INTRA-AND INTERSPECIFIC INTERFERENCE BETWEEN SWEET CORN (*ZEA MAYS* L.) AND A LIVING MULCH OF WHITE CLOVER (*TRIFOLIUM REPENS* L.)

by

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Living mulches are vegetative covers that can grow in association with row crops and may prevent soil erosion and suppress weeds. Crop reduction from association with the living mulch is a frequent problem with this cultural practice. The interference between a white clover (Trifolium repens L. "New Zealand") living mulch and sweet corn (Zea mays L. "Golden Jubilee") was studied using an established clover sward, that was mowed and then sprayed with 1 to 1.5 kg ai/ha of atrazine [6-chloro-N-ethyl-N'-(1-methyl-ethyl)-1,3,5,triazine-2,4-diamine]. Corn, at different densities and planting arrangements, was planted into a 10-to 15-cm-wide band tilled in the clover. Replacement-series experiments and systematic density experiments also were conducted in this study. The experiments were irrigated. Interference by clover reduced corn yields. However, when corn row width was reduced from 76 cm to 38 cm, intraspecific interference among corn plants was reduced, and

corn plants became more productive and clover suppressive. Corn and clover competed for the same resources (mainly for light) when grown in mixture for 35 days after corn emergence. Clover appeared to be the superior competitor. However, the two species partially avoided competition. Nitrogen concentration in corn tissue (48 days after planting) was reduced when the corn was grown with clover, whereas the concentrations of P, K,and S were not altered by the presence of the legume. Twenty-four days after spraying clover with atrazine, up to 31 kg N/ha had been released into the soil from the clover. Thirty-four days later, the N concentration in soil of sprayed and unsprayed plots was the same. Soil moisture (20 cm depth) was not affected by the presence of the clover mulch.

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Weed control is an important and expensive operation for sweet corn producers. Two or more cultivations or herbicide applications are common during production of this crop. These treatments can leave a considerable portion of the soil surface exposed to eroding wind and rain.

Living covers (white clover, vetch, and others) growing in association with corn are able to prevent erosion losses and suppress weeds (Hargrove, 1982; Sweet, 1982). According to Vrabel (1983), intercropping sweet corn with a legume cover crop also increases nitrogen availability to sweet corn. Unsuppressed white clover intercropped with sweet corn usually will interfere and lower corn yields (Hartwig, 1977; Pendleton et al., 1956; Sweet, 1985). Thus, interference needs to be minimized without causing significant cost increases for living mulches to be an alternative feasible to farmers. Management practices should optimize the capacity of sweet corn to suppress the growth of the mulch. The factors involved in sweet corn-white clover interference must be known before management practices for these intercropped species can be defined.

This research focused on (a) the impact of white clover interference on sweet corn, (b) determining the type of interference between sweet corn and the clover mulch, and (c) factors involved in the interference process. Interactions between both species for light and soil nutrients were studied. By manipulating intra- and interspecific components of interference, a cropping situation to minimize clover interference was sought. This aspect of the study involved planting corn at several population densities, spatial arrangements, and proportions with clover. The potential nitrogen contribution to the system by white clover, during the growth cycle of corn, also was investigated.

My research was conducted during 1984 and 1985 in the field, and in growth chambers. The specific research objectives were to:

(1) evaluate the effect of different sweet corn densities and arrangements on corn growth, yield, and competitiveness against an established white clover sward.

(2) study the effect of sweet corn leaf area, and dry matter, on (a) corn yield and (b) clover suppression.

(3) assess the effect of clover interference on sweet corn growth, leaf area, and marketable yield.

(4) observe the effect of intercropped white clover on the carbon allocation pattern of sweet corn.

(5) define the type of interference between the species.

(6) establish the magnitude of nitrogen released into the soil solution by atrazine-suppressed white clover, and to define the pattern of its release.

(7) study the effect of competition on tissue concentration and total uptake of nitrogen, phosphorus, potassium, and sulfur.

(8) establish the importance of light as a limiting factor in the intercrop system.

Conventional field experiments were used to: (a) quantify sweet corn yield losses from clover interference, (b) study intra- and interspecific responses to changes in sweet corn populations and spatial arrangements, and (c) measure sweet corn growth components and foliar nutrient content. With soil samples from an adjacent experiment, the release of nitrogen by suppressed white clover was monitored. Systematic designs (Bleasdale, 1966; Nelder, 1962; Freyman and Dolman, 1971) were used to evaluate the intraspecific effect of systematic sweet corn density increments at different spatial arrangements. Replacement-series experiments were conducted to establish the type of interference between the associated species, to investigate possible niche differentiations between the species, and to detect environmental factors involved in corn-clover interference.

LITERATURE REVIEW

1. Multiple Cropping

1.a. Definitions and perspective.

Multiple cropping occurs when more than one crop is grown on the same land during a year (Kass, 1978). This is a practice found mostly in tropical and subtropical areas of the world. It is practiced among subsistence peasant farmers (Gomez and Gomez, 1983), and involves mixtures of their staple crops. In temperate zones, such as the Pacific Northwest, the mixtures usually involve different species of a pasture, mixed timber and grass ranges, forage crops with a companion grain, and grains or forage grown between fruit trees.

Multiple cropping has attracted considerable scientific attention in the recent years. The international agricultural research centers (CIAT, 1981; IITA, 1984), in the tropics and subtropics, have devoted a great deal of effort to multiple cropping research. Experiments conducted in the U.S., with corn, soybean, and cowpea, suggest that multiple cropping systems also could be a means of increasing yields in temperate regions (Allen and Obura, 1983).

Since multiple cropping is a general term, more precise definitions need to be considered. Mixed cropping is when two or more crops are grown simultaneously, and intermingled without row arrangement (Kass, 1978). The term intercropping denotes a difference in spatial arrangement, referring to more than one crop grown simultaneously, usually in alternate rows. A temporal difference occurs in relay plantings, where a maturing annual crop is interplanted with seedlings or seeds of a subsequent crop (Kass, 1978).

1.b. Reasons for multiple cropping

Multiple cropping in peasant agriculture was not developed to maximize yields or economic returns (Gliessman et al., 1981). Stability of food production was the priority. Peasant farmers in the tropics face several hazards while growing crops. In semiarid areas, erratic and undependable rainfalls prevail, soils are poor, and pests and diseases are abundant. Growing different crops with different requirements, with sensitive growth stages occurring at different times, and growing through most of the season, assures stability of food production (Okigbo,1979; Rao and Willey, 1978); Willey, 1979). Thus, multiple cropping results from the need of small farmers to avoid risk, and focus on sustained, long-term yields (Gliessman et al., 1981; Lima and Lopes, 1979). Some authors have suggested that multiple cropping may result in pest reduction (Gliessman and Altieri, 1982; Listinger and Moody, 1976). Stability seems associated with plant diversity. Intercropping systems that include a legume also can be advantageous by increasing nitrogen availability to the non-legume species (Vrabel, 1982).

Multiple cropping can provide complete and prolonged vegetation coverage of the soil surface. The vegetation reduces weed infestations (Okigbo, 1979; Listinger and Moody, 1976), and protects against soil erosion (Gomez and Gomez, 1983), particularly with row crops (Siddoway and Barnett, 1983).

1.c. Factors involved in multiple cropping.

Interference is a central issue in multiple cropping. Competition will occur when several crops are grown in close proximity. The plants compete for light, nutrients and water (Trenbath, 1976). Thus, success in multiple cropping depends on the relative capacity of the species to avoid competition with its neighbors. Such avoidance may occur when the intercrop components exploit the growth environment in different ways. Such complementary use of the resources has been termed "annidation" (Trenbath, 1976). An example of annidation in space is when one component of a mixture is tall, tolerant of strong light and high evaporative demand, while the other is short, shade tolerant and requiring high humidity (Trenbath, 1976). Such plants or species should not interfere much for light, and competition for water should be low. This observation is partly the case of shade trees in a coffee or cocoa crop. A logical possible combination of species would be to have C_4 plants as the taller canopy, with C_3 plants as the understory.

Below ground, competition begins when the depletion zones of two adjacent root systems overlap. Thus, the spatial distribution of the roots of intercrop components should affect the intensity of competition (Trenbath, 1976; Osiro and Kibira, 1979). Snaydon and Harris (1979) point out that given the differences in root distribution pattern of crops, weeds, and pastures, there should be opportunities for the complementary use of soil resources by component species.

Differences in the time of utilization of resources are important in intercropping (Snaydon and Harris, 1979; Osiro and Kibira, 1979). According to Rajat De, and Singh (1979), it is important that the peak periods of growth of the two species do not coincide when two crops are grown together. In this way, sugarcane (a slow-growing crop during the first three months) was successfully intercropped with cowpea or peas which are short-duration crops, maturing in 80 to 90 days. The quick-maturing crops completed their life cycle before sugarcane made great demands for resources. Competition can be partly avoided when major demands of resources occur at different times, and if the resource in demand is renewable (Rao and Willey, 1978; Spitters, 1980); Snaydon and Harris, 1979).
Annidation with respect to nutrients occurs in a mixture of species when a legume uses atmospheric nitrogen, while a non-legume species draws NH_4^+ and NO_3^- from the soil solution. This example represents a complementary association rather than a competitive one (Trenbath, 1976). Nitrogen transfer from the legume to the other species may occur (Rao and Willey, 1978). However, competitive interactions for N between a legume and a non-legume often occur (Singh and Gautam, 1979).

Some experiments have compared the performance of multiple croppings in different, well characterized, soils. These experiments suggest that multiple cropping is most successful in light-textured soils. The low fertility of such soils may result in grass crops greatly benefiting from an intercropped legume. The legumes themselves may grow better in light-textured soils (Kass, 1978).

Kass (1978) reports that the best intercropping results are reported for mixtures involving cotton, groundnuts and maize-legume combinations. These mixtures also are among those most commonly used by farmers. Jensen (1952) suggests that mixtures of small grains often result in small yield advantages over pure stands. Species that are taxonomically related often tend to have similar morphology and growth requirements. Such plants should occupy similar niches, and competition in time and space for environmental resources should be intense.

In selecting genotypes for intercropping, Francis (1976) proposed the following varietal characteristics as desirable for species grown in mixture:

Photoperiod insensitivity: the plant can grow throughout the year.

Early maturity: allows greater flexibility in intercropping or relay-cropping.

