms "first permanent wilting point" and "ultimate wilting point" to describe respectively the water status of the soil at which the basal leaves of a sunflower plant wilt and at which the entire plant wilts and fails to recover if placed in a saturated atmosphere overnight. The range between is called "wilting range". It is usually narrower for coarse textured soil than for finer soil with high clay content. The low limit of available water, i.e. the "permanent wilting percentage" is often found by measuring water content of a soil when the suction is 15 atmospheres. The moisture used in growth, which is called the "available moisture", is given by the difference between water contents of soils at the field capacity and the permanent wilting point. For the coarser sandy soil water is available to the plant when it is present in the soil in amounts

between 5% and 15% of the soil's dry weight. The available water is relatively large in the finer textured clay soil where the range is from 16% to 48% dry weight (Thomas et al., 1973).

Stress has been defined as "any environmental factor capable of inducing a potentially injurious strain in plants" (Levitt, 1980), where the "strain" can be reversible or irreversible. Because of the complexity of plant/water relations, there is no single index of water supply be the environment (soil water content, etc.) which can be used to express the degree of water deficit stress normally called water stress to which a plant is subjected (Fitter and Hay, 1987). Overall, it can been seen that exposure of plants to even mild water stress can affect growth and lead to the disrupting of metabolic processes. To grow and reproduce successfully in all but the most humid environments, plants must be able to survive periods of exposure to water stress varying in length from hours to years. Although it is clear that there are substantial differences amongst plant species in their resistance to injury by dehydration, it is difficult to quantify such differences because of uncertainties in establishing appropriate indices of dehydration "stress" and the resulting "strain" or injury (Parker, 1970).

With a given climatic zone, the availability of water for plant uptake depends upon the water-storing properties of the soil. Since the concentration of solutes in the soil water is generally very low, the major forces retaining water in soil pores are the metric forces, which increase as pore diameter decreases. The amount of soil water which is available for

uptake by a plant depends primarily upon the size distribution of the soil pores. In general, medium to fine textured soils tend to hold more water for plant use than coarse textured soils. Plants do not draw water only from the immediate vicinity of their actively-absorbing roots (Hainsworth and Aylmore, 1986). The maintenance of a steady flow of water into a root from a drying soil requires 1) a progressive lowering of root xylem water potential to maintain the potential gradient between the xylem and the remaining soil water; and 2) a progressive increase in the steepness of the gradient to overcome the increasing resistance to water flow offered by the drying soil (Fitter and Hay, 1987).

Problems of water shortage and maintenance of turgor are universal among terrestrial plants. The physiological and morphological characteristics and life-cycles which have evolved in response to water deficit can be divided into three main classes: 1) adaptations leading to acquisition of the maximum amount of available water such as avoidance of water stress, and the amelioration of its effects; 2) adaptations leading to the conservation and efficient use of the acquired water such as amelioration and tolerance, but also avoidance in the case of those species which restrict their activities to periods of water availability; and 3) adaptations in mainly biochemical and ultrastructural which protect cells and tissues from injury or death during severe desiccation (Fitter and Haym 1987).

C4 species are more efficient at using water than the C3 species, which are generally, but no exclusively adapted to more mesic

environments. In general, the ability of plants to use water efficiently and avoid the damaging effects of water stress varies with ontogeny. Most plants are very sensitive to drought at the beginning of the reproductive phase of development, but relatively insensitive during vegetative growth (Fitter and Hay, 1987).

Measurement of soil water is necessary for agricultural, hydrological and engineering studies. The water in the soul is in a highly dynamic state, and evapotranspiration, precipitation, irrigation and temperature conditions continuously affect the state and movement of water. What ever maybe the cause, there is likely to be a great variation in the water content and its energy status at different places in the same field. Therefore, measurement of soil water content has received a great deal of attention. For a complete evaluation of a soil water system, one must know not only the amount of water in the soil and the energy status of the water, but also changes with three-dimensional space and time, which is difficult to make under field conditions but is possible under controlled laboratory conditions (Ghidyal and Tripathi, 1987). The direct and indirect methods of measuring soil water content can be broadly classified into following main groups: 10 thermo-gravimetric; 2) lysimetric; 3) penetrometer; 4) electrical; 5) nuclear; 6) acoustic (ultrasonic); 7) chemical; and 8) thermal.

Ritchie et al. (1983) studied field-measured limits of soil water availability as related to laboratory-measured properties, and the results suggest that if absolute accuracy is necessary in water balance calculations,

laboratory-estimated soil water limits should be used with caution. If available, field-measured limits would be preferred. A user-orientated model of the soil water balance in wheat was developed to evaluate the impact of water supply on crop yield and provide information for a risk analysis where the water supply is highly variable (Ritchie, 1985). The model consists of components that have been altered to simulate corn and potato growth and development.

3.0 METHODS AND MATERIALS

Three experiments were used to evaluate the joint influence of H. glycines and C. album on early development of G. max. The first two experiments were conducted in a growth chamber at the MSU Pesticide Research Center. The third experiment was conducted in 1989 in microplots at the MSU Department of Entomology, Collins Road Research Farm in East Lansing.

3.1 General Methodology. A completely randomized design with four replications of each treatment was used in each experiment. The controlled conditions in the growth chamber consist of a 16 hour photoperiod of 1000 foot candles, a maximum tempreture of 24 ^{C}, and a minimum temperature of 16C. Steam-sterilized loamy sand soil (2 hr, at 98C) was used in all three experiments. Manganese was added at the equilivalent of 100 lb/A. G. max cv Corsoy 79 was used in all three trials. Seeds were inoculated with Bradyrhizbium japonicum before planting. Seeds of C. album were obtained from MSU Department of Crop and Soil Science, and stored in a 4 C cooler. The seeds of the both plants were germinated in vermiculate under greenhouse conditions. Plants were distructively sampled 14, 28, and 42 days after planting. The samples were dried to constant weight in an oven at 90C. Root and shoot dryweights of soybean and lambsquarter plants were

determined for the first, second and third harvest using a balance (Mettler P1210). Roots of the first harvest were weighed on an analytical balance.

3.2 First Growth Chamber Experiment. The first experiment, consisted of ten treatments developed from 4 experimental vaiables: ± H. glycines, ± G. max, ± C. album, and number of plants per pot (Table 3.1). Each experiment unit was a 6-inch-in-diameter clay pot filled with steam-sterilized soil. H. glycines inoculum was obtained from soil from Gratiot County. Soil in appropriate experimental units was inoculated with 5,000 viable units(eggs and second-stage junveniles) of H. glycines two days after soybean trans- planting.

3.3 Second Growth Chamber Experiment. The second growth chamber experiment was a modification of the first experiment, and consisted of 10 treatments derived from five experimental variables: ± H. glycines, ± G. max, ± C. album, number of plants, and planting time (Table 3.2). The H. glycines inoculum level consisted of 10,000 viable units per pot. Plastic pots were used instead of clay pots. A central pot with no plant was established for determination of water loss due to chamber condition.

3.4 Microplot Experiment. To simulate commercial soybean production conductions, a third experiment was conducted in microplots under 1989 field condition. The experiment consisted of 120 microplots,

and the same design and experi- mental variables used in the second growth chamber experiment (Table 3.2). Each microplot was a 30 cm long by 25 cm internal diameter open-ended unglazed clay drainage tile. The microplots were established 0.3 m apart in the middle of 1.0 m strips of soil fumigated with 500 lbs/A of 98% methyl bromide and 2% chloropierin. Circa 10,000 cm^3 of steamed loamy sand soil was placed in each microplot. A twin shell blender (2.8 x 1,000 cm) was used to thoroughly incorporate 15,000 viable units of H. glycines into the soil used for each microplot innoculated with this nematode. The microplot experiment began on July 8, 1989.

Table 3.1

Treatments and experimental variables
used in the first growth chamber experiment

Treatment	H. glycines	G. max	C. album
		(No. plants)	(No. plants)
1	-[1]	+ (1)	-
2	-	+ (2)	-
3	-	+ (1)	+ (1)
4	-	-	+ (2)
5	-	-	+ (1)
6	+	+ (1)	-
7	+	+ (2)	-
8	+	+ (1)	+ (1)
9	+	-	+ (2)
10	+	-	+ (1)

1) + = present
- = absent

Table 3.2

Treatments and experimental variables

used for the second growth chamber experiment

and microplot experiment

Treatment	H. glycines	G. max (No. plants)	C. album (No. plants)
1	-[1]	+ (1)	-
2	-	+ (2)	-
3	-	-	+ (1)
4	-	-	+ (2)
5	-	+ (1)	+ (1)2
6	-	+ (1)	+ $(1)^3$
7	+	+ (1)	+ $(1)^2$
8	+	+ (1)	+ $(1)^3$
9	+	+ (1)	-
10	+	+ (2)	-

1) + = present; - = absent

2) C. album planted 7 days before G. max.

3) C. album planted 7 days after G. max.

3.5 Relative Growth Rate Analysis The following formula was used to calculate the Relative Growth Rate(RGR) from the data collected in all three experiments.

$$RGR = dW(1/dT)(1/W) \qquad [F3\text{-}1]$$

where RGR = at an instant in time, the rate of increase in plant dry weight per unit of existing weight per unit time

dW = the weight change over a period of time

dT = the time change

W = the weight after a period of time

3.6 Water Utilization Analysis. The thermo-gravimetric method (Ghildyal, B.P. and R.P. Tripathi. Soil Physics. 1987. page 232-234), a simplest and the most widely used procedure for the determination of water content of the soil, was used to study the influence of H. glycines and C. album on water utilization by G. max in the second growth chamber experiment. The experimental design was showed in Table 3.2.

Soil moisture samples in 10 ml^3 beakers were weighed on a balance (Mettler P1000) each day before watering. The samples were dried to constant weight in an oven at 90 C. The difference between the moist weight and dry weight was used to determine the water content in each soil sample.

The soil water content data were used for development of the watering plan designed to apply constant amounts of water to each treatment pot, and a variable amount of water to the check pot, keeping moisture on the surface of the check pot. A summary of watering scheme is given in Table 3.3.

Six formula were used for the soil moisture data analysis in this research. The first formula calculated the water consumption on a daily average basis (F3.2).

$$W1 = T1/14 \qquad \text{(F3.2)}$$

where

W1: Water lost each day in treatment pots in 14 day period

T1: Total amount of water applied in 14 day period

The method of measuring soil water was also used to obtain the water consumption each day. The second formula was used (F3.3):

$$W1' = M1 \times N1 + W4 - M2 \qquad \text{(F3.3)}$$

where

W1': Water lost each day in treatment pots by measuring

M1: Water amount in a 10 ml beaker that day before watering

N1: Number of adjustment, range: 93.2 - 96.7

W4: Water applied to the pot that day

M2: Water amount in the 10 ml beaker next day before watering

To determine how much water entered the plant(s), the third and forth formula were used (F3.4 & F3.5).

$$W2 = W1 - W3 \qquad \text{(F3.4)}$$

where

W2: Water to plant(s)

W1: Water lost each day in treatment pots in 14 day period

W3: Water lost in the check pot

$$W2 = W1' - W3 \qquad \text{(F3.5)}$$

where

W2: Water to plant(s)

W1': Water lost each day in treatment pots by measuring

W3: Water lost in the checking pot

For checking efficiency of water lost in each treatment, the fifth and sixth formula was used (F3.6 & F3.7).

$$N2 = W5 - W6 \qquad (F3.6)$$

where

N2: Coefficient of water lost in each treatment

W5: Water amount in the soil of a 10 ml beaker in the check pot each day before watering

W6: Water amount in the soil of a 10 ml beaker in each treatment pot each day before watering

$$N3 = \log W7 - 1.5 \qquad (F3.7)$$

where

N3: Coefficient in the ending of water consumption

W7: Average water consumption per treatment

3.7 Statistical Analysis. The experimental results were analyzed with principles and methods of statistics. The Statistical analysis, such as Student-Newman-Keuls multiple range test and TTest, were conducted through ANOVA procedure in a computer system known as SAS SYSTEM. The other statistical analysis, such as factorial analysis, were conducted by self-designed ANOVA computer procedure.

The Student-Newman-Keuls multiple range test (SNK test) was performed on all maineffect means. The SNK test begins on comparing the maximum and minimum means. If the range is not significant, no further testing is done and the set of means is declared homogeneous. If the maximum difference is declared significant, the test continues. At any stage, where a difference is not significant, testing stops and the set is declared homogeneous. Otherwise, testing continues. SNK test makes more declarations of significance than when Tukey's test is used but fewer than with the LSD.

ANOVA is one of several procedures available in the SAS SYSTEM to perform analysis of variance for balanced data, which is data with equal numbers of observations for every combination of the classification factors, from a wide variety of experimental designs. The analysis of variance is a technique for analyzing experimenatal data. A continuous dependent response variable is measured under experimental conditions identified by independent classification variables. The variation in the response is explained as being due to effects in the classification with random error accounting for the remaining variation.

The SAS SYSTEM is a software system for data analysis and report writing. The goal is to provide data analysts one system to meet all their computing needs. Base SAS software provides tools for 1) information storage and retrieval; 2) data modification and programming; 3) creating reports all in one SAS session; 4) statistical analysis; and 5)

file handling capability.

A factorial experiment refers to the treatment combinations. The factorial set of treatments was used in a completely randomized design for this research. In a factoreal experiment the treatments consist of combinations fo two or more factors each at two or more levels. The combinations are such that level of every factor occurs together with each level of every other factor. The number of treatments is the product of the number of levels of all factors. Factorial experiments are used in practically all fields of research. They are of great value in exploratory work where little is known concerning the optimum levels of the factors, or even which ones are important.

If the interaction is nonsignificant, it is concluded that the factors under consideration act independently of each other; the simple effects of a factor are the same for all levels of the other factors, within chance variation as measured by experimental error. The average of simple effects, namely the main effect, is appropriate and the best estimate of the common difference. Where factors are independent, the factorial experiment saves considerable time and effort. This is so since the simple effects are equal to the corresponding main effects and a main effect, in a factorial experiment, is estimated as accurately as it would be if the entire experiment had been devoted to that factor. When the factors are largely independent, the table of treatment means and analysis of variance summarize the data well.

A significant interaction is one that is too large to be explained on the basis of chance and the null hypothesis of no interaction. With a significant interaction, the factors are not independent of one another; the simple effects of a factor differ and the magnitude of any simple effect depends on the level of the other factor of the interaction term. Where factors interact, a single-factor experiment will lead to disconnected and possibly misleading information. When the factors are not independent, the data require a detailed study with the possibility of further experimentation.