Short and non-lodging plants: reduces competition for light.

Population responsiveness: allows flexibility in varying crop proportions in a mixture, and in obtaining the highest total field population of a multiple cropping system.

However, evidence shows (Kass, 1978) that the above characteristics may not always ensure good performance in the mixture of species. Poor results may occur if plant characteristics of only one species are considered in the selection process. According to Kass (1978), experimental results illustrate the need to consider the effects of the intercropped species upon each other, when selecting the most adequate plant type to be grown in mixture. Yield advantages may result by combining species able to better use resources than when grown in pure stands. This requires species with complementary use of resources, instead of competitive resource exploitation (Rao and Willey, 1978). The greatest yield benefits of mixtures may result from combining crops with very different growth patterns (Osiru and Kibira, 1979). The concept of annidation, previously discussed, is implicit here.

Temporal complementarity in the use of resources may be achieved with genotypes of differing growing period. Thus, making their major resource demands at different times. Temporal complementarity has provided the largest yield advantages in crop mixtures (Rao and Willey, 1978). Reducing the height of a dominant crop may reduce intercrop competition and allow for better yields from the lower component. Higher yield advantages of mixtures over monocrops may, thus, result (Rao and Willey, 1978). Suppressed companion crops have to tolerate an environment modified by the dominant component. Thus shade tolerance represents a favorable genotype adaptation for many mixtures (Rao and Willey, 1978).

Crop population and proportions of the species in the mixture affect the outcome of the polyculture, in terms of biomass or final yield (Trenbath, 1976). Availability of environmental resources can be affected by the spatial relationships between the components of the polyculture (Huxley and Maingu, 1978).

According to Rajat De, and Singh (1979), standard row distances often are not adequate to accommodate companion crops. This suggests that modifying the planting pattern of the base crop could make intercropping feasible. It was found that increasing sorghum row spacing improved light harvest by an intercropped companion crop (Rajat De and Singh, 1979). Lima-Lopes (1979) found that total grain yield of intercropped maize and beans were better at higher plant populations, and when the spatial arrangement was one row of maize for every two or three rows of beans.

Yields of a suppressed companion crop could be increased if plants of the dominant species were allocated to a smaller area than usual by grouping them together (Rao and Willey, 1978). This arrangement would ease competition on the dominated crop, and in most cases the yields of the dominating crop was not affected. Arranging plants of the dominant species in hills or wider rows, increased light interception by the suppressed component (Rao and Willey, 1978).

Wahua and Miller (1978) found that intercropping reduced the yields of sorghum growing with soybeans. The most economically advantageous mixture was obtained when soybean was planted 5 cm apart between rows of sorghum seeded at a density of 5 plants/m^2, in a square pattern. In another experiment, corn was interplanted in a tall fescue sod at different plant densities and row spacings (Harper, Wilkinson, and Box, 1980). It was found that increasing corn populations and reducing row spacing suppressed growth and stand of the tall fescue sod. This effect resulted from lower solar radiation transmission through the corn stand under those conditions. When wheat and ryegrass were intercropped, the planting geometry of wheat had no effect on the associated ryegrass. However, increasing wheat sowing density reduced ryegrass growth substantially (Medd et al., 1985).

1.d. Advantages and disadvantages of multiple cropping

Multiple croppings appear to be beneficial more often than detrimental (Kass, 1978). The main advantage that small farmers of tropical and subtropical areas have recognized is the stability of food production (Rao and Willey, 1978; Kass, 1978; Willey, 1979). As discussed in section 1.c., there are often yield advantages of the mixtures over the monocrops (Rao and Willey, 1978; Kass, 1978; Willey, 1979). Part of this yield advantage has been attributed to a lower incidence of pests, diseases and weeds. With increased crop diversity, lower pest incidence may occur. Pest populations tend to be more stable and levels of biocontrol higher (Listinger and Moody, 1976; Willey, 1979; Altieri and Liebmann, 1986).

Intercropping isolates plants of the same species from each other thus helping reduce disease and pest transmission. In such complex systems non-host plants may interfere, with the pest's ability to find a host. Non-host plants may also interfere with the dispersal of fungal or bacterial spores. However, the effect of multiple cropping on pest and disease incidence is controversial, with as many positive cases as there are negative ones (Kass, 1978). Closed canopies, for example, create more humid conditions which, in turn, can favor diseases (Listinger and Moody, 1976). The more complete ground coverage by intercropped canopies results in increased preemptive use of light and, thus, in better weed suppression (Listinger and Moody, 1976; Willey, 1979; Altieri and Liebmann, 1986).

The role of allelochemical interference between intercropped species is not well known (Altieri and Liebmann, 1976). However, it is suggested that the presence of squash in mixtures with corn and cowpea, in Mexican farms, may be an effective means of weed control through selective allelochemical inhibition[1].

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[1] Personal observations.

When a nitrogen-fixing legume is present in a crop mixture, better nitrogen status of soil and plants would be another advantage of multiple cropping (Willey, 1979).

The main disadvantage of multiple cropping is the interference occurring among the intercropped species. This interference generally reduces the yields of species in mixture as compared to monocrop yields (Willey, 1979). The complications for mechanical harvest and crop management are also a major drawback of these systems (Kass, 1978; Willey, 1979.
Another negative aspect already commented on is the unpredictability of polycropping systems regarding insect and disease incidence (Willey, 1979). However, according to Altieri and Liebmann (1986) the diversification of crop habitats often reduced the incidence of pests

1.e. Measurements of the combined yield

Below is an index to evaluate the relative advantage of growing crops in mixture, or as monocultures. This index is the Land Equivalent Ratio (LER). It is expressed as:

$$LER = \frac{\text{Yield of Crop A in mixture with Crop B}}{\text{Yield of Crop A in monocrop}} + \frac{\text{Yield of Crop B in mixture with Crop A}}{\text{Yield of Crop B in monocrop}}$$

This formula can be extended for use with mixtures of several species (Kass, 1978). It represents the areas of sole crops needed to produce the same yields of these crops that were achieved by multiple cropping (Kass, 1978, Willey, 1979). LER avoids comparing or adding yields of different species. LER puts things on a comparable basis (Willey, 1979) by using relative yields[2]. There are three possible results:

LER = 1, yields of the mixture could have been obtained by monocrops growing on the same areas (Trenbath, 1976; Spitters, 1980, and 1983).

LER < 1, monocultures would need a larger area to produce the same as the cropping mixture: the use of intercropping is advantageous (Trenbath, 1976; Spitters, 1980 and 1983).

LER > 1, indicates a more efficient use of the resources. This usually results from both species exploiting the environment in different ways (Trenbath, 1976; Spitters, 1980, 1983). There is a complementary use of the resources, as opposed to a competitive relationship, as when LER = 1 (Trenbath, 1976).

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[2] Relative yield of the species a is: Yield of a in mixture/yield of a in monoculture.

The LER has been criticized for not considering factors such as economic returns, or neglecting the farmers' needs to maintain specific proportions among the crops grown in mixture (Kass, 1978; Spitters,1983; and Willey, 1979).

Trenbath (1976) further expanded LER by deriving terms related to the resource capture efficiency or conversion efficiency. Thus, advantages or disadvantages of an intercropping could be traced to differences in those terms.

To avoid plant density effects on LER, the mixture and the monoculture have to be grown at the same total density, preferably those recommended for farmer use (Spitters,1983). Thus, to establish the total density in mixture, one plant of crop A has to be found equivalent to $\underline{n}$ plants of crop B (Trenbath, 1976). According to Trenbath (1976), and Spitters (1980, 1983), LER may become the Relative Yield Total (RYT) of de Wit and van den Bergh (1965) if mixtures and monocrops are part of the same replacement series. In some cases the term " land equivalent ratio" has been used for RYT, but in calculating LER the replacement concept has not always been applied, otherwise both indexes are calculated in the same way. For two species in mixture $\underline{a}$ and $\underline{b}$, Relative Yield is:

$$RY\underline{a} \text{ or } \underline{b} = \frac{(\text{yield of } \underline{a} \text{ or } \underline{b} \text{ in mixture})}{(\text{yield of } \underline{a} \text{ or } \underline{b} \text{ in monocrop})}$$

and $$RYT = RY\underline{a} + RY\underline{b},$$

According to Harper (1977), when RYT = 1, the two species of the mixture are competing for the same environmental resources. RYT > 1 suggests that the species avoid competition by making different demands on resources (niche differentiation may occur), or have a symbiotic relationship. When RYT < 1, mutual antagonism is suggested, where each species damages the environment of the other more than its own. When, for example, each species produces a substance toxic to the other. These interpretations of RYT values overlap with those mentioned for LER.

Allen and Obura (1983) added to LER a consideration for the length of time a crop is on the land. This was termed Area Time Equivalent Ratio (ATER):

$$\text{ATER:} \quad [(RY\underline{c} \times t\underline{c}) + RY\underline{p} \times t\underline{p})]/T$$

Where RY = relative yield of species c̲ or p̲; t = duration (days) for species c̲ or p̲, and T = duration (days) of the intercropped system. Productivity estimated by LER tended to be higher than the ATER values for the intercropping of corn with soybean or with cowpea.

A measure of the aggressiveness of one species towards another can be obtained from the results of a replacements series. This measure is the "Relative Crowding Coefficient" which, according to Harper (1977), can be expressed as follows:

$$\text{Relative crowding coefficient of species A with respect to B (50:50 mixture)} = \frac{\text{Mean yield per plant of A in mixture}}{\text{Mean yield per plant of B in mixture}} \times \frac{\text{Mean yield per plant of B in pure stand}}{\text{Mean yield per plant of A in pure stand}}$$

The crop with the higher coefficient is the dominant one.

An "aggressivity index" (Willey, 1979) can be calculated, with data from a replacement series, to establish the competitive superiority of one species over another. It is also used to rank the competitiveness of several species against one test species. According to Willey (1979), aggressivity (A) of species a growing with b is:

$$A^{ab} = \frac{1}{Za}\,(\text{Relative yield of } \underline{a}) - (\text{Relative yield of } \underline{b})\,\frac{1}{Zb}$$

in which Za and Zb are the sown proportions of each species in the mixture.

An aggressivity value of Zero indicates absence of competitive differences between both components. Both species will have the same numerical value, but the dominated species will have a negative sign. The larger the value, the greater the difference in competitive abilities (Willey, 1979).