4.0 RESULTS

4.1 First Growth Chamber Experiment. The results for the first growth chamber experiment are presented under the categories of plant dry weight, relative growth rate.

4.1.1 Plant Dry weight. After 14 days, H. glycines, C. album and G. max competition had no detectable significant (P=0.05) influence on the dry weight of G. max (Table 4.1). Impacts, however, were detected after 28 days. The presence of C. album or more than one G. max plant resulted in significantly (P=0.05) less G. max dry weight on a per plant basis (Table 4.1). The results were similar after 42 days of plant growth. In this experiment, H. glycines alone had no significant (P=0.05) influence on the dry weight of G. max.

There were no significant (P=0.05) interactions among H. glycines, G. max and C. album on the dry weight of G. max (Table 4.2 and 4.3). On all three harvest dates, the expected joint impact of H. glycines and C. album was the same as the measured joint impact (Table 4.4).

The presence of G. max or more than one C. album plant resulted in significantly (P=0.05) less C. album dry weight on a per plant base (Table 4.5). In this experiment, the presence of H. glycines associate with G. max did not significantly (P=0.05) alter the impact plant competition by G. max

or more than one C. album plant on the dry weight of C. album (Table 4.5).

Table 4.1

Joint influence of Heterodera glycines and Chenopodium album on the dry weight of Glycines max[1].

Treatment			G. max dry weight (g/plant)		
H. glycines	G. max	C. album	14 days	28 days	42 days
-	+ (1)[2]	-	0.42 a[3]	2.85 a	6.38 a
-	+ (2)	-	0.31 a	1.81 c	4.38 bc
-	+ (1)	+ (1)	0.32 a	2.14 bc	3.68 c
+	+ (1)	+ (1)	0.34 a	1.78 c	3.25 c
+	+ (1)	-	0.38 a	2.53 ab	5.45 ab
+	+ (2)	-	0.29 a	1.72 c	3.95 c

1) First growth chamber experiment.

2) Number in brackets indicates number of plants per experimental unit.

3) Means followed by the same letter are not significantly (P=0.05) different according to the Student-Newman-Keuls Multiple Range Test.

Table 4.2
Influence of Heterodera glycines and Chenopodium album on the dry weight of Glycine max.

FACTOR		G. max dry weight (g/plant)		
A	B	14 days	28 days	42 days
+H. glycines	+C. album	0.34	1.88	3.25
	-C. album	0.38	2.53	5.45
-H. glycines	+C. album	0.32	2.14	3.68
	-C. album	0.40	2.85	6.38

ANALYSIS OF VARIANCE (14TH DAY)

Source	df	SS	Mean square	F
Treatment	3			
A	1	0.000076	0.000076	0.016882 n.s.[2]
B	1	0.014101	0.014101	3.109567 n.s.
AB	1	0.001914	0.001914	0.422074 n.s.
Error	12	0.054418	0.004534	

ANALYSIS OF VARIANCE AT (28TH DAY)

Source	df	SS	Mean square	F
Treatment	3			
A	1	0.327756	0.327756	2.432065 n.s.
B	1	1.856406	1.856406	13.77517 **[3]
AB	1	0.003906	0.003906	0.028985 n.s.
Error	12	1.617175	0.134764	

ANALYSIS OF VARIANCE (42TH DAY)

Source	df	SS	Mean square	F
Treatment	3			
A	1	1.842806	1.842806	3.131128 n.s.
B	1	23.93655	23.93655	40.67081 **
AB	1	0.257556	0.257556	0.437616 n.s.
Error	12	7.062525	0.588543	

1) First growth chamber experiment.
2) n.s. = no significance at the 0.05 level.
3) ** = significant at the 0.01 level

Table 4.3
Influence of Heterodera glycines and planting density on the dry weight of Glycines max[1].

FACTOR		G. max dry weight (g/plant)		
A	B	14 days	28 days	42 days
+H. glycines	1 plant	0.38	2.53	5.45
	2 plants	0.29	1.72	3.95
-H. glycines	1 plant	0.40	2.85	6.38
	2 plants	0.31	1.81	4.39

ANALYSIS OF VARIANCE (14TH DAY)

Source	df	SS	Mean square	F
Treatment	3			
A	1	0.001425	0.001425	0.264180 n.s.[2]
B	1	0.035438	0.035438	6.569574 *[3]
AB	1	0.000022	0.000022	0.004182 n.s.
Error	12	0.064731	0.005394	

ANALYSIS OF VARIANCE (28TH DAY)

Source	df	SS	Mean square	F
Treatment	3			
A	1	0.170156	0.170156	1.487908 n.s.
B	1	3.385600	3.385600	29.60491 **[4]
AB	1	0.054056	0.054056	0.472687 n.s.
Error	12	1.372312	0.114359	

ANALYSIS OF VARIANCE (42TH DAY)

Source	df	SS	Mean square	F
Treatment	3			
A	1	1.883756	1.883756	3.647936 n.s.
B	1	12.19755	12.19755	23.62084 **
AB	1	0.237656	0.237656	0.460226 n.s.
Error	12	6.196675	0.516389	

1) First growth chamber experiment.
2) n.s. = no significance at 0.05 level.
3) * = significant at 0.05 level.
4) ** = significant at 0.01 level.

Table 4.4

Analysis of Joint Influence of H. glycines and C. album on the Dry Weight of G. max[1]

	Dry weight of G. max (g/plant)		
	14 days	28 days	42 days
Influence of H. glycines[2]	0.04	0.32	0.93
Influence of C. album[3]	0.10	0.71	2.70
Expected joint influence[4]	0.14(0.10)[5]	1.03(0.59)	3.63(0.67)
Actual joint influence[6]	0.08(0.03)	0.97(0.24)	3.13(0.61)
(Expected - Actual)[7]	0.06 n.s.[8]	0.06 n.s.	0.50 n.s.

1) The first growth chamber experiment.
2) Influence of H. glycines was calculated by the following formula: IN = dry weight of G. max (g/plant) without H. glycines - dry weight of G. max (g/plant) with H. glycines
3) Influence of C. album was calculated by the following formula: IW = dry weight of G. max (g/plant) without C. album - dry weight of G. max (g/plant) with C. album
4) Expected joint influence of H. glycines and C. album was calculated by the following formula: IE = IN + IW
5) Number in brackets indicates stand error in TTest procedure.
6) Actual joint influence of H. glycines and C. album were dry weights of G. max (g/plant) with H. glycines and C. album.
7) The difference between expected and actual joint influence.
8) There is no significant difference (P=0.05) between expected joint influence of H. glycines & C. album and actual one.

Table 4.5

Influence of Glycine max and Heterodera glycines on the dry weight of Chenopodium album[1].

Treatment			C. album dry weight (g/plant)		
H. glycines	G. max	C. album	14 days	28 days	42 days
-	-	+ (1)[2]	0.12 a[3]	2.54 a	6.06 a
-	-	+ (2)	0.09 b	1.35 b	3.64 b
-	+ (1)	+ (1)	0.10 b	1.87 b	3.28 b
+	+ (1)	+ (1)	0.09 b	1.76 b	3.48 b
+	-	+ (1)	0.14 a	2.48 a	6.29 a
+	-	+ (2)	0.10 b	1.39 b	3.62 b

1) First growth chamber experiment.

2) Number in brackets indicates number of plants per experimental unit.

3) Means followed by the same letter are not significantly (P=0.05) different according to the Student-Newman-Keuls Multiple Range Test.

4.1.2 Relative Growth Rate. The relative growth rate (RGR) of G. max was the highest during the first 14 days of the experiment, and lowest in the third growth period (Table 4.6). The relative growth rate of the soybean plant without H. glycines or C. album was ca 0.07 during the first growth period, 0.06 during the second 14 days, and 0.04 in the third 14 days (Table 4.6). The experimenatal variables had no significant (P=0.05) influence on the relative growth rate of G. max in the second 14 days, but had an impact during the third 14 days. Competition among C. album and G. max, and the joint action of C. album & H. glycines resulted in a decrease in the relative growth rate of G. max (Table 4.6). There were no significant (P=0.05) interaction among H. glycines, G. max and C. album on the RGR of G. max (Table 4.7 & 4.8). On all three harvest dates, the expected joint impact of H. glycines and C. album was the same as the measured joint impact (Table 4.9).

Table 4.6

Relative Growth Rate (RGR) of Glycine max[1].

Treatment			RGR in three growth periods(days)		
H. glycines	G. max	C. album	1-14	15-28	29-42
-	+ (1)[2]	-	0.0714[3]a	0.0609a[4]	0.0396a
-	+ (2)	-	0.0714a	0.0593a	0.0419a
-	+ (1)	+ (1)	0.0714a	0.0606a	0.0300b
+	+ (1)	+ (1)	0.0714a	0.0585a	0.0245b
+	+ (1)	-	0.0714a	0.0608a	0.0382a
+	+ (2)	-	0.0714a	0.0595a	0.0402a

1) First growth chamber experiment.

2) Number in brackets indicates number of plants per experimental unit.

3) $RGR = dW(1/dT)(1/W)$ [F3.1]

where RGR = Relative Growth Rate = at an instant in time, the rate of increase in plant dry weight per unit of existing weight per unit time

dW = the weight change over a period of time

dT = the time change

W = the weight after a period of time

4) Means followed by the same letter are not significantly (P=0.05) different according to the Student-Newman-Keuls Multiple Range Test.

Table 4.7
Influence of Heterodera glycines and Chenopodium album on relative growth rate (RGR) of Glycines max[1].

FACTOR		RGR of G. max	
A	B	15-28th day	29-42th day
+H. glycines	+C. album	0.0290	0.0290
	-C. album	0.0370	0.0368
-H. glycines	+C. album	0.0297	0.0298
	-C. album	0.0396	0.0396

ANALYSIS OF VARIANCE (15-28th DAY)

Source	df	SS	Mean square	F
Treatment	3			
A	1	0.000010	0.000010	0.203578 n.s.[2]
B	1	0.000320	0.000320	5.989765 *[3]
AB	1	0.000003	0.000003	0.063980 n.s.
Error	12	0.000641	0.000053	

ANALYSIS OF VARIANCE (29-42th DAY)

Source	df	SS	Mean square	F
Treatment	3			
A	1	0.000013	0.000013	0.253137 n.s.
B	1	0.000308	0.000308	5.782112 *
AB	1	0.000003	0.000003	0.074889 n.s.
Error	12	0.000640	0.000053	

1) First growth chamber experiment.
2) n.s. = no significance at 0.05 level.
3) * = significant at 0.05 level.

Table 4.8
Influence of Heterodera glycines and planting density on relative growth rate (RGR) of Glycines max[1].

FACTOR		RGR of G. max	
A	B	15-28th day	29-42th day
+H. glycines	1 plant	0.038	0.036
	2 plants	0.059	0.040
-H. glycines	1 plant	0.040	0.040
	2 plants	0.059	0.042

ANALYSIS OF VARIANCE (15-28th DAY)

Source	df	SS	Mean square	F
Treatment	3			
A	1	0.000006	0.000006	0.227509 n.s.[2]
B	1	0.001765	0.001765	64.69449 **[3]
AB	1	0.000007	0.000007	0.258930 n.s.
Error	12	0.000327	0.000027	

ANALYSIS OF VARIANCE (29-42th DAY)

Source	df	SS	Mean square	F
Treatment	3			
A	1	0.000026	0.000026	0.719334 n.s.
B	1	0.000035	0.000035	0.943707 n.s.
AB	1	0.000002	0.000002	0.058823 n.s.
Error	12	0.000449	0.000037	

1) First growth chamber experiment.
2) n.s. = no significance at 0.05 level.
3) ** = significant at 0.01 level.

Table 4.9
Analysis of Joint Influence of H. glycines and C. album
on the Relative Growth Rate of G. max[1]

	Relative Growth Rate of G. max	
	15 - 28 days	29 - 42 days
Influence of H. glycines[2]	0.00024	0.00259
Influence of C. album[3]	0.00025	0.00978
Expected joint influence[4]	0.00049(0.004)	0.01237(0.008)
Actual joint influence[6]	0.00205(0.001)	0.01124(0.003)
(Expected - Actual)[7]	-0.00156 n.s.[8]	0.00113 n.s.

1) The first growth chamber experiment.
2) Influence of H. glycines was calculated by the following formula: IN = dry weight of G. max (g/plant) without H. glycines - dry weight of G. max (g/plant) with H. glycines
3) Influence of C. album was calculated by the following formula: IW = dry weight of G. max (g/plant) without C. album - dry weight of G. max (g/plant) with C. album
4) Expected joint influence of H. glycines and C. album was calculated by the following formula: IE = IN + IW
5) Number in brackets indicates stand error in TTest procedure.
6) Actual joint influence of H. glycines and C. album were dry weights of G. max (g/plant) with H. glycines and C. album.
7) The difference between expected and actual joint influence.
8) There is no significant difference (P=0.05) between expected joint influence of H. glycines & C. album and actual one.

4.2 Second Growth Chamber Experiment. The results of the second growth chamber experiment are presented in sections on plant dry weight, relative growth weight and water utilization.

4.2.1 Plant Dry Weight. After 14 days of growth, H. glycines, C. album and G. max competition had no detectable significant (P=0.05) influence on the dry weight of G. max (Table 4.10). Impacts, however, were detected after 28 days. The presence of H. glycines in combination with two G. max plants, and in combination with one G. max plant with early emergence of C. album, resulted in significantly (P=0.05) less G. max dry weight on a per plant base, compared to the other treatments (Table 4.10). The presence of H. glycines had a significant (P=0.05) impact similar to that of the other experimental variables (Table 4.10). After 42 days. H. glycines, C. album and G. max had significant (P=0.05) influences on the dry weight of G. max (Table 4.7). The presence of C. album, H. glycines or more than one G. max plant resulted in significantly (P=0.05) less G. max dry weight on a per plant base (Table 4.10). With one G. max plant per experimentatal unit, the presence of H. glycines made one significant (P=0.05) difference ('b'), and the presence of early emergence of C. album made another one ('c', Table 4.10). In this experiment, the presence of H. glycine in G. max had a significant (P=0.05) influence on the dry weight of G. max. The early presence of C. album also had a significant (P=0.05) influence on the

dry weight of G. max. The experimental vairable of the presence of H. glycines and the early emergence of C. album had the biggest impact on the dry weight of G. max (Table 4.10).