2. <u>Living mulches: a particular case of intercropping</u>

Sweet corn for canning in Oregon grows over approximately 16,000 ha (Miles, 1986). It is usually grown in rows 80- to 100-cm wide (Mansour, 1975). Therefore, a large surface of loose, cultivated soil remains uncovered by vegetation and exposed to the fall and winter rains of Western Oregon. This cropping practice creates a series of problems related to soil conservation, environmental pollution and weed control.

2.a. The benefits

2.a.1. Soil erosion and runoff control.

The annual erosion rate in Western Oregon ranges from 0.2 to 9 metric tons per ha, and can exceed 25 metric tons in the Willamette Valley (Harward et al., 1980). A soil cover, or increased roughness of the soil surface, could reduce raindrop impact and minimize erosion losses (Daniel et al., 1980). According to Miles (1986), erosion rates in Oregon have been great enough to warrant erosion control practices. Erosion problems led to conservation tillage systems, including cover cropping and live mulching (Unger, 1980; Daniel et al., 1980). In Oregon, erosion losses have been recognized, and have determined the need for serious erosion control practices. Research on conservation tillage technologies has been considered crucial for agriculture in the humid regions of the U.S. (Larson, 1981).

Harward et al. (1980) emphasize the need to maintain a permanent plant cover wherever possible. The presence of grass or legume living mulches in no-tillage corn has significantly reduced erosion (Hargrove, 1982). Hartwig (1977) found increased erosion control when corn was planted with a crownvetch cover crop. Langdale (1983) found that a legume cover reduced runoff by 50 to 90%. Burwell et al. (1975 found an alfalfa cover very efficient in reducing annual sediment losses (less than 0.1 ton/ha).

2.a.2. Infiltration and soil structure.

Poor infiltration accompanies the erosion process (Harward et al., 1980). The impact of rain on soil aggregates releases particles that seal cracks in the soil surface, forming a crust that hinders infiltration. Thus begins the runoff process (Harward et al., 1980). The major soil transport mechanism is this surface runoff. Farm practices must reduce raindrop impact and limit surface crusting. The use of a ground cover, living or inert, is one of such practices (Mannering et al., 1968; Daniel et al., 1980). Triplett et al. (1968) found that soil moisture and water infiltration rates increased with the percent of soil surface covered with a dead mulch. The yield of a maize crop was thus increased. According to Mooers (1925), the use of legumes as living mulches improves soil structure.

2.a.3. Water pollution.

The runoff from cropland, with dissolved nutrients and other contaminants, reduces water quality of streams and lakes. The sediment removed by the runoff process carries the bulk of nutrients, pesticides and toxic metals. The dissolved nutrients are readily utilized by algae and aquatic weeds. Phosphorus is a key element in algal nutrition (Harward et al., 1980; Burwell et al., 1975; Daniel et al., 1980). Nitrogen found in drinking water presents a risk, mainly by causing methemoglobinemia in infants and nitrate-related cancers. Many pesticides found in water are believed to be related to several forms of cancer (Cantor and Blair, 1986).

Reduction of surface runoff is one way to control water contamination (Harward et al., 1980; Burwell et al., 1975). Increased surface residues, or living plant covers, seem capable of reducing runoff and sediment pollution of streams and lakes (Harward et al., 1980; Burwell et al., 1975; Daniel et al., 1980).

2.a.4. Soil organic matter.

Organic matter stabilizes soil structure, promoting water infiltration. Frequent tillage and continuous cultivation deplete the organic fraction of the soil and soil nitrogen (Jenny, 1933). Many legumes provide good ground cover, increasing N and organic matter levels in the soil (Mt. Pleasant, 1982; IITA, 1985), while preventing erosion and avoiding organic matter loss. Similar effects are obtained with the use of cover crops in rotations (Hargrove, 1981).

2.a.5. Soil compaction.

The frequent passage of agricultural equipment, applies high pressure to the soil causing compaction and deformation. This increases soil bulk density, affects soil penetration by roots and limits O_2 and CO_2 exchange at root level. The rate of water infiltration also is reduced. Soil compaction can reduce crop yields if plants are subjected to moisture stress or if nutrient uptake is impaired (Vomocil, 1961, and 1977). Lindeman et al. (1982) found that compaction decreased plant growth, nodulation and yield of soybeans. Cover cropping can reduce soil compaction (Vomocil, 1961).

2.a.6. Energy costs of tillage.

Reduced tillage practices have allowed significant fuel savings (Hargrove, 1981; Daniel et al., 1980). Conservation tillage systems such as chisel ploughing, no-till, and the use of intercropped living mulches for no-till planting, allow 34 to 76% reductions in energy consumption (Daniel et al., 1980). The bulk of the energy consumed in no-till corn production is as fertilizers, rather than fuel. Energy consumed as nitrogen fertilizers represent 68% of the fuel energy consumed in no-till farming (Daniel et al., 1980). Since the use of a legume as a living mulch may provide considerable quantities of fixed nitrogen, and conserve soil and water resources, its use in conservation tillage systems appears justified (Hargrove, 1981).

2.a.7. Weed suppression.

The potential of various intercropped cover crops to suppress weeds has been recognized (Kurtz et al., 1952; Elkins et al., 1979; Akobundu et al., 1980; Cardina and Hartwig, 1982). Sweet (1982) obtained satisfactory weed control using white and ladino clovers as living mulches. The best results were obtained if the clovers were planted early. Ogg (1982) obtained good weed control of field bindweed and dandelion, using ryegrass and red fescue as living mulches in peach orchards. When red fescue "Elka" was used, allelopathic effects may have been present. In these experiments, the elimination of the weed flora by the mulch helped reduce infestations of green peach aphids. Dandelions (Taraxacum officinale Weber), mustards (Brassica spp.), field bindweed (Convolvulus arvensis L.)and lambsquarters (Chenopodium album L.) were excellent hosts for the green peach aphid.

The cover crop mainly suppresses annual weeds; after some time, a shift to perennials often occurs (Elkins et al., 1979). The first plant to establish in a new habitat will preempt a large amount of environmental resources thus reducing the possibilities for survival of late-emerging individuals (Harper, 1977; Radosevich and Holt, 1984). If a living mulch is established early, it will replace weed species. Management will be targeted to only two species: the crop and the mulch, this should be much easier to manage than a crop and several weed species (Sweet, 1982). Cardina and Hartwig (1982) and Hartwig (1977), growing corn with a permanent crownvetch (Coronilla varia) cover, observed that the presence of this species significantly reduced weed yields, including yellow nutsedge. Cooper (1985) observed better weed suppression when a living mulch of white clover was established in fall, compared to spring plantings. The use of intercropped living covers may be an efficient weed management alternative, where a heterogeneous weed flora is replaced by a more manageable one-species sward.

The effect of living mulches on weeds is not only through competition, but also because it decreases the amount of weed seed in the soil (IITA, 1985). Weeds are prevented from growing and setting seed; seeds in the undisturbed soil do not find adequate conditions to germinate and may rot. If weeds manage to germinate, their seedlings are smothered by the mulch.

2.a.8. Role of legumes and nitrogen fixation.

One advantage of using legumes as cover crops is to add atmospheric nitrogen fixed by them to the soil (Hartwig, 1977; Mt. Pleasant, 1982; White et al., 1981; IITA, 1985). Legume mulches conserve nitrogen that, otherwise, would be lost to leaching and denitrification (Phillips and Phillips, 1984). According to Ebelhar and Frye (1981), corn grown without nitrogen fertilizer, in a hairy vetch mulch, yielded 68 to 59 bushels/A more than growing on corn or rye residue. The release of nitrogen into the soil, under a legume cover crop, results from sloughed off senescing nodules and roots (Mt. Pleasant, 1982; Hoglund and Brock, 1978; Vrabel, 1983).

Drought, grazing, mowing or herbicide suppression to control the growth of the mulch can result in carbohydrate starvation of roots and nodules, therefore inhibiting nitrogen fixation. Nodules will then senesce and decompose, and nitrogen will be released from the legume into the soil (Vrabel, 1983; Akobundu, 1980; Hartwig, 1983;

Sweet, 1982; Hoglund and Brock, 1978; Butler et al., 1959). The released nitrogen can be taken up by a crop growing with the mulch (Akobundu, 1980; Hoglund and Brock, 1978).

The amount of nitrogen released depends, among other factors, on the mulch species involved. According to Sweet (1982), atrazine-suppressed white and ladino clovers released 23 Kg N/ha. Nitrogen was not released from unsuppressed established legumes. Walker et al. (1950) found that a white clover sward could release approximately 110 Kg nitrogen per hectare into the soil, to be taken up by an associated grass species during the first year of establishment. This quantity was doubled in subsequent years.

Nitrogen release should follow the inhibition of nitrogen fixation that results from carbohydrate starvation of roots when the foliage of the legume is damaged. The extent and intensity of foliar damage will determine the level of nitrogen fixation inhibition. Vrabel (1983) found that levels of white clover suppression with herbicides, and of the ensuing inhibition of nitrogen fixation could vary with the mode of action of the herbicide used. Glyphosate injury is gradual and does not affect photosynthesis (and carbohydrate supply to nodules) to the extent triazines do. Thus, the decrease of nitrogen fixation by white clover, after glyphosate treatment, was not as severe as with atrazine. The author speculates that the amount of root tissue killed and the subsequent release of nitrogen also must be less with glyphosate.

Vrabel (1983) concludes that the degree of clover suppression determines the extent of nitrogen release into the soil. Only a severe suppression of clover growth results in significant release of nitrogen by the clover's underground organs. Knowing the pattern of nitrogen release might help in timing the suppression treatment so that nitrogen is released at a favorable time for the crop's utilization.

The utilization of soluble soil nitrogen, replaces much of the nitrogen that would otherwise be symbiotically fixed from the atmosphere (McAulliffe et al., 1958). Added mineral nitrogen will inhibit nitrogen fixation by the legume living mulch (Hoglund and Brock, 1978; McAuliffe et al., 1958).

2.a.9. Species for living mulches.

The objectives of a green mulch crop are to restore fertility, control weeds, eliminate the continuous ploughing and cultivating, improve water infiltration and reduce erosion. The species used should be able to establish rapidly, with low and dense growth that can be managed to minimize interference with the associated crop (Akobundu, 1984; Voelkner, 1979).