There were no significant (P=0.05) interactions among H. glycines and plant density (Tables 4.11 & 4.12). There was, however, a significant (P=0.05) interaction between C. album and H. glycines on G. max dry weight on day 28 (Table 4.13), but not inrelation to RGR (Table 4.14). In all cases, the expected joint influence of H. glycines and C. album was the same as the actual joint impact (Table 4.15).

Pod dry weight per G. max plant was evaluated 42 days after planting. This parameter was used as an indicator of potential yield in this experiment. H. glycines and C. album had a significant(P=0.05) influence on the pod dry weight of G. max (Table 4.16). The presences of H. glycines resulted in significantly (P=0.05) less G. max pod dry weight on a per plant base. The joint presence of H. glycines and early emergence of C. album resulted in significantly (P=0.05) less G. max pod dry weight (Table 4.16). Early emergence of C. album had significant(P=0.05) influence on the dry weight of G. max pod dry weight. Late emergence of C. album had no significant (P=0.05) influence on G. max pod dry weight in the absence of H. glycines; however, this combination resulted in significantly (P=0.05) less G. max pod weight (Table 4.16).

There were no significant (P=0.05) interactions among H. glycines and C. album in relation to G. max dry weight (Table 4.17); however, there was

a significant (P=0.05) interaction between H. glycines and the population density of G. max in relation to pod dry weight (Table 4.18). In the joint impact analysis, the actual G. max pod dry weight loss was significantly (P=0.05) less than the predicted pod weight for both weed planting dates (Table 4.19).

After 14 days of experimental period, H. glycines, G. max and C. max competition had a few significant (P=0.05) influence on the dry weight of C. album (Table 4.20). The late emergence of C. album resulted in significantly (P=0.05) less C. album dry weight (Table 4.20). The result was similar after 28 days and 42 days of plant growth. More than one C. album plants resulted in significantly (P=0.05) less C. album dry weight on a per plant base after 28 days (Table 4.20), and the result was similar after 42 days of plant growth. In the presence of G. max, or both G. max and H. glycines, the early emergence of C. album did not result in significantly (P=0.05) less C. album dry weight after 28 days of plant growth (Table 4.20), but the result had some changes after 42 days. In the presence of G. max, the early emergence of C. album resulted in significantly (P=0.05) less C. album dry weight after 42 days (Table 4.20). In the presence of G. max and H. glycines, however, the early emergence of C. album still did not result in significantly (P=0.05) less C. album dry weight after 42 days of plant growth (Table 4.20). H. glycines played a significant (P=0.05) role to weaken G. max so that C. album could keep its competitive advantage.

4.2.2 Relative Growth Rate. The relative growth rate of G. max in this experiment was the highest in the first 14-day growth period, and lowest in the third growth period. The presence of H. glycines resulted in smaller relative growth rate of G. max after 28 dyas and 42 days of plant growth (Table 4.21). The early colonization of C. album resulted in smaller relative growth rate of G. max after 42 days (Table 4.21). In the early colonization of G. max, the growth of C. album was too low for meaningful calculation of a relative growth rate for C. album (Table 4.22). In all cases, the expected RGR was not significantly (P=0.05) different from the observed RGR (Table 4.23).

Table 4.10

Joint influence of Heterodera glycines and Chenopodium album on the dry weight of Glycines max[1].

Treatment			G. max dryweight (g)		
H. glycines	G. max	C. album	14 days	28 days	42 days
-	+ (1)	-	0.44 a[4]	2.08 a	4.90 a
-	+ (2)	-	0.38 a	1.43 ab	3.59 bc
-	+ (1)	+ (1)[2]	0.41 a	1.42 ab	3.39 bc
-	+ (1)	+ (1)[3]	0.44 a	1.48 ab	3.73 bc
+	+ (1)	+ (1)[2]	0.41 a	1.23 b	2.80 c
+	+ (1)	+ (1)[3]	0.44 a	1.51 ab	3.53 bc
+	+ (1)	-	0.41 a	1.86 ab	3.94 b
+	+ (2)	-	0.37 a	1.29 b	2.99 bc

1) Second growth chamber experiment.

2) C. album planted 7 days before G. max.

3) C. album planted 7 days after G. max.

4) Means followed by the same letter are not significantly (P=0.05) different according to the Student-Newman-Keuls Multiple Range Test.

Table 4.11
Influence of Heterodera glycines and planting density on the dry weight of Glycines max[1].

FACTOR A	FACTOR B	G. max dry weight (g/plant) 14 days	28 days	42 days
+H. glycines	1 plant	0.43	1.86	3.94
	2 plants	0.37	1.29	2.99
-H. glycines	1 plant	0.44	2.08	4.90
	2 plants	0.38	1.43	3.59

ANALYSIS OF VARIANCE (14TH DAY)

Source	df	SS	Mean square	F
Treatment	3			
A	1	0.001701	0.001701	0.55 n.s.[2]
B	1	0.009751	0.009751	3.13 n.s.
AB	1	0.000232	0.000232	0.07 n.s.
Error	12	0.064731	0.005394	

ANALYSIS OF VARIANCE (28TH DAY)

Source	df	SS	Mean square	F
Treatment	3			
A	1	0.126025	0.126025	2.60 n.s.
B	1	1.500625	1.500625	30.92 **[3]
AB	1	0.007225	0.007225	0.15 n.s.
Error	12	0.5823	0.048525	

ANALYSIS OF VARIANCE (42TH DAY)

Source	df	SS	Mean square	F
Treatment	3			
A	1	2.425806	2.425806	14.81 **
B	1	5.118906	5.118906	31.25 **
AB	1	0.124256	0.124256	0.76 n.s.
Error	12	1.965875	0.163822	

1) Second growth chamber experiment.
2) n.s. = no significance at 0.05 level.
3) ** = significant at 0.01 level.

Table 4.12
Influence of Heterodera glycines and Chenopodium album on relative growth rate (RGR) of Glycines max[1].

FACTOR A	FACTOR B	RGR of G. max 15-28th day	RGR of G. max 29-42th day
+H. glycines	1 plant	0.055	0.037
	2 plants	0.051	0.041
-H. glycines	1 plant	0.056	0.041
	2 plants	0.052	0.043

ANALYSIS OF VARIANCE (15-28th DAY)

Source	df	SS	Mean square	F
Treatment	3			
A	1	0.000006	0.000006	0.92 n.s.[2]
B	1	0.000069	0.000069	10.38 **[3]
AB	1	0.000000	0.000000	0.00007 n.s.
Error	12	0.000080	0.000006	

ANALYSIS OF VARIANCE (29-42th DAY)

Source	df	SS	Mean square	F
Treatment	3			
A	1	0.000043	0.000043	1.18 n.s.
B	1	0.000038	0.000038	1.05 n.s.
AB	1	0.000003	0.000003	0.09 n.s.
Error	12	0.000442	0.000036	

1) Second growth chamber experiment.
2) n.s. = no significance at 0.05 level.
3) ** = significant at 0.01 level.

Table 4.13
Influence of Heterodera glycines and Chenopodium album on the dry weight of Glycines max[1].

FACTOR		G. max dry weight (g/plant)		
A	B	14 days	28 days	42 days
+H. glycines	C. album(-7 days)[2]	0.41	1.23	2.80
	C. album(+7 days)	0.44	1.51	3.54
-H. glycines	C. album(-7 days)	0.39	1.42	3.39
	C. album(+7 days)	0.44	1.48	3.73

ANALYSIS OF VARIANCE (14TH DAY)

Source	df	SS	Mean square	F	
Treatment	3				
A	1	0.000441	0.000441	0.13	n.s.[3]
B	1	0.006869	0.006869	2.06	n.s.
AB	1	0.000529	0.000529	0.16	n.s.
Error	12	0.040214	0.003351		

ANALYSIS OF VARIANCE (28TH DAY)

Source	df	SS	Mean square	F	
Treatment	3				
A	1	0.0256	0.0256	2.55	n.s.
B	1	0.1156	0.1156	11.50	**[4]
AB	1	0.0484	0.0484	4.82	*[5]
Error	12	0.040214	0.003351		

ANALYSIS OF VARIANCE (42TH DAY)

Source	df	SS	Mean square	F	
Treatment	3				
A	1	0.612306	0.612306	3.84	n.s.
B	1	1.139556	1.139556	7.14	*
AB	1	0.158006	0.158006	0.99	n.s.
Error	12	1.915725	0.159643		

1) Second growth chamber experiment. 2) Weeds planted 7 days before (-7 days) or 7 days after(+7 days) soybean planting. 3) n.s. = no significance at 0.05 level. 4) ** = significant at 0.01 level. 5) * = significant at 0.05 level.

Table 4.14
Influence of Heterodera glycines and Chenopodium album on the relative growth rate (RGR) of Glycines max[1].

FACTOR A	FACTOR B	RGR of G. max 15-28th day	RGR of G. max 29-42th day
+H. glycines	C. album(-7 days)[2]	0.048	0.040
	C. album(+7 days)	0.050	0.041
-H. glycines	C. album(-7 days)	0.052	0.041
	C. album(+7 days)	0.050	0.043

ANALYSIS OF VARIANCE (15-28th DAY)

Source	df	SS	Mean square	F
Treatment	3			
A	1	0.000013	0.000013	1.24 n.s.[3]
B	1	0.000000	0.000000	0.08 n.s.
AB	1	0.000022	0.000022	2.14 n.s.
Error	12	0.000128	0.000010	

ANALYSIS OF VARIANCE (29-42th DAY)

Source	df	SS	Mean square	F
Treatment	3			
A	1	0.000007	0.000007	0.45 n.s.
B	1	0.000008	0.000008	0.45 n.s
AB	1	0.000002	0.000002	0.13 n.s.
Error	12	0.040214	0.003351	

1) Second growth chamber experiment.
2) Weeds planted 7 days before (-7 days) or 7 days after (+7 days) soybean planting.
3) n.s. = no significance at 0.05 level. 5 level.

Table 4.15
Analysis of Joint Influence of H. glycines and C. album
on the Dry Weight of G. max[1]

	Dry weight of G. max (g/plant)		
	14 days	28 days	42 days
COMPARISON A[2]			
Influence of H. glycines[3]	0.03	0.22	0.95
Influence of C. album[4]	0.05	0.66	1.51
Expected joint influence[5]	0.08(0.02)[6]	0.88(0.23)	2.46(0.65)
Actual joint influence[7]	0.03(0.004)	0.85(0.085)	2.09(0.29)
(Expected - Actual)[8]	0.05 n.s[9]	0.03 n.s	0.37 n.s.
COMPARISON B[10]			
Influence of H. glycines	0.03	0.22	0.95
Influence of C. album	-0.003	0.60	1.17
Expected joint influence	0.027(0.016)	0.82(0.32)	2.12(0.70)
Actual joint influence	-0.002(0.05)	0.57(0.13)	1.36(0.38)
(Expected - Actual)	0.029 n.s.	0.25 n.s.	0.76 n.s.
[C]OMPARISON C[11]	0.02 n.s.	-0.22 n.s.	-0.39 n.s.

1) The second growth chamber experiment.
2) C. album planted 7 days before G. max.
3) Influence of H. glycines was calculated by the following formula: IN = dry weight of G. max (g/plant) without H. glycines - dry weight of G. max (g/plant) with H. glycines
4) Influence of C. album was calculated by the following formula: IW = dry weight of G. max (g/plant) without C. album - dry weight of G. max (g/plant) with C. album
5) Expected joint influence of H. glycines and C. album was calculated by the following formula: IE = IN + IW
6) Number in brackets indicates standard error in TTest procedure.
7) Actual joint influence of H. glycines and C. album were dry weights of G. max (g/plant) with H. glycines and C. album.
8) The difference between expected and actual joint influence.
9) There is no significant difference (P=0.05) between expected joint influence of H. glycines & C. album and actual one.
10) C. album planted 7 days before G. max.
11) Difference between comparison A and B.

Table 4.16

Joint influence of Heterodera glycines and Chenopodium album on the pod dry weight of Glycine max[1].

Treatment			G. max pod dry weight (g/plant)
H. glycines	G. max	C. album	(after 42 days)
-	+ (1)[2]	-	0.90 a[3]
-	+ (2)	-	0.68 b
-	+ (1)	+ (1)[4]	0.57 bc
-	+ (1)	+ (1)[5]	0.83 a
+	+ (1)	+ (1)[4]	0.50 c
+	+ (1)	+ (1)[5]	0.67 b
+	+ (1)	-	0.71 b
+	+ (2)	-	0.66 b

1) Second growth chamber experiment.
2) Number in brackets indicates number of plants per experimental unit.
3) Means followed by the same letter are not significantly (P=0.05) different according to the Student-Newman-Keuls Multiple Range Test.
4) C. album planted 7 days before G. max.
5) C. album planted 7 days after G. max.

Table 4.17
Influence of Heterodera glycines and Chenopodium album on the pod dry weight of Glycines max[1].

FACTOR A	FACTOR B	G. max pod dryweight[2] (g/plant)
+H. glycines	C. album(-7 days)[3]	0.50
	C. album(+7 days)	0.67
-H. glycines	C. album(-7 days)	0.57
	C. album(+7 days)	0.83

ANALYSIS OF VARIANCE (42TH DAY)

Source	df	SS	Mean square	F
Treatment	3			
A	1	0.051756	0.051756	17.12 **[4]
B	1	0.182756	0.182756	60.46 **
AB	1	0.008556	0.008556	2.83 n.s.[5]
Error	12	0.036275	0.003022	

1) Second growth chamber experiment.
2) 42 days after soybean planting.
3) Weeds planted 7 days before (-7 days) or 7 days after (+ 7 days) soybean planting.
4) ** = significant at 0.01 level.
5) n.s. = no significance at 0.05 level.

Table 4.18
Influence of Heterodera glycines and planting density on the pod dry weight of Glycines max[1].

FACTOR		G. max pod dryweight[2]
A	B	(g/plant)
+H. glycines	1 plant	0.71
	2 plants	0.66
-H. glycines	1 plant	0.90
	2 plants	0.68

ANALYSIS OF VARIANCE (42TH DAY)

Source	df	SS	Mean square	F
Treatment	3			
A	1	0.0441	0.0441	8.17 *[3]
B	1	0.0729	0.0729	13.51 **[4]
AB	1	0.0256	0.0256	4.744 *
Error	12	0.06475	0.005395	

1) Second growth chamber experiment.
2) 42 days after soybean planting.
3) * = significant at 0.05 level.
4) ** = significant at 0.01 level.