Several grass species were screened by Cook (1982) for use as living mulches. His choices for an orchard were perennial ryegrass, tall fescue, hard fescue, or a mixture of perennial ryegrass and hard fescue. Perennial ryegrass established fast, therefore being competitive in the early season when weeds also were becoming established. Perennial ryegrass had the best weed suppressing ability. As a bunch grass, it did not encroach into the crop row. This grass had the highest nitrogen requirements, therefore the choice of legume cover crops seems preferable.

Vrabel (1981) found that white and ladino clovers were excellent as living mulches with sweet corn. Treated with atrazine as a suppressant, they allowed corn to yield 75% higher than when planted without a living mulch crop. These two species suppressed weeds better than red clover or alfalfa sods. Butler (1959) subjected lotus, white, and red clover to shading or repeated defoliations. He found that white clover because of his stoloniferous growth habit and capacity for vigorous regrowth had the highest turnover of root and nodule tissue. This turnover resulted from the progressive death of older roots and nodules which were rapidly replaced by new and heavily nodulated adventitious roots that originate at stolon nodes. Thus association of white clover with a grass may increase nitrogen availability to the grass. White clover could be a successful living mulch species. Its low, stoloniferous growth habit is capable of filling gaps and smothering weeds; it has insect and disease resistance, and the capacity to survive suppression treatments (Vrabel, 1983).

2.b. Mulch-crop interference.

The mulch species can interfere with the crop. Therefore, the growth of the living cover needs to be regulated (Vrabel, 1983; Sweet, 1982; Hartwig, 1977; Pendleton et al, 1956).

Since the legume-Rhizobium symbiosis results in the fixation of atmospheric nitrogen, competition for nitrogen should be less important than for other factors. However, competition for nitrogen between a legume mulch and a non-leguminous crop can occur when added mineral nitrogen (fertilizer) inhibits atmospheric-nitrogen fixation by stimulating the legume to use mineral nitrogen from the soil solution (McAuliffe et al, 1958). The mineral nitrogen then will become a common source of this element for both species, and competition may occur.

Carbohydrate starvation after mowing or chemically suppressing a legume living mulch to reduce interference results in root and nodule death with the release, after mineralization, of significant amounts of mineral nitrogen. The released nitrogen interacts negatively with nitrogen fixation as additions of mineral nitrogen do. Increasing the density of the grass component in mixture with a legume, helps remove part of the soluble nitrogen released by the legume, and maintain its nitrogen fixation rates (Hoglund and Brock, 1978). During the mulch suppression period a crop could extract soluble nitrogen from the soil with almost no competition from the growth-impaired legume (Vrabel, 1983).

The differential mobility of water and nutrients in the soil solution will affect the competitive interactions for soil factors (section

3.c.2.). Several authors have reported competition as being mainly for nitrogen and water between corn and intercropped species (Adams et al., 1970; Stivers, 1956; Peterson, 1955).

Severe suppression of the sod is required to minimize competition (Mt. Pleasant, 1982; Vrabel, 1983; Lewis and Martin, 1967). Suppression has successfully been achieved by using herbicides sometimes in combination with mowing (Vrabel, 1983; Cooper, 1985). Shading by the main crop has potential to suppress the intercropped sod. Harper et al (1980) found a negative correlation (- 0.95) between corn plant density and radiation transmission. A radiation transmission lower than 30% severely depressed the winter growth of a tall fescue sod intercropped with corn. Shading is very suppressive of legumes because nodulation depends upon the supply of carbohydrates from photosynthesis (Cooper, 1977).

Crop management capable of increasing canopy development and placing crop plants in narrow (close) rows should increase shading and suppression of an associated mulch. Increased shading also could be achieved with higher crop planting densities (Ghafar and Watson, 1983; Peterson, 1955; Altieri and Liebman, 1986; Walker and Buchanan, 1982; Hinton and Minotti, 1982).

2.c. A sweet corn-white clover living mulch system - problems and potentials.

The main problem with the living mulch system seems to be the need to reduce living mulch interference. If the mulch is not suppressed, yield reduction might be important (Sweet, 1982; Kurtz, 1952; Pendleton, 1956). Compared to a non-living mulch situation, the added costs of mowing and applying herbicides to suppress the mulch are a disadvantage of the system. Cost-benefit relationships need to be examined. Management practices at little or no additional cost, such as modifications of planting patterns and densities, may help reduce the costs of mulch suppression (Altieri and Liebman, 1986; Walker and Buchanan, 1982). Cooper (1985), working with sweet corn and white clover found that mowing the clover, selling its clippings as green forage,and suppressing the clover mulch with 1.0 Kg ai/ha atrazine resulted in a higher net return compared to conventional sweet corn farming.

Living mulches have potential to increase rodent incidence since they provide an adequate habitat year round (De Calesta, 1982). Vrabel (1982) indicated that mice and moles can become a problem in a white clover-sweet corn system.

The sweet corn-white clover living mulch system has potential for success under several circumstances. Such system should be useful in areas subjected to rain erosion (Hargroove, 1982) or surface water contamination by runoff from agricultural lands (Langdale, 1983). An additional benefit from the presence of white clover growing with sweet corn would be its use as a forage. In a cropping sequence the system will benefit from the nitrogen incorporated into the soil by the clover.

3. Interference, competition, resources

When plants grow relatively close to each other, growth patterns in mixture often differ from those observed when plants grow without neighbors. Growth in mixture can respond to all possible types of interactions between plants. Thus, growth may be stimulated, depressed, or remain unchanged. The term interference refers to stimulatory, inhibitory or neutral plant growth alterations resulting from the proximity of neighbors (Donald, 1963; Harper, 1977; Radosevich and Holt, 1984).

The causes of interference are diverse. Interference may result from the consumption of resources in limited supply, from the release of toxins or stimulatory substances in the growing environment, or from protective or predatory interactions (Harper, 1977; Radosevich and Holt, 1984). Competition and Amensalism are two examples of negative or inhibitory interference. Competition deals with the resources plants consume: mainly light, water, nutrients, oxygen, and carbon dioxide. The supply of resources often is limiting and the presence of neighbors aggravates the situation (Radosevich and Holt, 1984). Competition is the adverse effect on all plants consuming a resource that is in short supply. When the growth of only one species is depressed while the other is unaffected, there may be a case of Amensalism. If there has been a release of a toxic substance by the unaffected component of the mixture, it is a particular case of amensalism known as Allelopathy (Radosevich and Holt, 1984). The antagonism can be mutual, resulting in the depressed growth of both species.

These definitions, however differ among authors. Silvertown (1982) considers interference to be only the negative interactions, and competition to occur when interference reduces the number of individuals, or the size of their offspring, or both. This definition is restrictive, and in this paper the concepts given by Harper (1977), and Radosevich and Holt (1984) will be followed.

3.a. Yield-density relationships.

When the number per area of individuals of a given species increases, intraspecific interference among neighbors will begin when resources become limiting. There is a "plastic" response by which increases in density result in reductions of individual growth, while the total yield per area increases (Harper, 1977). As the plants at all densities grow larger with time, they will eventually reach the carrying capacity of the environment. The carrying capacity is first reached by the highest densities. Further increases in growth per plant will be balanced with the corresponding amount of "mortality" (Silvertown, 1982). The result is the relationship shown in Figure 1. (figures are at the end of the Literature Review), where total yield per area is constant and independent of plant density. This relationship is known as the "law of constant final yield" (Harper, 1977; Radosevich and Holt, 1984), where the relationship between the mean weight of an individual plant (w) and plant density is given by the following expression:

$$w = kd^{-1}$$

$$\text{if } Y = wd$$

$$\text{then } Y = d(kd^{-1}) = k = \text{constant.}$$

(Silvertown, 1982)

where k = constant, d = density, and Y = yield per area

Both, sparse and dense populations will in time reach constant final yield.

Sparse populations encounter mortality when they reach the carrying capacity of the environment. At higher densities the smaller plants face mortality <u>before</u> the carrying capacity is encountered (Fig. 2.). For these higher densities, the relationship between single plant weight (w) and density (d) is:

$$w = kd^{-3/2} \text{ (Silvertown, 1982)}$$

$$(k = \text{constant})$$

This is known as the "-3/2 power law or the self-thinning law" (Radosevich and Holt, 1984; Silvertown, 1982). The exponent in this equation has been empirically derived (Westoby, 1981).

At carrying capacity total weight per area (w x d) does not increase with time, whereas under self-thinning total weight increases two units for every two density units lost.

When yield is considered in terms of reproductive output (such as seeds) instead of total biomass as in Figure 1., a parabolic (Fig. 3) yield-density relationship is often obtained (Donald, 1963; Silvertown, 1982). There can be several reasons for this yield decrease at high densities. There can be density-dependent mortality before flowering, increased sterility, or reduction in the number of seeds produced per plant (Silvertown, 1982). With corn, sterility is a consequence of shading at higher densities (Duncan, 1969). The barren plants will utilize resources without contributing to yield. When yield is a reproductive component, it seems that an optimum-yielding density needs to be established. In the case of forages, the plateau situation depicted in Figure 1 prevails (Donald, 1963), and seeding rate will be regulated by seed cost and the need to overcrowd existing weed populations. However, if the forage has to include a reproductive organ for higher feeding value, then barrenness at high densities could be a problem in spite of total forage biomass being adequately high.

A different aspect about density is its use in crop-weed management. Increasing wheat density reduced competition from ryegrass (Medd et al, 1985). Ghafar and Watson (1983) reduced yellow nutsedge infestation and increased corn yields by raising a corn population to 130,000 plants/ha, the weed was severely shaded. Similar observations are reported by Walker and Buchanan (1982). However, unlike forages, crop plant populations cannot be raised beyond a maximum grain-yielding density without yield loss if the spatial arrangement is maintained. Zimdahl (1980) cites several examples of how increasing weed populations resulted in higher crop losses.

3.b. Space capture and spatial relationships.

"Space" is a concept that integrates all the resources required by a plant to live. Each plant occupies a "space" that according to de Wit (1960) reflects the unspecified limitations of the environment, since the supply of consumable environmental resources (light, water, nutrients, oxygen and carbon dioxide) is limited. The presence of neighbors, demanding the same resources, will result in competition for space (Radosevich and Holt, 1984). Taking this space by preempting resources is known as space capture.

Late emerging plants will grow very little because earlier plants have preempted most of the existing space (Radosevich and Holt, 1984). Space is captured early in the life of an individual; this determines its final yield (Fischer and Miles, 1973) and its place in the hierarchy of size classes in its population.

Early emergence or cultural practices fostering plant development, are ways to enhance space capture. In some cases rearrangement of planting patterns has allowed increased crop space capture thus increasing its competitive ability against weeds or other associated species.

A planting pattern where the plants are equidistantly distributed, or at least placed in a square grid, seems best for crop production (Fischer and Miles, 1973; Duncan, 1969; Pant, 1979; Spitters, 1982; Altieri, 1986; Walker and Buchanan, 1982). Using an equidistant (equilateral or hexagonal) pattern or a square planting arrangement reduces intraspecific competition, as opposed to a rectangular planting arrangement. A crop planted in a rectangular pattern with wide rows, will have the plants close to each other within rows and intraspecific interference will be expressed. If the same density is maintained and the intra-row distance becomes the same as the inter-row distance, then plant spacing will be almost maximum for the densitiy employed. Such spacing will reduce intraspecific interference, and allow maximum individual plant development. Improved plant development will enhance the interspecific competitiveness of the crop (Fischer and Miles, 1973; Spitters, 1982; Altieri, 1986; Burnside, 1963; Walker and Buchanan, 1982; Taylor, 1980; Peterson, 1955). This equidistant or quasi-equidistant planting pattern allows a more uniform plant distribution (Duncan, 1969; Burnside, 1963). Plants have thus better early space capture, developing large canopies that provide greater crop photosynthesis, lower evaporation (higher water use efficiency), early ground cover and weed suppression (Taylor, 1980; Burnside, 1963), and higher yields (Walker and Buchanan, 1982).

According to the of Fischer and Miles (1973) postulated from theoretical models, reducing row width (therefore making intraplant and inter-row distances more similar) has a stronger effect on weed suppression than increasing plant density. Increasing plant density, within a rectangular arrangement enhances intraspecific interference. Conversely, the higher the plant population, the greater the yield advantage of narrower rows (Duncan, 1969).

These effects have been reported for different crops. Taylor (1980) observed higher soybean yields using narrow-rows and related this to better canopy development. When corn was intercropped with alfalfa, Peterson (1955) found higher corn yields and alfalfa suppression when row width was reduced from 80 inch to 60 or 40 inch for the same population. The advantage of the narrow rows and a more equidistant arrangement of corn plants, also was seen whether this crop grew alone or intercropped with alfalfa (Peterson, 1955). Spitters (1982), however, found no advantage in using narrow rows with cereals.

An important disadvantage of equilateral arrangements is indicated by Taylor (1980). In dry years the early development of large canopies as with narrow row/equidistant distribution will increase the early use of stored soil moisture. Less moisture will be available during the critical grain-filling stages. Under high moisture conditions, Wiese et al (1964) obtained best results when sorghum was planted in 12-inch rows rather than in 30- or 40-inch rows. With less moisture, cultivated 40-inch rows outyielded narrow rows.

Changing plant spatial geometry may affect the microclimate within corn stands, 1968); Duncan (1969) indicates that hexagonal planting may be the best, but disease or insect control may favor other planting patterns. Another criticism to equidistant planting is the need for adapting seeding equipment for this purpose. Duncan (1969) sees no major problem with this, whether a hexagonal or square pattern is sought for seeding corn.

3.c. Relevant factors in competitive interactions.

Plants require certain factors for growth, mainly light, water, nutrients, oxygen and CO_2 (Trenbath, 1976; Radosevich and Holt, 1984). The environmental supply of these factors is often limited. When roots and shoots of different plants overlap competitive relationships for limiting factors begin (Trenbath, 1976). The presence of neighbors aggravates the growth reduction imposed by the inadequate supply of environmental resources (Radosevich and Holt, 1984). In intercropping situations, the different competitive abilities of the species will determine uneven sharing of resources, which needs to be managed in order to maintain productivity of all species in the mixture. Variations in spatial relationships between different components of a mixture will regulate the intensity of intra- and interspecific competition processes (Trenbath, 1976). The basic effect of competition is the alteration of normal growth patterns. This will affect the growth rate and reproductive output of plants.

3.c.1. Competition for light.

Competition for light is almost always present (Radosevich and Holt, 1984; Trenbath, 1976) except when plants are too very small to shade each other or themselves. Photosynthesis and growth are proportional to the intercepted radiation (Trenbath, 1976). This radiation is not stored as a reservoir nor transported within the plant (Trenbath, 1976). Therefore, the use of photons for photosynthesis is instantaneous; photons not intercepted are lost.

Competition for light among leaves within a canopy can take place before canopies of adjacent plants shade each other and compete for light (Donald, 1963). An advantageous display of leaves (Trenbath, 1976) and the ability to place the canopy over that of a neighbor will determine success to compete for light (Radosevich and Holt, 1984; Donald, 1963).

Plant height is an important component of competition for light (Zimdahl, 1980). Trenbath (1976) noted that small differences in height, even early in life, can lead to strong competition effects. LAI and light-receiving ability of leaves greatly influence photosynthesis and growth (Zimdahl, 1980). LAI is a useful tool to examine productivity and potential for light capture (Radosevich and Holt, 1984).

3.c.2. Competition for soil factors.

To study the competitive interactions for soil factors (nutrients and water), their differential mobility in the soil solution needs to be considered.

The main mechanism by which nitrogen reaches the root is the mass flow of soil solution caused by plant water absorption (Barber, 1984). Potassium and phosphorus, however, reach the roots mainly by diffusion, a process that usually occurs within only 0.1 to 15mm from the root surface (Barber, 1984). Hence, water and nitrogen are more mobile in the soil than potassium and phosphorus (Trenbath, 1976; Caldwell et al., 1985; Kurtz et al., 1952). Competition for nitrogen and water will start when the nitrogen and water depletion zones of neighboring plants overlap. The degree of overlap will affect the intensity of competition. The depletion zone of water and nitrogen is not limited to just the soil area contacted by the roots, it also includes the soil volume within the diffusion range of water and nitrates (Kurtz et al., 1952). The depletion zone of mobile nutrients can be 40 times larger than that of phosphorus and potassium (Trenbath, 1976).

Phosporus and potassium have low mobility in the soil and reach the roots essentially by diffusion (Trenbath, 1976; Caldwell et al., 1985). Since diffusion of P and K towards the root occurs within small distances from the root surface (Barber, 1984), root proximity (0.1 to 15 mm) seems important when competition is for immobile nutrients (Trenbath, 1976; Caldwell et al., 1985; Kurtz et al., 1952). Root proximity would be required in competition for phosphorus since its low effective diffusion coefficient in soil (De = 1×10^{-8} to 1×10^{-10} cm^2/s) implies that only phosphorus close enough to reach the root can be absorbed (Barber, 1984). Nitrate and water, however, are absorbed over greater distances than P and K, thus root proximity is not so critical for competition to occur. Competition for nitrate and water should occur more readily than for phosphorus or potassium (Kurtz et al., 1952).

Competition for phosphorus may occur. Caldwell et al. (1985) observed that Agropyron desertorum was much more efficient in competing for potassium than A. spicatum, and this was related to a higher number of mycorrhizal infection points in A. desertorum. Mycorrhizae extend the effective uptake zone of the root. According to Movat and Walker (1959) interspecific competition for phosphorus is closely related to root cation exchange capacity (CEC). Gray et al. (1953) observed that competition for potassium was a function of root CEC.

If root proximity is required to compete for soil factors then root density and distribution patterns of the associated species will determine the intensity of competition below ground (Trenbath, 1976). The uptake of water occurs just beneath the plants (Pavlychenko, 1940). Modifications of the planting arrangement are expected to affect crop water relations (section 3.b.).

3.c.3. Competition for other factors.

Competition for factors such as oxygen and CO_2 has been difficult to determine. The normal concentrations of these gases in the atmosphere and air turbulence within the canopies may preclude competition for these gases (Zimdahl, 1980).

3.d. Some experimental approaches to study interference.

Interference among plants involves complex relationships, where different species interact for environmental resources. The capacity to seize these resources, under various levels of availability, may differ among species (Roush and Radosevich, 1985; Vengris et al, 1955)and is environmentally conditioned (Pearcy, Tumosa, and Williams, 1981).

According to Caldwell et al.(1985) competition among plants is studied in experiments where "the competitive setting is manipulated in many ways". Examples of such manipulations are the removal or additions of neighbors, or variations in the levels of resource availability. Competition appears when resources become limiting. When specific resources are made limited for an experimental mixture of species, some knowledge may be gained with respect to the competitive relationships of that mixture. For example, the superior competitors under that specific set of growing conditions may be identified, as well as certain limiting growth factors. Competition studies are complex situations where environmental factors interact with plants, modulated by the experimental conditions selected.

The complexity of plant-plant associations has caused the "unusual" appearance, to some agronomists, of certain experimental designs to study interference. These designs or experimental approaches are discussed below. The following experiments allow the examination, of environmental resources being competed for, the levels of intra- and interspecific interference, plant response to density, the effects of varying proportion of species in mixture, and the impact on interference of different spatial arrangements of plant species in the field.

3.d.1. Additive experiments.

In additive experiments one species (usually a crop or another test species) is planted at constant density, and the competitor species is sown at varying densities (Silvertown, 1982). This allows a comparison of the aggressiveness of different competitors against one indicator species. In general, the yield-density results follow the law of diminishing returns, though total crop loss may occur (Radosevich and Holt, 1984).

Essentially, this design has been used to answer the question of how much crop yield is lost to weed interference (Zimdahl, 1980). The additive design also has been used to establish threshold densities of weed infestation, below which weed damage is not significant (Schweizer and Bridge, 1982). Regression analysis and analysis of variance are adequate ways of analyzing results.

(a) Advantages

The additive design can establish the economical damage from incomplete weed control measures (Spitters and van den Bergh, 1982). It simulates the situation where a crop is planted at one density and is infested by random densities of weeds (Silvertown, 1982).

(b) Disadvantages

Spatial arrangement and species proportion are two variables that are not controlled by this design. It is inappropriate to determine levels of intra- or interspecific interference, or to establish which species is most competitive. Long term conclusions on the result of species interaction are not possible (Radosevich and Holt, 1984; Silvertown, 1982). Spitters and van den Bergh (1982) add that there is no adequate mathematical model available that enables us to make predictions on various competitive situations. Thus, the interpretation of results needs to be done cautiously since they are valid only for a given set of cropping conditions. Broad generalizations should be avoided.