Table 4.19
Analysis of Joint Influence of H. glycines and C. album
on the Pod Dry Weight of G. max[1]

	G. max pod dry weight (g/plant) after 42 days
COMPARISON A[2]	
Influence of H. glycines[3]	0.39
Influence of C. album[4]	0.30
Expected joint influence[5]	0.69(0.07)
Actual joint influence[7]	0.19(0.001)
(Expected - Actual)[8]	0.50 *[9]
COMPARISON B[10]	
Influence of H. glycines	0.39
Influence of C. album	0.07
Expected joint influence	0.46(0.05)
Actual joint influence	0.24(0.04)
(Expected - Actual)	0.22 *
COMPARISON C[11]	0.28 *

1) The second growth chamber experiment.
2) C. album planted 7 days before G. max.
3) Influence of H. glycines was calculated by the following formula: IN = dry weight of G. max (g/plant) without H. glycines - dry weight of G. max (g/plant) with H. glycines
4) Influence of C. album was calculated by the following formula: IW = dry weight of G. max (g/plant) without C. album - dry weight of G. max (g/plant) with C. album
5) Expected joint influence of H. glycines and C. album was calculated by the following formula: IE = IN + IW
6) Number in brackets indicates standard error in TTest procedure.
7) Actual joint influence of H. glycines and C. album were dry weights of G. max (g/plant) with H. glycines and C. album.
8) The difference between expected and actual joint influence.
9) There is significant difference (P=0.05) between expected joint influence of H. glycines & C. album and actual one.
10) C. album planted 7 days before G. max.
11) Difference between comparison A and B.

Table 4.20

Influence of Glycine max and Heterodera glycines on the dry weight of Chenopodium album[1].

Treatment			C. album dry weight (g/plant)		
H. glycines	G. max	C. album	14 days	28 days	42 days
-	-	+ (1)[2]	0.09 a[5]	1.70 a	4.11 a
-	-	+ (2)	0.06 ab	1.09 b	2.43 c
-	+ (1)[3]	+ (1)[3]	0.09 a	1.44 a	3.30 b
-	+ (1)[4]	+ (1)[4]	0.04 b	0.11 c	0.59 d
+	+ (1)[3]	+ (1)[3]	0.08 a	1.47 a	3.93 a
+	+ (1)[4]	+ (1)[4]	0.03 b	0.10 c	0.70 d

1) Second growth chamber experiment.
2) Number in brackets indicates number of plants per experimental unit.
3) C. album planted 7 days before G. max.
4) C. album planted 7 days after G. max.
5) Means followed by the same letter are not significantly (P=0.05) different according to the Student-Newman-Keuls Multiple Range Test.

Table 4.21

Relative Growth Rate (RGR) of Glycine max[1].

Treatment			RGR in three growth period(days)		
H. glycines	G. max	C. album	1-14	15-28	29-42
-	+ (1)	-	0.0714	0.0563	0.0417
-	+ (2)	-	0.0714	0.0522	0.0414
-	+ (1)	+ $(1)^2$	0.0714	0.0518	0.0407
-	+ (1)	+ $(1)^3$	0.0714	0.0500	0.0429
+	+ (1)	+ $(1)^2$	0.0714	0.0475	0.0401
+	+ (1)	+ $(1)^3$	0.0714	0.0504	0.0410
+	+ (1)	-	0.0714	0.0556	0.0377
+	+ (2)	-	0.0714	0.0509	0.0405

1) Second growth chamber experiment.

2) C. album planted 7 days before G. max.

3) C. album planted 7 days after G. max).

4) $$RGR = dW(1/dT)(1/W) \qquad [F3.1]$$

where RGR = Relative Growth Rate = at an instant in time, the rate of increase in plant dry weight per unit of existing weight per unit time

dW = the weight change over a period of time

dT = the time change W = the weight after a period of time

Table 4.22

Relative Growth Rate (RGR) of Chenopodiom album[1].

Treatment			RGR in three growth periods(days)		
H. glycines	G. max	C. album	1-14	15-28	29-42
-	-	+ (1)	0.0713	0.0678	0.0419[4]
-	-	+ (2)	0.0714	0.0676	0.0392
-	+ (1)	+ $(1)^2$	0.0714	0.0669	0.0402
-	+ (1)	+ $(1)^3$	0.0714	------[5]	------[5]
+	+ (1)	+ $(1)^2$	0.0714	0.0678	0.0448
+	+ (1)	+ $(1)^3$	0.0714	------[5]	------[5]

1) Second growth chamber experiment.

2) C. album planted 7 days before G. max.

3) C. album planted 7 days after G. max.

4) $$RGR = dW(1/dT)(1/W) \qquad [F3.1]$$

where RGR = Relative Growth Rate = at an instant in time, the rate of increase in plant dry weight per unit of existing weight per unit time

dW = the weight change over a period of time

dT = the time change

W = the weight after a period of time

5) Meanless to calculate it by [F3.1].

Table 4.23
Analysis of Joint Influence of H. glycines and C. album
on the Relative Growth Rate of G. max[1]

	Relative Growth Rate of G. max	
	2nd period	3rd period
COMPARISON A[2]		
Influence of H. glycines[3]	0.0013	0.0042
Influence of C. album[4]	0.0046	0.00003
Expected joint influence[5]	0.0059(0.0015)	0.00417(0.0076)
Actual joint influence[7]	0.0088(0.0009)	0.0007(0.0028)
(Expected - Actual)[8]	-0.0031 n.s[9]	0.0035 n.s.
COMPARISON B[10]		
Influence of H. glycines	0.0013	0.0042
Influence of C. album	0.0065	-0.0021
Expected joint influence	0.0078(0.0034)	0.0021(0.0098)
Actual joint influence	0.0059(0.0021)	0.00003(0.004)
(Expected - Actual)	0.0019 n.s.	0.00207 n.s.
COMPARISON C[11]	-0.050 n.s.	0.00143 n.s.

1) The second growth chamber experiment.
2) C. album planted 7 days before G. max.
3) Influence of H. glycines was calculated by the following formula: IN = dry weight of G. max (g/plant) without H. glycines - dry weight of G. max (g/plant) with H. glycines
4) Influence of C. album was calculated by the following formula: IW = dry weight of G. max (g/plant) without C. album - dry weight of G. max (g/plant) with C. album
5) Expected joint influence of H. glycines and C. album was calculated by the following formula: IE = IN + IW
6) Number in brackets indicates standard error in TTest procedure.
7) Actual joint influence of H. glycines and C. album were dry weights of G. max (g/plant) with H. glycines and C. album.
8) The difference between expected and actual joint influence.
9) There is no significant difference (P=0.05) between expected joint influence of H. glycines & C. album and actual one.
10) C. album planted 7 days before G. max.
11) Difference between comparison A and B.

4.2.3 Water Untilization Over the 42 days of plant growth, the accumulated water applied to all treatments with plants was 1,475 ml per experimental unit. The check pot without plants required 1,100 ml of water to keep the soil surface moist(Table 4.24). Based on the amount of water applied, ca. 25.4% went to the plants, and ca. 74.6% dissipated in the chamber. Based on the water amount measured, ca. 29.8% went to plants; and ca. 70.2% dissipated in the chamber. All of the plants in the chamber used a total of ca. 13.5 kilograms of water. Based on a total of 211.3 grams of G. max and C. album dry weight biomass produced in this experiment (Table 5.1), 64.3 grams of water were required per 1.0 gram dry weight of plant biomass.

Based on the water applied (Table 4.24), and Formula 3.2, the average daily water input was 35.11 ml and of which 8.92 ml reached the plants (Table 4.25). Base on the daily measurements and Formula 3.3, dayly water consumption increased during the first 28 days of plant growth, and decreased during the last 14 days (Table 4.26)

Daily water consumption was measured for each treatment to evaluate the roles of G. max, H. glycines and C. album in competition for water resource (Table 4.27). Two plants of C. album consumed more water than that with any of other treatments. The treatment with one C. album planted seven days early, and a single G. max plant grew in the presence of H. glycines consumed the second largest amount of water. Comparisons of one plant per pot indicated that C. album ranked first in water

consumption, followed by G. max infested with H. glycines, and G. max without the presence of H. glycines third (Table 4.27).

In the presence of H. glycines, G. max used more water than in the absence of this nematode (Table 4.27). In the presence of **H. glycines** in G. max, C. album, and earlier colonized C. album, was more competitive for water than in the absence of H. glycine in G. max (Table 4.27).

Formula 3.6 was used to calculate the water consumption coefficient in each treatment from another point (Table 4.28). The results showed in Table 4.28 had a similar tendency to the water consumption in Table 4.27. The larger the water consumption , the greater the coefficent.

Using a log-transformation of the water consumption coefficient , the water balance threshold coefficient for soybean was was presumed to be near zero (Fig. 4.1). Below this threshold, G. max water utilization was not impacted; and G. max water utilization was influenced above the threshold. Water utilization in the presence of late planted C. album with G. max is below the soybean-water balance threshold. In other words, late planted C. album with G. max did not influence soybean water utilization (Fig. 4.1). All other treatments had a impact on water utilization. G. max used more water than in the absence of H. glycines or C. album.

When Formula 3.7 was used to analyze the water consumption partitioning end points, H. glycines had a significant (P=0.05) impact on water consumption efficiency (Table 4.29). C. album did not have a significant (P=0.05) influence on water consumption efficiency of G. max

(Table 4.30). Answers to them are showed in Figure 4.2. The water utilization in single G. max plant was assumed to be normal and assigned the value of zero (Fig. 4.2). All of the other experimental treatment resulted in the use of more water, and there were apparent differences in water utilization among the treatments.

Table 4.24

Accumulated Water Applied to Each Experimental Unit

Watering category	Accumulated water input 14 days	28 days	42 days	Average daily water input
Experimental units	450 ml	975 ml	1475 ml	35.11 ml
Check pot(no plants)	350 ml	750 ml	1100 ml	26.19 ml

Table 4.25

Water partitioning per experimental unit[1]

Water partitioning	Accumulated water resource partitiong 1-14 days	15-28 days	29-42 days	dailymean
Daily water input (total)	32.14 ml	37.50 ml	35.70 ml	35.11 ml
Water partitioned to plants	5.95 ml	11.31 ml	9.51 ml	8.92 ml

1) According to Formula 3.2. Based on amount of water imput.

Table 4.26

Water partitioning per experimental unit[1]

Water partitioning	Accumulated water resource partitiong 1-14 days	15-28 days	29-42 days	dailymean
Daily water input (total)	31.56 ml	36.48 ml	33.82 ml	33.95 ml
Water partitioned to plants	7.73 ml	12.65 ml	9.99 ml	10.12 ml[2]

1) According to Formula 3.3. Based on the daily measurement.

2) On an average in the check pot, daily water lossed by measurement is 23.83 ml.

Table 4.27

Influence of G. max, H. glycines and C. album

on water utlization

Experimental design			Water consumption			
H. glycines	G.max	C. alba	1-14	15-28	29-42	daily average
-	+ (1)	-	28.08 ml	31.60 ml	30.25 ml	29.98 ml
-	+ (2)	-	31.21 ml	34.89 ml	33.95 ml	33.35 ml
-	+ (1)	+ (1)[1]	33.35 ml	39.67 ml	35.07 ml	36.03 ml
-	-	+ (1)	30.23 ml	35.69 ml	33.13 ml	33.02 ml
-	-	+ (2)	35.44 ml	41.21 ml	38.19 ml	38.28 ml
-	+ (1)	+ (1)[2]	31.87 ml	35.21 ml	32.68 ml	33.25 ml
+	+ (1)	-	28.37 ml	32.57 ml	31.35 ml	30.76 ml
+	+ (1)	+ (1)[1]	34.53 ml	40.29 ml	37.63 ml	37.48 ml
+	+ (2)	-	33.51 ml	37.36 ml	33.36 ml	34.74 ml
+	+ (1)	+ (1)[2]	32.89 ml	36.43 ml	32.92 ml	34.08 ml

1) C. album planted 7 days before G. max.

2) C. album planted 7 days after G. max.

Table 4.28 Water consumption cofficient in each treatment

Experimental design			Water consumption cofficient[3]
H. glycines	G. max	C. album	
-	+ (1)	-	0.95
-	+ (2)	-	1.15
-	+ (1)	+ (1)[1]	1.13
-	-	+ (1)	1.11
-	-	+ (2)	1.34
-	+ (1)	+ (1)[2]	0.99
+	+ (1)	-	1.05
+	+ (1)	+ (1)[1]	1.25
+	+ (2)	-	1.21
+	+ (1)	+ (1)[2]	1.14

1) Planting of C. alba 7 days earlier than G. max.

2) Planting of C. alba 7 days later than G. max.

3) Calculated by Formula 3.6.

Table 4.29
Influence of Heterodera glycines and planting density on the water consumption coefficient of Glycines max[1].

FACTOR A	FACTOR B	The comsumption coefficient
+H. glycines	1 plant	1.05
	2 plants	1.21
-H. glycines	1 plant	0.95
	2 plants	1.15

ANALYSIS OF VARIANCE

Source	df	SS	Mean square	F	
Treatment	3				
A	1	0.0192	0.0192	1.26	n.s.[2]
B	1	0.0972	0.0972	6.35	*[3]
AB	1	0.0012	0.0012	0.078	n.s.
Error	12	0.1224	0.1224		

1) Second growth chamber experiment.
2) n.s. = no significance at 0.05 level.
3) * = significant at 0.05 level.