3.d.2. Replacement series or substitute design .

The replacement series design is introduced to overcome some of the limitations of the additive experiments. It accounts for the effects of different proportions in the mixture of species. Conducted and analyzed according to Joliffe (1984), replacement series can separate intra and interspecific effects. This is a most informative design according to Silvertown (1982). In this experiment the proportions of two species A and B in the mixture vary from 0 to 100% while the total density A + B is held constant (Harper, 1977). The total density needs to be sufficiently high to ensure competition (Harper, 1977). According to Radosevich and Holt (1984) total density in replacement series experiments should correspond to the plateau of density-independent biomass yields in a yield-density plot (Fig. 1.). While working with intercroppings however, Spitters (1980) proposes that the total density should be similar to that used by the farmer. Perhaps because these densities may represent the carrying capacity of the environment.

According to Harper (1977), (following de Wit, 1960), four different models depicted by four replacement diagrams illustrate the possible outcome from interference in a replacement series experiment. These models allow the identification of several interactions such as competition for same resources, niche differentiation, antagonism, and others (Fig. 4.).

In addition to the replacement diagrams, the Relative Yield Total index (section 1.e.) is a useful tool to examine data from replacement series, and can help identify resources being competed for under different growing conditions (Hall, 1974). The Relative

Crowding Coefficient (section i.e.) also can be derived from the results of a replacement series experiment to quantify the aggressiveness of one species upon another (Harper, 1977).

(a) Advantages

The effect of species proportion is not confounded with that of density (Silvertown, 1982). This design allows us to find the most logical species proportions for intercropping. One of the main assets of this design, according to Radosevich and Holt (1984), is its predictiveness with regards to species shifts in different agricultural environments. It also provides a reasonable measure of plant interference, allowing the examination of plant interactions in diverse agroecosystems, a useful tool for work with intercropping situations

(b) Disadvantages

One of the problems with this design is that interference is examined at only one constant density, instead of also considering the effect of varying densities (Conolly, 1986; Spitters and van den Bergh, 1982; Huxley and Maingu, 1978).

Other limitations of the replacement series are that only two species can be studied at a time, and effects of spatial arrangements need to be studied in separate experiments. Replacement series experiments may be complicated to set under field conditions, thus being better suited for pot experiments (Radosevich and Holt, 1984). Pots however, force plants to share the same limited soil resources and space. This may not correspond with field conditions where roots can exploit different sections of the soil profile (Harper, 1977).

Joliffe (1984) criticized the conventional analysis of data from replacement series experiments for not properly quantifying the relative contribution of intra- and interspecific interactions to the overall interference. He proposed a new mathematical approach for interpretation of replacement series results. This technique requires additional monocrop density series to be conducted with the replacement experiment.

To develop his analysis Joliffe (1984) used a yield-density relationship in monoculture that linearized with a double reciprocal transformation takes the form:

$$1/Ym = 1/(OBZ)+1/O$$

This expression estimates the asymptotic response of total biomass yield per area (Ym) to changes in the density (Z) of a species in monoculture. The asymptotic maximum yield at infinite planting density is O, and B represents the rate of approach to O. The terms B and O can be estimated by regression.

From the above relationship "projected yields" can be estimated:

$$Yp = OBZ$$

Where Yp is a hypothetical monospecific yield obtained in the absence of intra- and interspecific interference. Projected yields are used to estimate the relative response to intraspecific interference (Rm).

$$Rm = (Yp - Ym)/Yp$$

The relative response to interspecific interactions (Rx) is given by:

$$Rx = (Ym - Yx)/Ym$$

Where Yx represents the biomass yields per area of a certain species growing in mixture with another.

Rm and Rx allow the quantification of the relative importance of intra and interspecific interactions in the competition process.

3.d.3. Systematic designs

In these experiments plant density is systematically changed within a constant spatial arrangement. The original designs were by Nelder (1962) and Bleasdale (1967), and basically involved planting along a series of spokes emanating from the center of a "wheel" (or "fan" if only a section of the "wheel" is considered). The shape of the area around each plant (defined by the position of its neighbors) can be determined (Nelder, 1962; Bleasdale, 1967; Assemat, 1986). These designs have been used mostly to determine the effect of density on intraspecific interference, and to define the best crop planting densities. One can, however, superimpose this design onto a uniform stand of another species (weed or crop) growing as a uniform soil cover, or onto another crop at constant density, such that both species grow in alternate rows ("spokes"). Thus the density of the main crop that results in the most favorable RYT value would be determined (Wahua and Miller, 1978). The crop density that best suppresses a dense stand of certain weed species also can be established.

A variation of Nelder's (1962) design, introduced by Freyman and Dolman (1976), allows the use of straight parallel rows with set widths. This approach is convenient when working with row crops. In all the different versions of systematic experiments, the space per plant changes systematically along each "spoke", or radius, over the whole range of densities. The pattern of spatial arrangement remains constant for all the plants. Often systematic spacing variation is just one factor among others (genotypes, spatial arrangement, level of resources) applied to the whole systematic plots.

Since these experiments study the yield response to changes of a quantitative variable (density), the statistical analysis of the data should be through regression analysis (Mead and Stern, 1980).

Addition series experiments are another systematic approach (in addition to the Nelder experiments discussed) to study plant interactions. The effects of species density and proportion are considered in this approach.

The interpretation of addition series experiments is based on the reciprocal yield law (Spitters, 1983ab; Radosevich, 1987). Using expanded reciprocal yield models, the yield of a species can be estimated from the densities of the other species in mixture (Radosevich, 1987). The expanded reciprocal yield models (Spitters, 1983ab) take the form:

$$1/w_1 = b_{1.0} + b_{1 \cdot 1}N_1 + b_{1 \cdot 2}N_2$$

With w: weight per plant, $b_{1.0}$: inverse of the theoretical weight per plant, N_1 and N_2: densities of species 1 and 2, $b_{1.1}$ and $b_{1.2}$ (regression coefficients) estimate intra and interspecific competitive effects. More species can be incorporated to the model.

The experimental approach consists of systematically varying species densities and proportions. This approach, applied to two species, can be illustrated by the following diagram (from Radosevich, 1987):

	1A	2A	3A
1B	1A:1B	2A:1B	3A:1B
2B	1A:2B	2A:2B	3A:2B
3B	1A:3B	2A:3B	3A:3B

Where A and B are the two species, and 3A:3B is a mixture with total density of 6 and proportion A:B = 0.5:0.5.

(a) Advantages

Systematic designs (Nelder and similars) are useful in screening a wide range of densities within a relatively small area. These designs also can be superimposed to ongoing experiments with plots too small to be split into a wide range of densities. The effect of other factors, such as spatial patterns and resource levels also can be considered.

The value of the addition series approach is that it separates intra- and interspecific competition effects. Competitive ability of the species studied, and degree of niche differenciation also can be estimated (Spitters, 1983ab)

(b) Disadvantages

In general, when row width is allowed to vary as in "wheel" experiments (Nelder, 1962); Bleasdale, 1966), plants remain in the center of a trapezoidal area which may not reflect real field conditions. Spatial relationships are not accounted for by the addition series approach (Radosevich, 1987).

The lack of randomization within the systematic density series complicates the statistical interpretation of results (Mead and Stern, 1980).

4. Growth analysis

Plant growth analysis is a technique that separates growth into functional and structural components. It allows the study of physiological and morphological responses to different growth environments (Ledig, 1974). These responses, when related to final crop yield, provide an analytical framework to understand yield variations in terms of growth parameters.

When growth rates under diverse environmental extremes (humidity, temperature, light, and others) are compared, it is possible then to predict, for a set of environmental conditions, which species will become dominant, or when will a weed turn problematic (Patterson, 1982). Studying the growth in mixture of two different species, allows us to understand the factors involved in the competitive success of a given species (Radosevich and Holt, 1984). Plant growth analysis may help understand the response of species in mixture to different levels of competition.

Sequential sampling of plant material allows calculation of several growth parameters. Some of the most relevant of these parameters (Ledig, 1974; Hunt, 1982) are:

LAI: Leaf Area Index, is the dimensionless measure of photosynthetic area expanded over a given land area (Harper, 1977). It expresses also the mean crop leafiness in relation to land surface and, provides an idea of the functional size of a crop (Hunt, 1982)

LAR: Leaf Area Ratio, a morphological parameter expressing amount of leaf area per unit of plant biomass (dm^2/g of total weight). Measures relative leafiness of plants

NAR: Net Assimilation Rate, represents the photosynthetic efficiency of the plant (the rate of plant material produced per unit leaf area). Is expressed in g/dm^2/week. Is a physiological index.

RGR: Relative Growth Rate, the most important index of productivity, and measure of total growth per plant over time, usually expressed as g/g/week. This index integrates the morphological and physiological concepts of LAR and NAR respectively. (Radosevich and Holt, 1984)

In agriculture, or when the productivity of vegetation is considered, growth analysis data are not expressed on a "per plant basis". Instead, the crop or plant community under study is considered as a functional unit and growth analysis results are expressed on a "per crop or unit land area" (Hunt, 1982; Patterson, 1982). Thus, we have:

CGR: Crop Growth Rate, used instead of RGR, can be expressed as g biomass/m^2land surface/week.

According to Hunt (1982), crop growth rate has two components, namely the leaf area index (morphological component) and the net assimilation rate (physiological component). Primary growth analysis data can be subjected to function or curve fitting. According to Hunt (1982) this would be a "functional approach" to growth analysis. The fitted function would then be used to derive the growth analysis quantities described above.

MATERIALS AND METHODS

Several field experiments were conducted under sprinkler irrigation at two experimental locations in the Willamette Valley: The Oregon State University Horticulture and Hyslop Agronomy farms both near Corvallis, Oregon. Soils data for each location are summarized in Appendix table 1. Sweet corn (*Zea mays* L. var. "Golden Jubilee") and white clover (*Trifolium repens* L. var. "New Zealand") were used in all the experiments.

1. Sweet corn density and distribution in the presence of a living mulch.

The effect of corn densities and planting pattern on the yield of sweet corn growing in association with white clover was assessed in the O.S.U. Horticulture farm. The four experimental treatments consisted of combinations of high and low sweet corn densities with two row spacings. Thus four planting patterns of sweet corn were evaluated (Table 1).