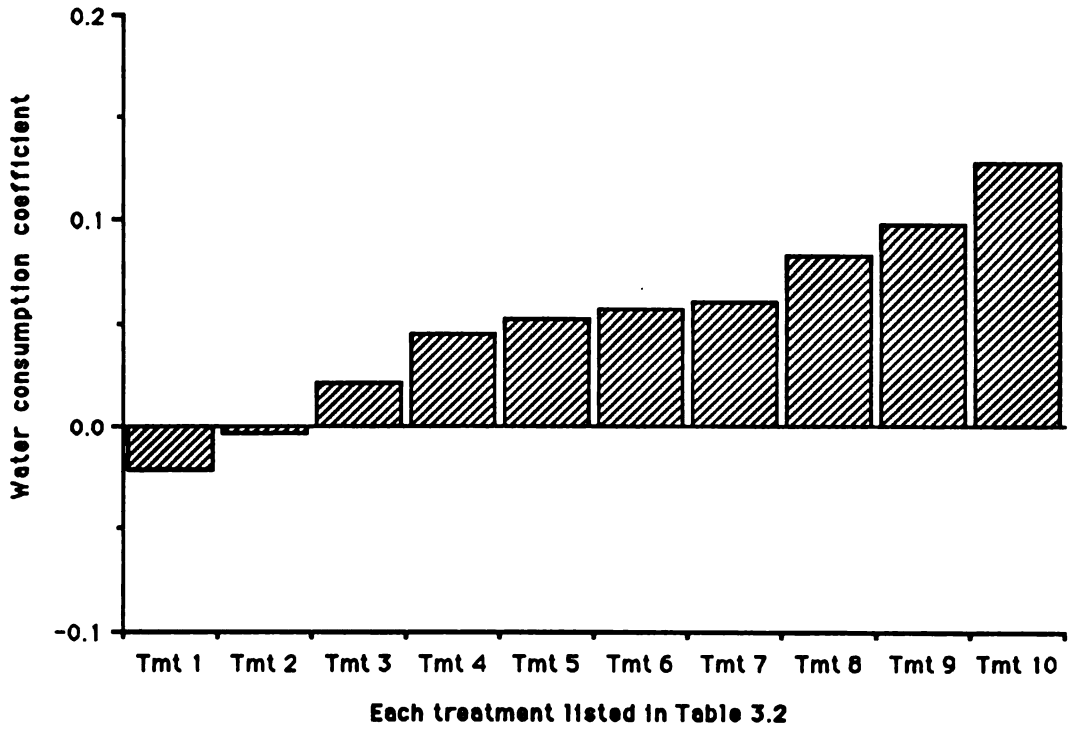
Table 4.30
Influence of Heterodera glycines and Chenopodium album on the water consumption coefficient of Glycines max[1].

Factor A	Factor B	The consumption coefficient
+H. glycines	C. album(-7 days)[2]	1.25
	C. album(+7 days)	1.14
-H. glycines	C. album(-7 days)	1.13
	C. album(+7 days)	0.99

ANALYSIS OF VARIANCE

Source	df	SS	Mean square	F	
Treatment	3				
A	1	0.054675	0.054675	4.13	n.s.[3]
B	1	0.046875	0.046875	3.54	n.s.
AB	1	0.000675	0.000675	0.05	n.s.
Error	12	0.1058	0.1058		

1) Second growth chamber experiment.
2) Weeds planted 7 days before (-7 days) or 7 days after (+7 days) soybean planting.
3) n.s. = no significance at 0.05 level. 5 level.

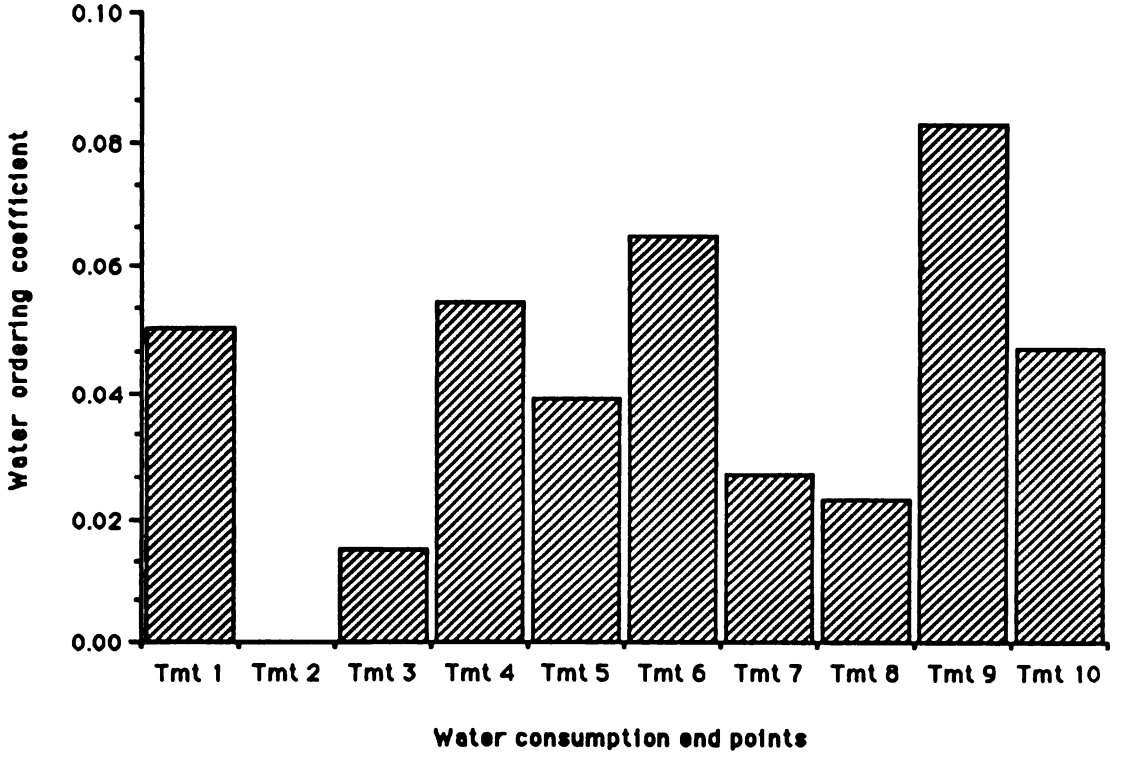


where

Treatment	Heterodera glycines	Glycine max	Chenopodium album
1	-1	+ (1)	-
2	-	+ (2)	-
3	-	-	+ (1)
4	-	-	+ (2)
5	-	+ (1)	+ (1) 2
6	-	+ (1)	+ (1) 3
7	+	+ (1)	+ (1) 2
8	+	+ (1)	+ (1) 2
9	+	+ (1)	-
10	+	+ (2)	-

Note: 1) + = present, - = absent; 2) C. album planted 7 days before G. max; 3) C. album planted 7 days after G. max.

Figure 4.1. Water consumption of log-transformation (second growth chamber experiment).



where

Code	Water consumption partitioning end point
1	C. album
2	G. max
3	G. max with H. glycines only
4	G. max and C. album with H. glycines
5	G. max and C. album without H. glycines
6	G. max and C. album of earlier planting
7	G. max and C. album of late planting
8	G. max (two plants)
9	C. album (two plants)
10	G. max (one plant) and C. album (one plant)

Figure 4.2. Water partitioning end points (second growth chamber experiment).

4.3. Microplot Experiment. The results from the microplot experiment are presented in sections on plant dry weight and relative growth rate.

4.3.1 Plant Dry Weight. After 14 days, H. glycines, C. album and G. max competition had no detectable significant (P=0.05) influence on the dry weight of G. max (Table 4.31). Impacts, however, were detected after 28 days. Early colonization of C. album, with or without the presence of H. glycines, resulted in significantly (P=0.05) less G. max dry weight (Table 4.31). Late emergence of C. album did not have significant (P=0.05) influences on the dry weight of G. max (Table 4.31). The results were similar after 42 days. The presence of H. glycines in one G. max plant, two G. max plants, or jointed with early colonized C. album, resulted in significantly (P=0.05) less G. max dry weight on a per plant base (Table 4.31).

There were no significant (P=0.05) interaction among H.glycines, C. album and G. max plant density on the dry weight and RGR of G. max (Table 4.32 & 4.33). In all cases, the actual plant dry weights were not significantly (P=0.05) different from the expected plant dry weights (Table 4.34).

After 14 days, H. glycines, G. max and C. album competition had significant (P=0.05) influence on the dry weight of C. album (Table 4.35). The late planed C. album resulted in significantly (P=0.05) less C. album dry weight on all three harvest dates. The presence of more than one C.

album plant resulted in significantly (P=0.05) less C. album dry weight on a per plant base after both 28 and 42 days. With early colonized C. album, dry weight was not significantly (P=0.05) impacted by the H. glycines, C. album and G. max competition structure after both 28 days and 42 days of plant growth (Table 4.35).

4.3.2 Relative Growth Rate. The relative growth rate of G. max associated with early planting of C. album was the highest in the first growth period, second in the second growth period, and lowest in the last growth period (Table 4.36). There were no significant (P=0.05) interaction among G. max density, H. glycines and C. album for G. max RGR (Table 4.37 & 4.38). The predicted RGR was not significantly (P=0.05) different from the actual(Table 4.39). The relative growth rate of late emerged C. album, which is restrained by the early colonized G. max, appeared abnormal (Table 4.40).

Table 4.31

Joint influence of Heterodera glycines and Chenopodium album on the dry weight of Glycine max[1].

Treatment			G. max dry weight (g/plant)		
H. glycines	G. max	C. album	14 days	28 days	42 days
-	+ (1)	-	0.64 a[4]	2.72 a	10.49 a
-	+ (2)	-	0.60 a	2.25 ab	7.36 c
-	+ (1)	+ (1)[2]	0.64 a	2.11 b	7.13 c
-	+ (1)	+ (1)[3]	0.63 a	2.70 a	10.28 a
+	+ (1)	+ (1)[2]	0.64 a	2.09 b	6.86 c
+	+ (1)	+ (1)[3]	0.67 a	2.71 a	9.57 ab
+	+ (1)	-	0.54 a	2.27 ab	8.21 bc
+	+ (2)	-	0.58 a	2.29 ab	6.87 c

1) Microplot experiment.

2) C. album planted 7 days before G. max.

3) C. album planted 7 days after G. max.

4) Means followed by the same letter are not significantly (P=0.05) different according to the Student-Newman-Keuls Multiple Range Test.

Table 4.32
Influence of Heterodera glycines and Chenopodium album on the dry weight of Glycines max[1].

FACTOR A	FACTOR B	G. max dry weight (g/plant) 14 days	28 days	42 days
+H. glycines	C. album(-7 days)[2]	0.64	2.09	6.87
	C. album(+7 days)	0.67	2.71	9.57
-H. glycines	C. album(-7 days)	0.64	2.11	7.36
	C. album(+7 days)	0.63	2.70	10.3

ANALYSIS OF VARIANCE (14TH DAY)

Source	df	SS	Mean square	F
Treatment	3			
A	1	0.001521	0.001521	0.32 n.s.[3]
B	1	0.000225	0.000225	0.05 n.s.
AB	1	0.000961	0.000961	0.20 n.s.
Error	12	0.056992	0.004749	

ANALYSIS OF VARIANCE (28TH DAY)

Source	df	SS	Mean square	F
Treatment	3			
A	1	0.000009	0.000009	0.00009 n.s.
B	1	1.481089	1.481089	15.28 **[4]
AB	1	0.000729	0.000729	0.008 n.s.
Error	12	1.163318	0.096943	

ANALYSIS OF VARIANCE (42TH DAY)

Source	df	SS	Mean square	F
Treatment	3			
A	1	1.44	1.44	1.07 n.s.
B	1	31.6969	31.6969	23.62 **
AB	1	0.050625	0.050625	0.04 n.s.
Error	12	16.10245	1.341870	

1) Second growth chamber experiment.
2) Weeds planted 7 days before (-7 days) or 7 days after (+7 days) soybean planting.
3) n.s. = no significance at 0.05 level. 5 level.
4) ** = significant at 0.01 level.

Table 4.33
Influence of Heterodera glycines and planting density on the dry weight of Glycines max[1].

FACTOR		G. max dry weight (g/plant)		
A	B	14 days	28 days	42 days
+H. glycines	1 plant	0.54	2.27	8.20
	2 plants	0.58	2.29	6.76
-H. glycines	1 plant	0.64	2.72	10.49
	2 plants	0.60	2.25	7.13

ANALYSIS OF VARIANCE (14TH DAY)

Source	df	SS	Mean square	F
Treatment	3			
A	1	0.015129	0.015129	2.67 n.s.[2]
B	1	0.000049	0.000049	0.009 n.s.
AB	1	0.005929	0.005929	1.05 n.s.
Error	12	0.067924	0.005660	

ANALYSIS OF VARIANCE (28TH DAY)

Source	df	SS	Mean square	F
Treatment	3			
A	1	0.170569	0.170569	3.05 n.s.
B	1	0.199809	0.199809	3.58 n.s.
AB	1	0.239121	0.239121	4.28 n.s.
Error	12	0.670534	0.670534	

ANALYSIS OF VARIANCE (42TH DAY)

Source	df	SS	Mean square	F
Treatment	3			
A	1	7.029126	7.029126	9.03 *[3]
B	1	23.028	23.028	29.57 **[4]
AB	1	3.681606	3.681606	4.72 n.s.
Error	12	9.344143	0.778678	

1) The microplot experiment.
2) n.s. = no significance at 0.05 level.
3) * = significant at 0.05 level.
4) ** = significant at 0.01 level.

Table 4.34
Analysis of Joint Influence of H. glycines and C. album
on the Dry Weight of G. max[1]

	Dry weight of G. max (g/plant)		
	14 days	28 days	42 days
COMPARISON A[2]			
Influence of H. glycines[3]	0.10	0.45	2.29
Influence of C. album[4]	0.005	0.62	2.69
Expected joint influence[5]	0.105(0.12)6	1.067(0.40)	4.98(0.61)
Actual joint influence[7]	0.001(0.08)	0.631(0.15)	3.62(0.72)
(Expected - Actual)[8]	0.104 n.s.[9]	0.436 n.s.	1.36 n.s.
COMPARISON B[10]			
Influence of H. glycines	0.10	0.45	2.29
Influence of C. album	0.013	0.02	0.20
Expected joint influence	0.113(0.12)	0.47(0.28)	2.49(0.86)
Actual joint influence	-0.022(0.05)	0.26(0.09)	0.92(0.60)
(Expected - Actual)	0.135 n.s.	0.21 n.s.	1.57 n.s.
COMPARISON C[11]	-0.03 n.s.	0.226 n.s.	-0.21 n.s.

1) The microplot experiment.
2) C. album planted 7 days before G. max.
3) Influence of H. glycines was calculated by the following formula: IN = dry weight of G. max (g/plant) without H. glycines - dry weight of G. max (g/plant) with H. glycines
4) Influence of C. album was calculated by the following formula: IW = dry weight of G. max (g/plant) without C. album - dry weight of G. max (g/plant) with C. album
5) Expected joint influence of H. glycines and C. album was calculated by the following formula: IE = IN + IW
6) Number in brackets indicates standard error in TTest procedure.
7) Actual joint influence of H. glycines and C. album were dry weights of G. max (g/plant) with H. glycines and C. album.
8) The difference between expected and actual joint influence.
9) There is no significant difference (P=0.05) between expected joint influence of H. glycines & C. album and actual one.
10) C. album planted 7 days before G. max.
11) Difference between comparison A and B.

Table 4.35

Influence of Glycine max and Heterodera glycines on the dry weight of Chenopodium album[1].

Treatment			C. album dry weight (g/plant)		
H. glycines	G. max	C. album	14 days	28 days	42 days
-	-	+ (1)[2]	0.16 a[5]	2.78 a	29.99 a
-	-	+ (2)	0.12 a	2.19 b	23.38 b
-	+ (1)	+ (1)[3]	0.15 a	3.09 a	30.35 a
-	+ (1)	+ (1)[4]	0.07 b	0.14 c	0.68 c
+	+ (1)	+ (1)[3]	0.17 a	2.82 a	32.79 a
+	+ (1)	+ (1)[4]	0.06 b	0.19 c	0.81 c

1) Microplot experiment.

2) Number in brackets indicates number of plants per experimental unit.

3) C. album planted 7 days before G. max.

4) C. album planted 7 days after G. max.

5) Means followed by the same letter are not significantly (P=0.05) different according to the Student-Newman-Keuls Multiple Range Test.

Table 4.36

Ralative Growth Rate (RGR) of Glycine max[1].

Treatment			RGR in three growth periods(days)		
H. glycines	G. max	C. album	1-14	15-28	29-42
-	+ (1)	-	0.0714	0.0525	0.0556[4]
-	+ (2)	-	0.0714	0.0524	0.0491
-	+ (1)	+ $(1)^2$	0.0714	0.0546	0.0437
-	+ (1)	+ $(1)^3$	0.0714	0.0501	0.0565
+	+ (1)	+ $(1)^2$	0.0714	0.0545	0.0432
+	+ (1)	+ $(1)^3$	0.0714	0.0487	0.0551
+	+ (1)	-	0.0714	0.0543	0.0527
+	+ (2)	-	0.0714	0.0534	0.0472

1) Microplot experiment.

2) C. album planted 7 days before G. max.

3) C. album planted 7 days after G. max).

4) $$RGR = dW(1/dT)(1/W) \qquad [F3.1]$$

where RGR = Relative Growth Rate = at an instant in time, the rate of increase in plant dry weight per unit of existing weight per unit time

dW = the weight change over a period of time

dT = the time change

W = the weight after a period of time

Table 4.37
Influence of Heterodera glycines and Chenopodium album on the relative growth rate (RGR) of Glycines max[1].

FACTOR A	FACTOR B	RGR of G. max 15-28th day	RGR of G. max 29-42th day
+H. glycines	C. album(-7 days)[2]	0.0493	0.0494
	C. album(+7 days)	0.0535	0.0512
-H. glycines	C. album(-7 days)	0.050	0.051
	C. album(+7 days)	0.055	0.052

ANALYSIS OF VARIANCE (15-28th DAY)

Source	df	SS	Mean square	F
Treatment	3			
A	1	0.000001	0.000001	0.17 n.s.[3]
B	1	0.000082	0.000082	7.10 *[4]
AB	1	0.000000	0.000000	0.05 n.s.
Error	12	0.000140	0.000011	

ANALYSIS OF VARIANCE (29-42th DAY)

Source	df	SS	Mean square	F
Treatment	3			
A	1	0.000004	0.000004	0.38 n.s.
B	1	0.000009	0.000009	0.76 n.s
AB	1	0.000000	0.000000	0.02 n.s.
Error	12	0.000149	0.000012	

1) Microplot experiment.
2) Weeds planted 7 days before (-7 days) or 7 days after (-7 days) soybean planting.
3) n.s. = no significance at 0.05 level. 5 level.
4) * = significant at 0.05 level.

Table 4.38
Influence of Heterodera glycines and planting density on relative growth rate (RGR) of Glycines max[1].

FACTOR		RGR of G. max	
A	B	15-28th day	29-42th day
+H. glycines	1 plant	0.054	0.052
	2 plants	0.053	0.045
-H. glycines	1 plant	0.054	0.053
	2 plants	0.052	0.049

ANALYSIS OF VARIANCE (15-28th DAY)

Source	df	SS	Mean square	F	
Treatment	3				
A	1	0.000000	0.000000	0.79	n.s.[2]
B	1	0.000009	0.000009	1.67	n.s.
AB	1	0.000001	0.000001	0.22	n.s.
Error	12	0.000071	0.000005		

ANALYSIS OF VARIANCE (29-42th DAY)

Source	df	SS	Mean square	F	
Treatment	3				
A	1	0.000026	0.000026	2.41	n.s.
B	1	0.000121	0.000121	11.0	**[3]
AB	1	0.000007	0.000007	0.65	n.s.
Error	12	0.000132	0.000011		

1) The microplot experiment.
2) n.s. = no significance at 0.05 level.
3) ** = significant at 0.01 level.

Table 4.39
Analysis of Joint Influence of H. glycines and C. album
on the Relative Growth Rate of G. max[1]

	Relative Growth Rate of G. max	
	15 - 28 days	29 - 42 days
COMPARISON A[2]		
Influence of H. glycines[3]	0.00023	0.00124
Influence of C. album[4]	0.00488	0.00202
Expected joint influence[5]	0.0051(0.0039)	0.00326(0.0045)
Actual joint influence[7]	0.0052(0.0028)	0.00332(0.0027)
(Expected - Actual)[8]	-0.0001 n.s[9]	-0.00006 n.s.
COMPARISON B[10]		
Influence of H. glycines	0.00023	0.00124
Influence of C. album	-0.00007	0.00069
Expected joint influence	0.0002(0.0038)	0.00193(0.0031)
Actual joint influence	0.0010(0.0023)	0.00156(0.0018)
(Expected - Actual)	-0.0008 n.s.	0.00037 n.s.
COMPARISON C[11]	0.0007 n.s.	-0.00043 n.s.

1) The microplot experiment.
2) C. album planted 7 days before G. max.
3) Influence of H. glycines was calculated by the following formula: IN = dry weight of G. max (g/plant) without H. glycines - dry weight of G. max (g/plant) with H. glycines
4) Influence of C. album was calculated by the following formula: IW = dry weight of G. max (g/plant) without C. album - dry weight of G. max (g/plant) with C. album
5) Expected joint influence of H. glycines and C. album was calculated by the following formula: IE = IN + IW
6) Number in brackets indicates standard error in TTest procedure.
7) Actual joint influence of H. glycines and C. album were dry weights of G. max (g/plant) with H. glycines and C. album.
8) The difference between expected and actual joint influence.
9) There is no significant difference (P=0.05) between expected joint influence of H. glycines & C. album and actual one.
10) C. album planted 7 days before G. max.
11) Difference between comparison A and B.

Table 4.40

Relative Growth Rate (RGR) of Chenopodium album[1].

Treatment			RGR in three growth periods(days)		
H. glycines	G. max	C. album	1-14	15-28	29-42
-	-	+ (1)	0.0711	0.0670	0.0648[4]
-	-	+ (2)	0.0714	0.0674	0.0650
-	+ (1)	+ $(1)^2$	0.0714	0.0679	0.0647
-	+ (1)	+ $(1)^3$	0.0714	------[5]	------
+	+ (1)	+ $(1)^2$	0.0714	0.0671	0.0648
+	+ (1)	+ $(1)^3$	0.0714	------	------

1) Microplot experiment.

2) Planting of C. album 7 days earlier than G. max.

3) Planting of C. album 7 days late than G. max.

4) $$RGR = dW(1/dT)(1/W) \qquad [F3.1]$$

where RGR = Relative Growth Rate = at an instant in time, the rate of increase in plant dry weight per unit of existing weight per unit time

dW = the weight change over a period of time

dT = the time change

W = the weight after a period of time

5) Meanless if calculated by [F3.1].

5.0 DISCUSSION

5.1 Ontogeny of G. max. The biomass (dry weights of plants) and relative growth rate of G. max in all three experiments (Table5.1). The ontogeny of G. max had a trend of increasing relative growth rate from the first to third experiment. But there is a relatively large difference in relative growth rate between G. max in chambers and that in the microplots; and a smaller difference with C. album.

One plant dry weight of G. max in each treatment in each experiment was measured after 14 days, 28 days and 42 days. All the low dry weights appear in the designs with C. album and H. glycines. The influence of planting time of C. album and number of plants on one plant dry weight can be seen, too. There are also apparently differences in dryweights among three experiments, with the highest to microplots and the lowest to the second chamber experiment. One possible answer to the difference between two chamber experiments could be the different kind of pots used.

The relative growth rate of each treatment in each experiment was calculated in first 14 day, second 14 day, and third 14 day period. Relative growth rate in chambers decreases in the third period, but increase or decrease little in the microplots, whose growth stage in 42 days is younger than that in the chamber. The relative growth rate is a relative number. The difference in relative growth rate between treatments has been shorten, and easier to perform numerical analyzes. It seems to be that C. album, H.

glycines, planting time and planting number etc. cost the reduces of relative growth rate in G. max, in the third period, if not very clear in the second period. An average on the three relative growth rates of G. max in each treatment of three experiments was obtained. There are some differences on the tail-number of the combined relative growth rate. It is better to use the data from the 15th - 42th day, showed in Table 5.2, rather than the data in second or third period. Table 5.3 presents an almost of perfect answer to analyze the experimental factors.

The Student-Newman-Keuls Test was conducted in the computer SAS program to analyze the data of dry weight of one soybean plant in all the three experiments and pod dry weights of the second chamber experiment after 42 days. There are some significant observations. For example, in the second experiment, comparing with G. max without H. glycines and C. album, a significant (P=0.05) difference (b) happened when G. max with H. glycines; another significant (P=0.05) difference (c) added when G. max, H. glycines with earlier planting of C. album (Table 4.7).

5.2 Ontogeny of C. album. The biomass (dryweights of plants) and relative growth rate of C. album in each experiment produced are summered in the Table 5.1. Both have the trend of increasing relative growth rate from the first to third experiment. But there is a relatively large difference in RGR between G. max in chambers and that in the microplots; and a smaller difference with C. album. One plant dry weight and relative growth rate of

C. album in first, second and third 14 day period were also measured and calculated. The planting time is critical to C. album. The relative grow rate of C. album appears kind of stable, except for those planting late.

Table 5.1

Total Plant Dry Weights (PDR)

and Relative Growth Rates (RGR)

Plant	Experiment		14 days	28 days	42 days
G. max	1st chamber expt.	PDW	10.9g	68.4g	144.5g
	1st chamber expt.	RGR	0.0714	0.0600	0.0376
	2nd chamber expt.	PDW	16.2g	59.3g	141.4g
	2nd chamber expt.	RGR	0.0714	0.0519	0.0415
	microplot expt.	PDW	24.5g	91.8g	321.5g
	microplot expt.	RGR	0.0714	0.0524	0.0510
C. album	1st chamber expt.	PDW	3.3g	60.7g	140.6g
	1st chamber expt.	RGR	0.0714	0.0675	0.0406
	2nd chamber expt.	PDW	1.8g	28.0g	69.9g
	2nd chamber expt.	RGR	0.0714	0.0668	0.0428
	microplot expt.	PDW	3.5g	53.5g	141.4g
	microplot expt.	RGR	0.0714	0.0668	0.0444

Table 5.2 Combined Relative Growth Rate of G. max in Each Treatment

H. glycines	G.max	C.album	14 days	28 days	42 days
-	+ (1)	-	0.0714	0.0565	0.0456
-	+ (2)	-	0.0714	0.0546	0.0441
-	+ (1)	+ (1)	0.0714	0.0606	0.0300
-	+ (1)	+ (1)[1]	0.0714	0.0532	0.0422
-	+ (1)	+ (1)[2]	0.0714	0.0501	0.0497
+	+ (1)	+ (1)	0.0714	0.0601	0.0245
+	+ (1)	+ (1)[1]	0.0714	0.0510	0.0416
+	+ (1)	+ (1)[2]	0.0714	0.0496	0.0481
+	+ (1)	-	0.0714	0.0569	0.0429
+	+ (2)	-	0.0714	0.0546	0.0426

1) Planting of C. album 7 days earlier than G. max.

2) Planting of C. album 7 days later than G. max.

Table 5.3 The Change of Relative Growth Rate of G. max

Due to Experimental Factors

Factor (RGR)	Subfactor	
	Plant(s) (RGR)	Planting Time(RGR)
H. glycines	1 vs 2 plants (4)	same
only (3)	2 plants (2)	same
H.glycines	1 vs 2 plants (12)	same
with C.album(9-9.3)	2 plants (6)	same
	1 vs 2 plants (18)	C.album early (18)
	2 plants (7)	C.album early (7)
	1 vs 2 plants (10)	C.album later (10)
	2 plants (3)	C.album later (3)
C. album	1 vs 2 plants (6)	same
only (6-7)	1 vs 2 plants	C.album early (9)
	1 vs 2 plants	C.album later (6)

5.3 Water Utilization Performed Student-Newman-Keuls Multiple Range Test, it is hard to find significant (P=0.05) difference between water consumptions in each treatment. The way to analyze data is to point out which treatment uses more water , or which treatment uses less water due to designed experimental variables. More studies need to go to microcosms. Analyzing microphenomenon needs a different way. The qualitative and quantitative studies in interactions in microcosms is an interesting field of ecology.

According to results of this experiment, and principles & methods of system science, a conceptual model for soybean water utilization was established for studying extensively the soybean water utilization in the future.

Model is something that mimics the relevant features of the situation being studied. In this study, the problem was first formulated. What is the soybean water utilization in the presence of a parasite and a competing plant species under research condition? Second, the purpose of the model was to analyze the relations existed in this experimental body, and to obtain some quantitative formula that would be useful to analyze the soybean water utilization.

Then, the boundaries of the model needed to be define. The boundary of the system is a real or imagined separation of the system (part of the real world under the research) and the environment (the rest of the real world). The system in this study was an experimental unit. It included physical

factors, such as soil texture, air evaporation, etc., and biological factors, such as a plant species of C. album competing for water, the influence of nematode (or other parasites). The boundary of the system in this study could be a biological boundary if we had wanted to define it in that way.