Plots were 6 by 10 m, and treatments were arranged in a randomized complete block design with four replications. Sweet corn was planted 2-cm-deep into a 10 to 15-cm-wide tilled band in a mowed 2-year-old white clover sward. Corn planters (John Deere Flexiplanter 70), mounted behind the tiller, delivered the seed as the planting band was tilled. The experiment was conducted under sprinkler irrigation in 1984 and 1985. The sequence of tillage, planting, clover suppression, and fertilizing operations are shown in Table 2.

To determine the effect of clover interference on corn growth, corn plants were sequentially sampled for growth analysis in both growing seasons. The sampling schedule in 1984 was: July 15, July 30, August 14, August 28, and October 29, and in 1985: June 28, July 19, August 6, and September 27. Total above-ground biomass of two representative corn plants per plot was harvested at each sampling date, and leaf area and dry matter were determined for each plant (plants were dried for 5 days at 70 C and weighed). Relationships between these data and (a) yield of sweet corn ears, and (b) clover growth were studied. Weights of vegetative and reproductive components of corn plants obtained from the last sample date were used to determine differences in dry matter allocation patterns. Mean crop growth rate (CGR) values were obtained, using the equation:

$$C_{1-2} = \frac{W_2 - W_1}{T_2 - T_1}$$

where C is mean crop growth rate between the first and second sampling dates. W_1 and W_2 are plant dry weight values/unit surface area at times 1 and 2, and T_1 and T_2 indicate the boundaries of the time intervals. Hunt (1982) considers this to be an adequate index to express the behavior of plant communities, such as monocultures and intercrops, when they are considered as single functional units. In tilled and clover-covered plots (with 76-cm rows), three gypsum blocks were buried 20 cm deep, next to a corn plant. Soil moisture was periodically monitored with readings from the gypsum blocks with a KS-1 Delmhorst soil moisture tester.

Foliage growth of clover also was sampled in 1985 by clipping a 18 by 50 cm area between sweet corn rows. The clover samples were dried for 3 days at 70 C. Clover sampling dates were July 19, August 6, and September 15. On July 25, high contrast photographs of the corn canopy were taken (Kodalith orthofilm 6556 type 3) with a 7.5 mm fisheye lens mounted on a 35 mm camera. The camera was placed on the ground at the center of each plot, pointing skyward. The resulting high-contrast slides allowed estimates of percent canopy coverage of the area between the corn rows (Chan et al., 1986).

On October 24, 1984, and September 16, 1985, when corn moisture was 72%, ears with husks were harvested from three 1 meter sections of row per plot. Only ears with husks longer than 15 cm were harvested. The fresh weight of harvestable ears was determined.

2. Conventional vs. mulch systems

The effect of a clover mulch on sweet corn productivity was studied in 1984 and 1985. The treatments were:

(a) Conventional surface tillage with a rotary tiller (1984) or a mouldboard plow (1985). Sweet corn (66,000 plants/ha) in rows 76 cm apart was planted with John Deere Flexiplanter units.

(b) Same row width and density of sweet corn as (a) planted into a herbicide-suppressed (2-year-old) white clover sward.

(c) Sweet corn (79,000 plants/ha) seeded into herbicide-suppressed clover in 38 cm rows. This treatment was added in 1985 to determine the effect of a different planting pattern on sweet corn yield and clover growth. However, the planting procedure also resulted in a density of corn plants that was 1.26 times larger than that in the other two treatments.

In treatments (b) and (c), corn was seeded in a band tilled in the clover sod as described for experiment 1.

Timing and procedures for tillage, planting, clover suppression, biomass sampling, irrigation, fertilization, and harvest were the same as in the preceding experiment (Table 2), except for growth analysis sampling which was omitted on July 19, 1985.

In 1984, young and mature leaves of corn were sampled at 33, 48, and 115 days after planting and analyzed for N, P, K, and S at the Oregon State University Plant Analysis Laboratory. All the above-ground biomass of corn plants sampled 119 days after planting was analyzed for nutrient content in 1985. The experiment was conducted on the Chehalis silty clay loam soil (Appendix table 1.).

3. Density experiments

Systematically increasing sweet corn densities were planted in 1985 into a suppressed clover sward. This procedure was used to assess the intraspecific effect of different densities and spatial arrangements on corn productivity under a constant influence of a background level of white clover competition.

3.a. A fan design (Bleasdale, 1967; Nelder, 1962) was used in which corn was planted in rows that radiated from a point (Fig. 5). Distance between plants along the rows decreased systematicaly towards the point of origin. Each corn density occupied a concentric arch (Fig. 5). Although the density changed among arches, the geometry of plant arrangement (almost square) remained constant (Fig. 5).

Four sets of twelve densities (arches) occurred within 7 m by 5 m plots placed at different orientations in a 3-year-old white clover field. Clover was mowed and a 10 cm planting band was tilled over each arch with a rotary tiller. Corn was hand planted on June 23, 1985, into the tilled band. Fertilizer (30 kg N/ha and 68 kg P/ha) was broadcast over the plots on June 30. Clover regrowth was suppressed on July 1 by a combination of atrazine plus crop oil (1.5 kg ai/ha plus 2 L/ha). On August 9, 90 kg N/ha were applied. Five plants per density (arch) were harvested (October 23) when kernel moisture was 70%, and the weight of ears with husks (more than 15 cm long) was recorded. One arch at either extreme of the plots was discarded as a border row. In each plot, the above-ground biomass of one representative plant was sampled from each of five densities. The sample was dried (70 C for 3 days)and weighed. The density range harvested was from 25,000 to 173,000 plants/ha.

3.b. In a second experimental arrangement, the design of Freyman and Dolman (1971) was used. The density varied systematically while the row width was held constant in each plot (Fig 6). Thus a sequence of 11 densities (25,000 to 172,000 plants/ha) was planted in 11 parallel rows (76 cm apart) placed in each of four 8 m by 7 m plots. The plots were established at different orientations on a 3-year-old white clover sward. Planting, fertilizing, clover suppression, and harvesting were conducted as in experiment 3.a.

Most of the white clover in both experiments was killed by the atrazine-crop oil treatment. The experiments were conducted on the Chehalis silty clay loam soil. The results from both systematic experiments were statistically analyzed by regression.

4. Nitrogen release

An experiment was conducted in 1985 on the Woodburn silty loam soil (pH = 6, 25 g/kg organic matter, 122 mg P/kg, 254 mg K/kg, and 10.5 mg S/kg) to observe the magnitude of nitrogen released into the soil by a chemically-suppressed white clover sward. The 4 by 6 m plots were arranged in a split-plot design with randomized complete blocks. Main-plot treatments were: (a) combination of atrazine, 1.5 kg ai/ha plus crop oil 2 l/ha sprayed in 300 l water/ha over a 2-year-old white clover sward, and (b) the clover sward unsprayed. Atrazine was sprayed on June 4.

At each sampling date (subplot), five soil samples per plot were obtained with a core sampler (diameter = 2 cm) at depths of 0 to 30 and 30 to 60 cm. Each sample was analyzed for NO_3^- and NH_4^+ at the OSU Soil Science Laboratory. Soil was sampled on June 5, 17, and 28, July 11, and August 1, 1985.

5. Replacement series experiments

The objective of the replacement series experiments was to observe: (a) if corn and clover competed for environmental resources, (b) if competition was avoided by differences in resource demands, or use between the species (niche differentiation), (c) if yields were depressed by factors other than competition, and (d) the relative contributions of intra- and interspecific competition.

Two replacement series experiments were performed with corn and clover:

5.a. Field experiment.

This experiment consisted of five treatments: two monocultures and three mixtures of both species at 75:25, 50:50, and 25:75 ratios (Figure 7). Plant densities in monoculture were 2,000 plants/m^2 of corn and 10,000 plants/m^2 of clover. These densities were considered equivalent since it was estimated that one corn plant could replace five of clover. The total density in the mixtures was constant and equivalent to 2,000 plants/m^2 of corn (or to 10,000 plants/m^2 of clover). Since the replacement-series approach relies on density-independent yields (Radosevich and Holt, 1984), the total density in this experiment was determined assuming it would be within the range for constant final yield (Harper, 1977). Density series of corn and clover in monoculture also were conducted.

The plants were grown in the field in plastic pots (33 cm in diameter and 40 cm deep), filled with Chehalis silty clay loam soil (pH = 6.5, organic matter = 37 g/kg, 29 mg P/kg, 163 mg K/kg, 4.1 mg S/kg). Sprinkler irrigation was provided, and soil temperature was monitored (10 cm deep) in the ground and in the pots with thermisters connected to a CR5 Digital recorder.

White clover "New Zealand" was planted August 15, 1985. The seed had been previously inoculated with 13 g per pot of commercial Rhizobium inoculant suspended in 250 ml of water. On September 3, sweet corn "Golden Jubilee" was planted with clover (first trifoliolate leaf stage). The delay in planting allowed clover to develop some biomass before being overtopped by the rapidly growing corn plants, thus ensuring opportunity for mutual interference.

On October 12 (59 days after planting clover, and 39 days after planting corn), all the above-ground biomass was clipped from the pots. In the mixtures, corn and clover were separated, and the samples were dried (70 C for 3 days), and weighed.

5.b. Growth-chamber experiment.

Plants were arranged in 10 by 10 cm plastic pots filled with 847 g of greenhouse soil (pH = 6.5, 10 mg P/kg, 94 mg K/kg, 13 meq/100 g Ca, 8 meq/100 g Mg, 0.36 meq/100 g Na, 17 g/kg organic matter, and 21 meq/100 g cation exchange capacity). The pots were placed in a growth chamber set at a day/night temperature of 27/10 C, and on a daily photoperiod of 14 h with a light intensity of 1300 $\mu E/m^2/sec$. A thin, vertical aluminum plate, 10 cm wide and 20 cm tall, was placed between corn and clover to prevent canopy interference for light. The diffuse light of the growth chamber and daily rotation of each pot minimized possible differential shading by the plate.

The series consisted of two monocultures (at the same densities as in the first experiment) and 4 mixtures at 80:20, 60:40, 40:60, 20:80 ratios. The treatments were replicated 3 times. The pots were completely randomized in the chamber, and rerandomized four times during the experiment. Clover was inoculated, and it nodulated well.