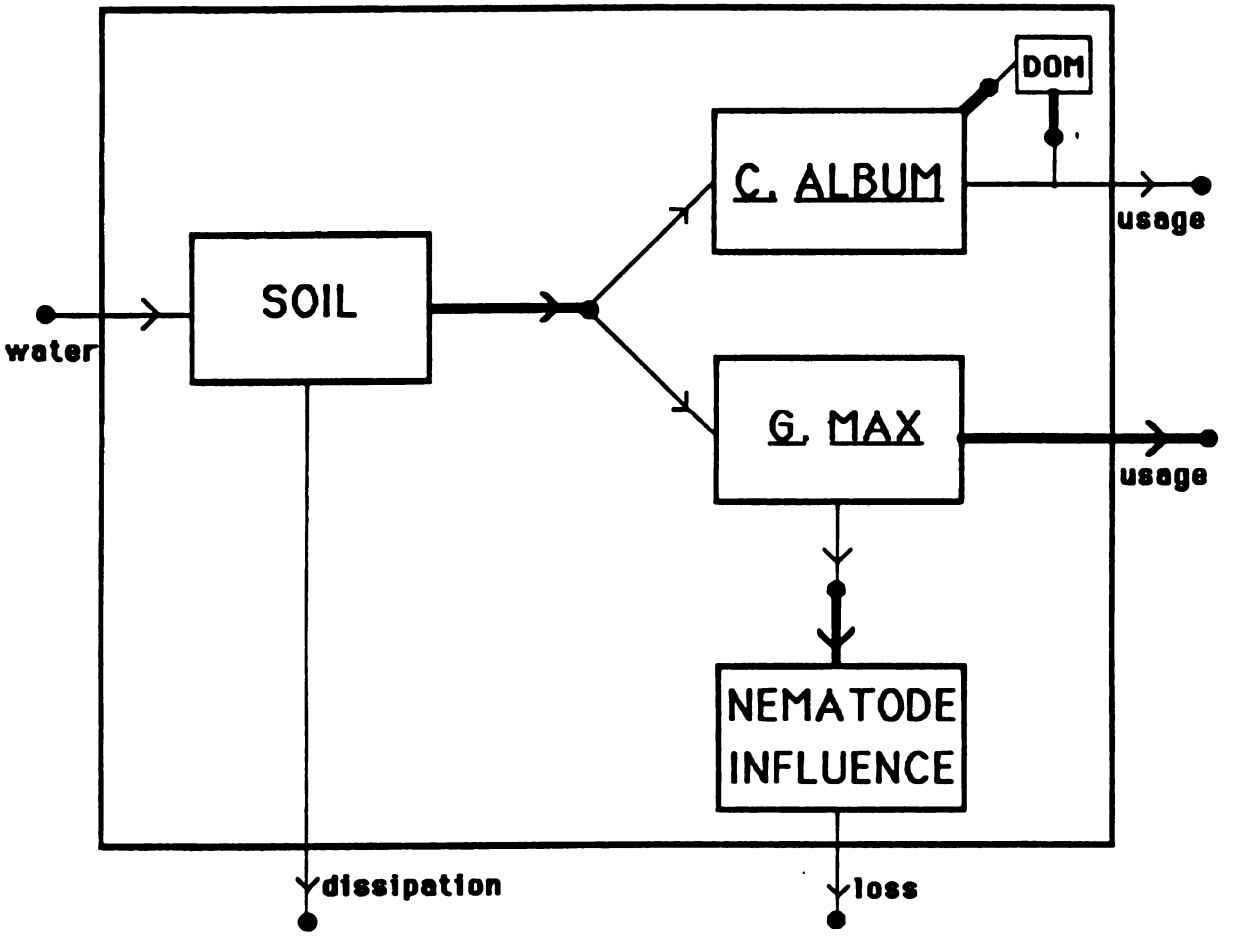
The next step was to postulate a relevant structure. The actual system was reduced was to an ideal system consisting of interconnections of simple, idealized elements that can be reasonably analyzed or be described mathematically. A block diagram is usually drawn for the complicated system. Soybean was located in the middle, surrounding by many elements of the model. That how water pass through those elements, what influences of those elements are, or what interactions existed in those elements could be studied well-organized. In general, most of the physical elements were not put into as variables in this experiment conducted. For example, all soil used were same soil, the chamber was under controlled conditions, etc. But we knew these physical elements were very important in water -plant relations. For example, the plastic pots (in the category of "other physical factors" in the model) were used in this study instead of clay pot (a variable). They kept soil moisture well; and therefore, reduced water inputs very much into the model, compared with that of clay pots. From the result of this study, three quarters of water dissipated due to these physical elements (occupied more size in the model diagram). Only about one quarter of water passed through those physical elements and got into

the biological "boundary". In the biological "boundary", the water utilization was affected smaller (occupy smaller size in the model). Many differences in water utilization were so small that they were of microphenomenon, according to results of this study.

After variables of interest were specified, each element had to be described mathematically. The model equations had to be developed. Equations had to be manipulated. All the formula (5.2.2) developed and used in this experiment were a good beginning for those steps in modeling. Some elements have been described mathematically. For example, the water dissipated was about three quarters; and the water to plants was about one quarter. And some factors have been described logarithmly (Figure 5.3). More details can be developed based on the information obtained in this research.

In the future, all parameters in the model will be determined from available data, the model will be tested and analyzed, and predictions will be made by using the model. More work are needed from the progresses made in our studies (Fig. 5.1).

Figure 5.1 A conceptual model for soybean water utilization



5.4 Recommendations for IPM. The inoculum level of H. glycines played an important role in the H. glycines, C. album and G. max competition. The significant difference in the Student-Newman-Kerls Multiple Range Test in the first growth chamber experiment with inoculum of 5,000 eggs and second-stage juveniles of H. glycines, is less than that in the second growth chamber experiment with 10,000 inoculum. The presence of 15,000 viable units in the microplot had some, if not all, significant (P=0.05) influences on the dry weight of G. max. In other words, the results were impacted by levels of inoculum. If the population density of H. glycines in the field is higher than the inoculum level used in the chamber and in the microplot, worsen impacts of H. glycines to G. max growth will be expected. The results can be developed into indexes of crop losses in the future after more researches.

Relative growth rate of G. max and C. album in each treatment were calculated in each treatment, and the latter appeared more stable. Some factors, such as the emerging time of C. album, the number of plant(s), etc., has a considerable influence on the growth of G. max. More work is needed.

According to the results of this experiments, if H. glycines and C. album are coexisted in a field, the strategies of IPM are: 1) detect the nematode population (MSU Nematology Diagnostic Laboratory provides the

service); 2) reduce the population of H. glycines and C. album; and 3) limit the time and space of C. album.

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7.0 APPENDIX A: OBSERVATIONS ON THE CURRENT STATE OF HETERODERA GLYCINES IN MICHIGAN

Because of the recent discovery of Heterodera glycines in Michigan in 1987, it is important to have a record of the current status of this nematode. Several studies were conducted in 1988 and 1989 to investgate the biology and management of H. glycines. These included investigations on the race composition, distribution, population dynamics, sampling effeiency, and influence of crop rotation on H. glycines. In Gratiot county, H. glycined causes serious damage to soybean, and existd in very high population densities. Most of studies were conducted at this location. Basic information is also provided about the infestations in VanBuren County and Saginaw county. It is highly likely that H. glyciens exists at non-detectable levels in many soybean-growing counties. The possibility of finding this nematode in the Southeastern MI Soybean-growing Region neighbouring with Ohio soybean-growing regions is high. MI soybean growers and soybean management activities should be made aware of this pest.

7.1 N.matode distribution H. glycines is currently known to exist on three farms in three counties in Michigan.

7.1.1 Gratiot county population. Heterodera glycines Ichinohe (soybean cyst nematode), was discovered in Michigan for the first time in April, 1987, in Gratiot County. It was found in soil on a farm owned by Mr. Joseph Stasa in Section 17 of Alba township. In 1986, Mr. Stasas planted soygean seeds and maintained the crop, but did not harvest because of extremely low yield in the field where H. glycines discovered later. In other words, H. glycines resulted in an economic yield loss of 100%. Additional observations indicate that the entire place is infested with H. glycines.

Gratiot County is located in a major soybean and dry bean growing region of Michigan (Figure 1.1); and the existence of H. glycines in this area is of significant concerns to Michigna agriculture. A bioassay was used to identify the race(s) of H. glycines presented in MI. Race determination is essential for selection of appropriate resistant soybean cultivars for specific fields.

Cv Lee, a good host; two resistant cvs, Pickett and Peking; and two resistant plant introduction lines, PI 88788 and PI 90763, were used as host differentials. A female index, based on the relative number of females on each differential was computed using Formula 3.1.

FI = # of cysts on test differential / # of cysts on Lee (F7.1)

where

FI: Female index.

The race of H. glycines in Gratiot County was identified as race 3(Table 7.1). Some interesting variations were found in the race composition study.

No significant difference (P=0.05) in race composition was observed between the population of H. glycines from the greenhouse, which was originally (1987) from the field in Gratiot County, and the population directly from the same field (1989).

In conclusion,

1) H. glycines from the Joe Stasa Farm in Gratiot County was identified as race 3.

2) H. glycines in the greenhouse population remained the same race characteristics as that in the original field after being maintained under greenhouse condition for two years on cv Corsoy 79.

7.1.2 Van Buren county population. The Van Buren County population of H. glycines was discovered in May, 1988, on a farm owned by Mr.

John Krohne in Sections 34 & 35, Keeler Township. The population density at the time of discovery was 11 cysts per 100 cm^3 of soil. The population was identified as Race 3 of H. glyciens. The site was only in its third crop of soybeans. Mr. Krohne is basically a strawberry and tomato farmer. He was using soybeans as a rotation crop. Approximately 60 soybean cyst nematode infested spots were observed in one 80 acre field. The spots were small, and most of the soybean plants in those areas died before the end of July. Bean production was low in the adjacent areas. Mr. Krohne normally purchases transplants from Tennessee. It is likely that this population of H. glycines was introduced into Van Buren County in infested soil associated with tomato or strawberry transplants. A SCN management program has been adopted. The site was seeded to winter wheat in 1988, and there are no future plan to plant the site to hosts of H. glycines.

7.1.3 Saginaw county population. The Saginaw County population of H. glycines was discovered on August 28, 1989, °n a farm owned by Mike Benkert in Section 33, Zilwaukee Township. The population density at the time of discovery were 75 cysts and 10 females, or 14,600 viable units per 100 cm^3. Race determination for the Saginaw population of H. glycines will be conducted in the near future. The tenant farmer is in the process of developing a comprehensive soybean cyst nematode management program for the Benkert Farm.

Table 7.1

Race determination for H. glycines

using the host differentials discriber by Golden et al

Reaction on soybean differentials				Result
Pickett	Peking	PI88788	PI90763	Race
-[1]	-	-	-	3

1) + = Number of females and cysts recovered was 10% or more of the number on Lee cultivar. The cultivar is designated as susceptible (+).

- = Number of females and cysts recovered was less than 10% of the number on Lee cultivar. The cultivar is designated as resistant (-).

7.2 Spacial distribution of Heterodera glycines in the field. The objective of this study was to determine the distribution of H. glycines populations in space and time. A site of approximately 6 acres with a high population density of H. glycines was chosen. A sampling grid consisting of 10 x 30 feet four-row plots was developed. Nine cores of soil per plot taken in a zigzag pattern were collected. Nematodes recovered from the soil were examined under a microscope for identification and quanlification. A Centrifugation-flotation and Heavy-sucrose Technique was used to recover cysts, eggs and second-stage juneniles of H. glycines using following procedures.

1) Wash 100 cm^3 of soil in a plastic pail, mix solution thoroughly for 10 seconds and alow to settle for 10 seconds;

2) Decant supernatant through a 25 mesh sieve and a 100-mesh sieve (use 325, 400 or 500-mesh sieve if eggs, second-stage juveniles or mycorrhizal spores are desired).

3) Wash residue from screen into centrifuge tubes and centrifuge at 420 g for 4.0 minutes, then centrifuge again with sucrose solution for 2.0 minutes;

4) Collect supernatant on 100, 325, 400 or 500-mesh sieve, rinse thoroughly, and wash sample into a 10 ml tube.

The result indicated that H. glycines existed in a very high population density in the soybean field studied. At end of the 1988 growing season, as many as 704 cysts containing 113,660 viable units (eggs and second-stage juveniles) per 100 cm^3 were recovered.

On May 18-24, 1988, a soybean field was divided into 161 plot, and sampled to evaluate the distribution of H. glycines. The results of the distribution of H. glycines in a field was showed in Figure 7.1. The population distribution of H. glycines was aggregate and not uniform or random. The type of distribution pattern is impacted by the eosystem and agricultural management procedures. A study was repeated in the same site on November, 1988 following the soybean production. The Pf was greater than the Pi; however, the distribution pattern was still aggregate. Growing soybean continually, rotating crop, applying chemical, etc. all have each certain impact on the distribution based on the theory of time and space. An interesting comparison can be found in Figure 3.3.

Summary,

1) An extremely high population density (1,100 viable units in 1.0 cm^3 soil) of H. glycines was found.
2) The distribution of H. glycines occurs in clusters,
3) The distribution pattern of H. glycines is dynamic.

Fig. 7.1 Distribution of H. glycines in the field (before 1988 season)

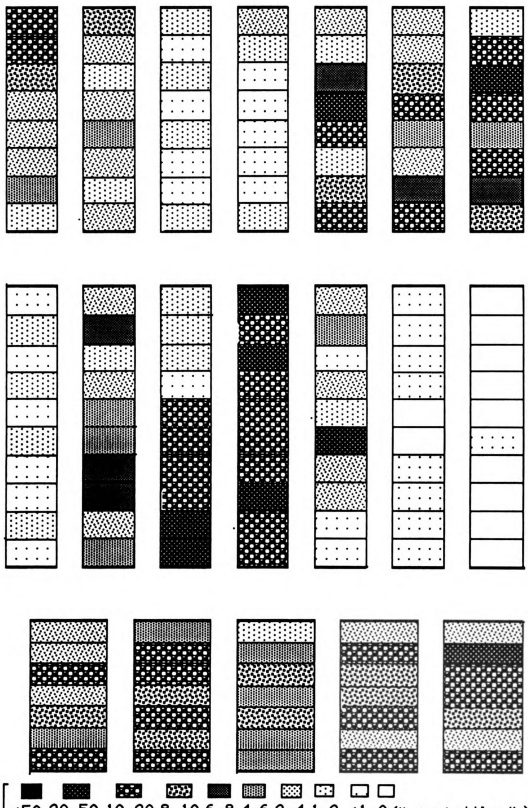
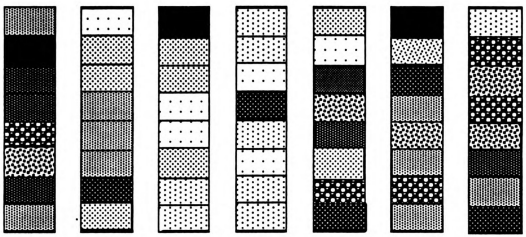
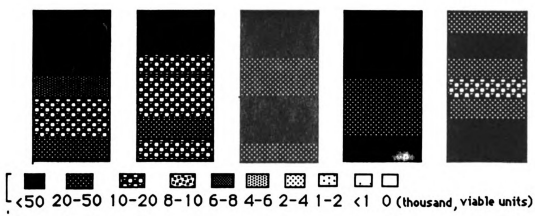


Fig. 7.2 Distribution of H. glycines in the field (after 1988 season)





7.3 Influence of crop rotation. A three-year crop rotation study program was initiated in 1988. The objective was to identify the impact of selected soybean production system rotation crops on the population dynamics and pathogenic potential of H. glycines. A randomized complete block design was used with 7 blocks, 8 treatments, a total of 56 plots. The three-year cropping pattern was designed (Table 7.2).

The results indicated that with the non-host crops, H. glycines population growth stoped, while populations associated with soybeans increased 721.3%. The rotation, however, did not have a significant influence (P=0.05) on the number of viable units of H. glycines in the first season.

Dry bean was found to be a host of H. glycines (Bird, 1987). A field study was used to study the nematode reproduction in drybean. There is no significant difference (P=0.05) in reproduction rate between Pi in the field for soybean and Pi in the field for dry bean at begin of the season. At end of the season, however, there is an extremely high significant difference (P=0.001). In other words, the reproduction of H. glycines on dry beans was significantly (P=0.001) less than on soybeans.

Table 7.2

Crop rotation patterns

in the soybean management program of H. glycines

Crop-rotation Pattern 1	soybeans/soybeans/soybeans
Crop-rotation Pattern 2	clean-fallow/clean-fallow/soybeans
Crop-rotation Pattern 3	corn/corn/soybeans
Crop-rotation Pattern 4	drybeans/corn/soybeans
Crop-rotation Pattern 5	oats-red clover/corn/soybeans
Crop-rotation Pattern 6	alfalfa/corn/soybeans
Crop-rotation Pattern 7	corn/drybeans/soybeans
Crop-rotation Pattern 8	clean-fallow/soybeans/soybean

Another field study was conducted to compare H. glycines cyst size asociated with soybeans and dry beans. H. glycines maintained on dry beans were smaller than those developed on soybeans. There was a highly significant difference (P=0.01) in cyst length, and an extremely highly significant difference (P=0.001) in cyst width.

Summury,

1) Rotation with non-host crops stoped the increase of H. glycines population density.
2) A one-year crop rotation limited, but did not eliminated the population H. glycines under field condition.
3) Compared to soybean, drybean is a poor host for H. glycines.

7.4 REPRODUCTION OF HETERODERA GLYCINES. A field experiment was used to study reproduction of H. glycines. Soil samples were collected from throughout the growing season a H. glycines- infected field. All samples were analyzed for cysts, eggs, and second-stage juveniles were observed. Both the technique of hatching by air-filling and the technique of hatching by a soaking solution of soybean roots was used in a hatching experiment.

The number of viable units in a cyst of H. glycines did not increase significantly (P=0.05) on soybeans throughtout the growing season. No significant differences (P=0.05) were found between the number of viable units per cyst in Pi and that in Pf.

H. glycines exhibited a ratio of 4.65:1 for eggs vs second-stage juveniles in a cyst. Two groups of parallel data were analyzed over an 84 day period in an experiment. An average in first group of data is 4.6:1 (range: 3.70 - 5.44), another one is 4.7:1 (range: 5.98 - 3.84). There was a mean of 4.65:1 for the ratio of eggs vs second-stage juveniles per cyst with a non-significance difference (P=0.05).

In the hatching experiment, a different hatch rate between the populations of H. glycines in the greenhouse and that in the field was observed. 628 second-stage juveniles were hatched from 100 cysts which came from the greenhouse, and only 76 from 100 cysts of the field.

Summary,

1) The number of viable units per cyst of H. glycines remained relatively constant on soybean thoughtout season.

2) The ratio of eggs vs second-stage juveniles per H. glycines cyst is about 4.65:1.

3) The number of second-stage juveniles hatched from greenhouse populations of H. glycines was greated than that from field populations.

4) The hatching method used in the experiment is a good way to obtain pure cultures of second-stage juveniles of H. glycines.

7.5 POPULATION DYNAMICS OF HETERODERA GLYCINES. The objective of population dynamics experiment was to determine Pi, Pm and Pf of H. glycines in a soybean growing season, and study population dynamics of H. glycines under field condition. The main methodology was as same as previously described for the rotation experiment.

The population of H. glycines increased continually in the soybean field throughtout the growing season. Pi was 3,600 viable units in 100 cm^3 of soil, Pm as 11,000 viable units, and Pf as 45,000 viavle units. From July 7 to September 29, 1988, routine sampling was conducted once a week to study the population dynamics of H. glycines (Figure 7.3 and 7.4).

The number of viable units in a cyst on an average in

the field changed during the 1988 growing season. Initially there was a decrease, then an increase (Figure 7.5). It also suggest that the number of this nematode in the first generation is not high.

Summary,

1) Pi of H. glycines increased more than 10 folds from a Pi of 3,600 to a Pf of about 45,000 viable units per 100 cm^3 of soil in a single soybean growing season.
2) H. glycines population in the field remained same or deseased in the first several weeks, then increased in nearly logarithum-rate. The increase becamed slower late in the growing ending period of the season.
3) The number of viable units per H. glycines cyst on an average was dynamic thoughout the growing season.
4) The number of H. glycines in the first generation is probably not very high.

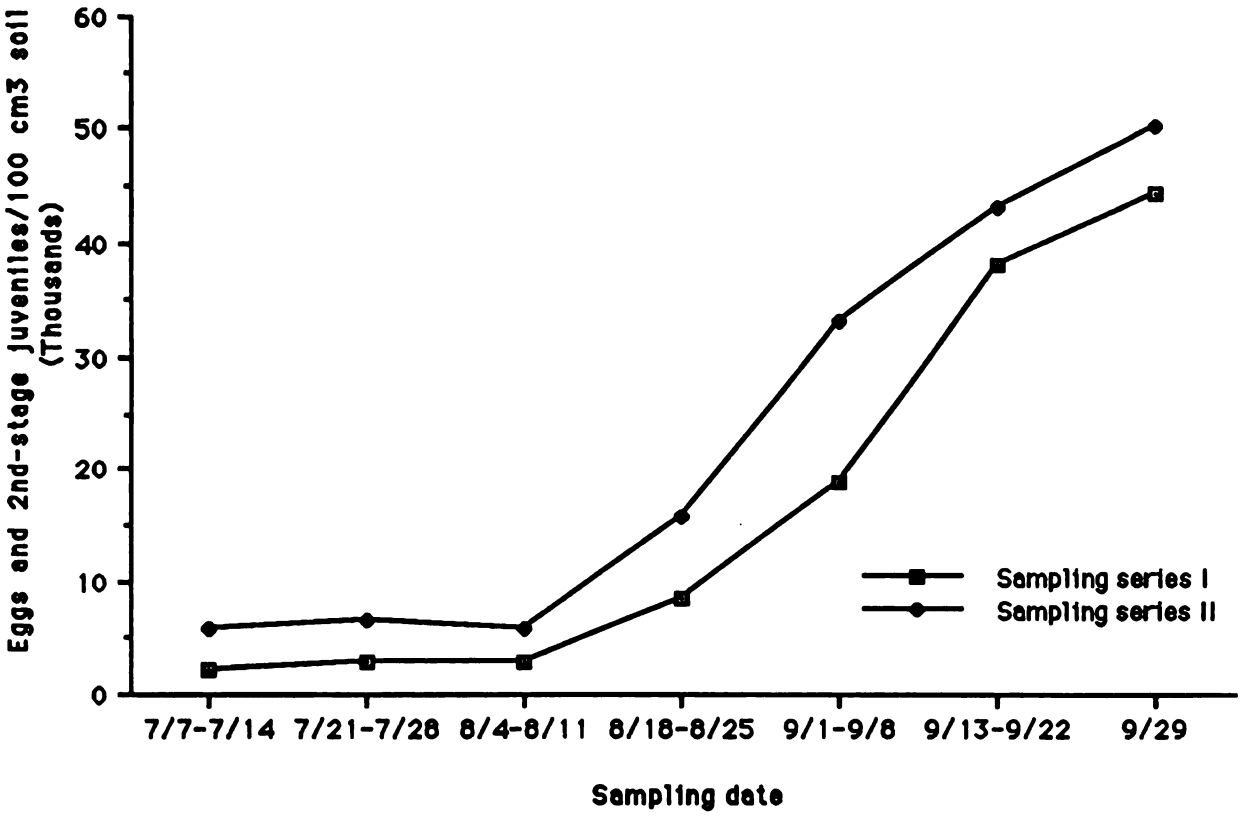


Figure 7.3. Field population dynamics (Heterodera glycines in 1988 season).

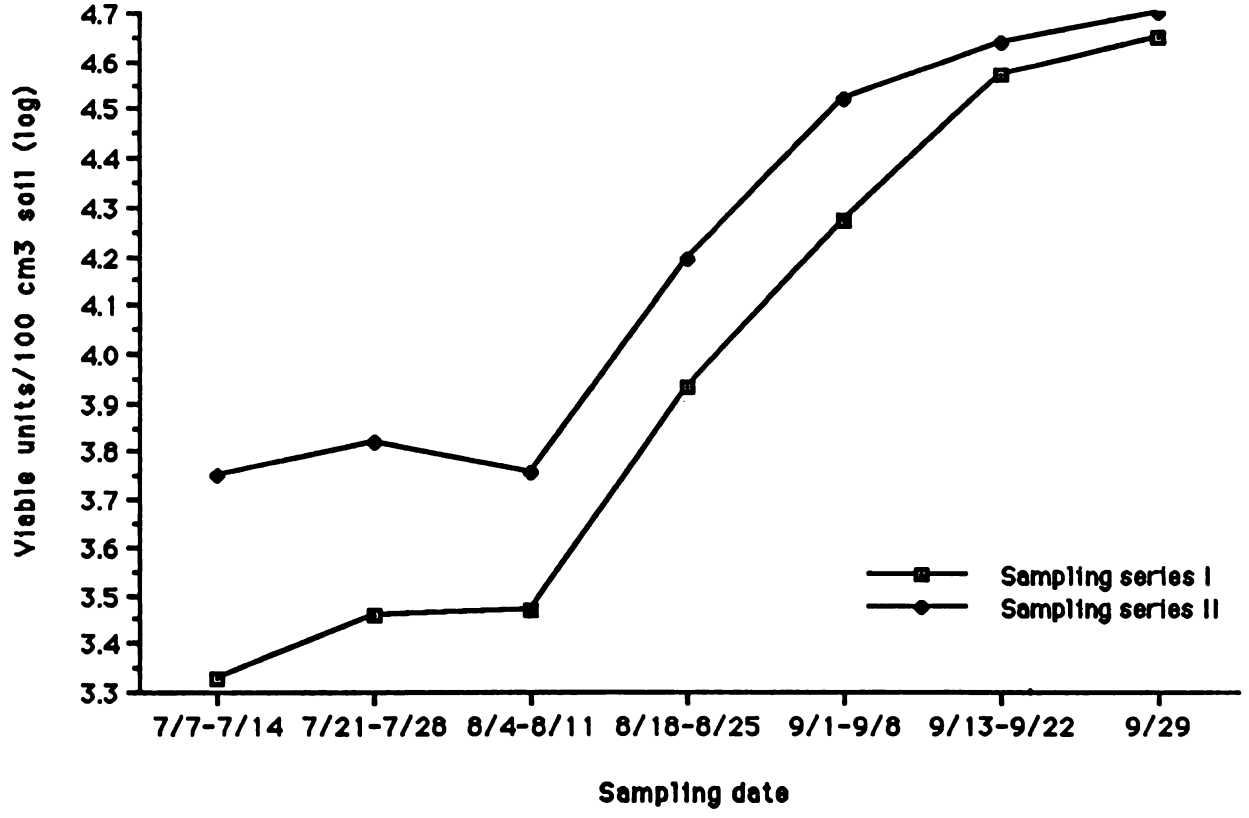


Figure 7.4. Population dynamics (logarithm) (Heterodera glycines in 1988 season).

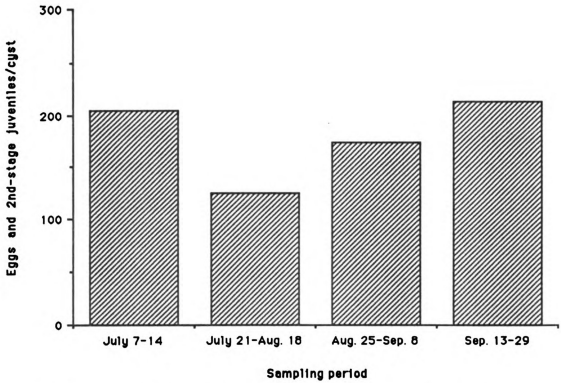


Figure 7.5. Dynamics of viable units/cyst (Heterodera glycines in 1988 season).

7.6 Discussion on sampling. The Five-point sampling method seems to be a good one for sampling H. glycines. In 1988, a special sampling study with a statistical approach was conducted to evaluate various sampling precedure for H. glycines. These included the Chessboard, Double-diagonal, Single-diagonal, Zigzag, and Five-points. The five-point precidure was the most sastified sampling method, and the zig-zag precedure is the least sastifactory for H. glycines on a statistical base. More studies are needed.