Clover emerged on February 3, 1986, and corn was planted 24 days later when clover was 4 cm high. Twenty mg N/kg of soil were applied in each pot 16 days after planting corn. This application, however, was exposed to leaching by the overhead irrigation.

The experiment was harvested 53 days after planting clover (29 days after planting corn). Corn and clover top growth was clipped, and the species were separated, oven dried (70 C for 4 days), and weighed.

In both experiments, the conventional analysis (Fig. 4) of the data (Harper, 1977) involved Relative Yields (RY) that were calculated as follows:

$$RY_A = \frac{\text{Yield of A in mixture}}{\text{Yield of A in monoculture}}$$

Regression equations were fitted to the (RY) data and departure from the "expected yields" (diagonal lines) was observed. The "expected yields" are hypothetically obtained when the interference between two species is equivalent; ie, when intra and interspecific effects are equal for either species. Relative Yield Totals[3] were estimated using the regressions fitted to relative-yield data. A regression curve was fitted to the RYT points. RYT data were interpreted according to Harper (1977).

[3] Section 1.e. of the Literature Review.

The data also were subjected to the analysis proposed by Jolliffe et al. (1984). This procedure allows intra and interspecific competitive effects to be estimated. An asymptotic function was fitted to yield-density data from the monoculture series. This function takes the following linear form:

$$1/Ym = 1/OZB + 1/O$$

Where Ym is vegetative yield per land area in monoculture as planting density (Z) increases. The maximum yield at infinite Z is the asymptote O, and B is the rate at which yields approach O with increasing density . The estimation of the parameters in the above equation by linear regression allowed the calculation of "projected yields" (Yp) that are hypothetical monoculture yields in the absence of intraspecific interference:

$$Yp = OZB$$

Yp and Ym allowed the quantification of relative intraspecific responses (Rm):

$$Rm = (Yp-Ym)/Yp$$

With data from the replacement series, the response to interspecific competition (Rx) was quantified by:

$$Rx = (Ym-Yx)/Ym$$

Where Yx are biomass yields of one species growing with another.

Rm and Rx were calculated from regressions fitted to Ym and Yx data.

Rx and Rm values were finally plotted in a modified replacement series diagram.

6.- Nutrient extraction.

Foliar samples of corn growing in the field, with or without a clover mulch, were subjected to total Kjeldahl and spectrometer analysis by the Plant Analysis Laboratory at Oregon State University. Thus N, P, K, and S tissue concentrations were determined.

RESULTS AND DISCUSSION

In 1985, corn yields in the conventional experiments[4] were 30% larger than in 1984. Higher fertilization rates at seeding time and better irrigation in 1985 may partially account for these higher yields. However, the response pattern to the treatments imposed was the same in both years.

Tables and figures follow the discussion of each of the following topics.

1. Response of sweet corn to intercropping with clover, and to different seeding densities and planting arrangements in the presence of clover.

When corn rows were 76 cm apart, clover interference depressed the growth rate of corn by 67% (Table 3a) and reduced ear yields by 32% (Table 4a)[5], compared to corn growing without clover. Competition for water and nutrients is usually involved in such yield reductions according to Altieri and Liebman (1986). Clover regrowth after suppression treatments apparently competed with the corn.

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[4] Systematic and replacement-series experiments are not considered here.

[5] Data from 1985, in Table 4a, are averages over two locations. In one such location a 12% yield reduction by clover interference was not significant ($p>0.05$). However, when data from both sites were averaged, clover had reduced corn yields significantly ($p<0.001$).

Spacing between adjacent corn plants in narrow rows was approximately 1.7 to 2 times greater than among plants growing in 76-cm rows (Table 1). Corn developed its highest leaf area indices (Table 5) in the larger spacings (within rows) of the low rectangularity[6] arrangements obtained with the 38 cm rows (Table 1). The 38-cm rows also caused a more complete canopy closure over the ground compared to the 76-cm row planting arrangements (Table 6). The clover mulch grew less under corn in narrow rows than under corn in the wide-row planting arrangement (Table 4). Consequently, suppression of clover growth was directly related to the development and spatial distribution of corn canopies. This observation has management implications, since the reduction or absence of clover growth increased corn yields (Table 4).

Comparing similar corn densities, Harper et al. (1980) also found less living mulch (Festuca arundinacea Schreb.) growth when corn was planted in narrow rows rather than in wide rows. Corn spacing in the row was greater (2x) in the narrow rows than in the wide ones. High solar radiation interception by corn canopies was suggested as an important factor in suppressing fescue (Harper et al.1980). Weed suppression by shading with corn has been reported (Ghafar and Watson, 1983). However, when shading is intense, a legume mulch may fix less nitrogen. Wiese et al. (1964) observed that for a given sorghum crop density, best weed suppression was obtained with narrow-row planting. Intraspecific interference, therefore, can be

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[6] Rectangularity = row width/distance between rows. A square distribution (Rect. = 1) is close to ideal for most crops (please refer to the literature review).

decreased with such planting arrangements, allowing the crop to compete better with weeds (Altieri and Liebman, 1986; Fischer and Miles, 1973; Spitters and van den Bergh, 1982).

Compared to the standard 76-cm row planting, using a narrow-row (38 cm) arrangement of sweet corn plants growing with a clover sward increased the average corn yield and crop growth rate by 71 and 34 %, respectively (Tables 3 and 4). When corn was planted in a clover mulch at the conventional density (66,000) and row width (76 cm), its growth rate was lowest (Table 3). The 38-cm row spacing allowed sweet corn yields in the clover mulch to be as high as in the conventionally tilled plots in the absence of clover (Table 4a).

Ear fresh weight per plant and the number of marketable[7] ears per plant increased by 20 and 16 % when 38-cm rows were used instead of 76-cm rows (Table 7a). However, these trends were not statistically significant ($p > 0.05$). In Table 7b, the above trends were confirmed and were statistically valid ($p < 0.05$) for the low (66,000 to 79,000 plants/ha) and high (131,000 plants/ha) densities. These results suggest that for a given density, the narrow row arrangement tended to stimulate greater ear production per plant.

Because corn plants had more space within the 38-cm rows than in the 76-cm-row arrangement, intraspecific interference was reduced thus explaining the increased production per plant (Brown et al., 1970). Corn plants presumably were able to explore a larger portion of the

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[7] Marketable ears were defined as those longer than 15 cm.

growth environment and increased resource capture, thus becoming more productive and more effective at suppressing clover than plants grown in wide rows. This narrow-row effect on corn productivity also has been observed in sweet corn growing in the absence of a living mulch (Mack, 1972).

In Table 7a, the lack of significance in the differences between treatment means possibly resulted from gaps in the clover cover and variability in corn stands (due to plant emergence problems and slug damage). These gaps may have somewhat reduced intra- and interspecific competitive pressure, thus lessening differences between treatments in this experiment.

In summary, the higher corn yields that were obtained with narrow rows rather than wide rows (Table 4), for both densities, resulted from:

(a) a higher number of plants in the narrow rows than in the 76 cm rows (79,000 and 66,000 plants/ha, respectively) when the low densities were used,

(b) tendency towards increased ear production per plant, and

(c) more complete ground cover (Table 6) and clover suppression (Table 4) from the favorable canopy distribution in the low rectangularity arrangements (Table 1) and increased plant leafiness (Table 5b, high density)[8].

Within each row width (38 or 76 cm), doubling the sweet corn density (131,000 plants/ha) did not improve corn yields. This result occurred (Table 4b) because plants were more crowded, producing smaller ears and lower ear weight per plant than at the low density (Table 7b). According to Duncan (1975), high intraspecific interference at high densities can reduce corn yields and increase the number of sterile plants. Using the high density instead of the lower one did not improve clover suppression within each row spacing (Table 4b). The high density with 76-cm rows still left a high percentage of the ground uncovered (Table 6), allowing abundant clover growth (Table 4b). High densities merely increased crop plant crowding within rows (Table 1). It seems that increases in plant density should be accompanied by a spatial arrangement of plants that also reduces rectangularity.

[8] Wide and narrow rows have essentially the same number of plants/ha at the high density. Therefore differences in LAI between row widths represent differences in leafiness of single corn plants.

The pattern of corn dry matter partitioning into vegetative and reproductive growth did not vary with the presence of clover (Table 8a), or with different densities and planting arrangements (Table 8b). Under the pressure of interference, there was no indication of a preferential allocation of carbohydrates to sustain ear growth at the expense of vegetative growth as has been reported for other crops (Pons and van Wieringen, 1985). Interference reduced ear weight in the same proportion that it lowered the weight of other plant parts. This stability in the harvest index of corn growing under interspecific interference also was observed by Francis et al. (1978).

Consistent soil moisture differences between corn growing alone or with a clover mulch could not be detected at 20 cm soil depth (Fig. 8). Measurements at higher depths may be required to establish differences in water uptake by corn growing with or without a living mulch of clover.

Data from the previous field experiments were analyzed by regression to determine how variations in corn biomass and leaf area affected corn yield and clover suppression. These relationships suggested criteria to manage this intercropping system.

Regression analysis demonstrated that the largest and most clover-suppressive plants corresponded to the narrow row treatments (Fig 9a). These plants also had developed the highest leaf area indices (Fig. 9b). The highly significant relationship between corn yield per hectare and its LAI followed an asymptotic trend, where the rate of yield increase with LAI diminished after a somewhat sharp initial phase (Fig. 10c and d). A similar pattern was observed for the effect of leaf area per plant and plant biomass on the yield of single corn plants (Fig. 10a, b, e and f). The number of marketable ears per plant also was asymptotically related to corn biomass (Table 9).

The reduction in the rate of yield increase with LAI when vegetative growth is large, may result from increased self-shading among corn plants, intra-plant competition (vegetative vs. reproductive), or intraspecific canopy interference. Duncan (1975) found that corn yields increased with LAI until a plateau occurred when light interception by the canopy was essentially complete. Little increase in photosynthesis per unit area was possible beyond the point of complete light intercepcion. Further LAI increments usually resulted in barren plants and yield reductions (Duncan, 1969 and 1975).

Increasing the size and leafiness of corn plants, and raising corn densities will increase corn LAI. Canopy coverage of the ground would then be high, which could be an effective management measure to depress clover growth and its competitiveness. Under the conditions of this experiment, yields were not reduced by high LAI.

Stepwise regression[9] identified two variables important in determining corn yields in 1984. Leaf area per plant and corn biomass contributed significantly to a model, and accounted for 78% of the yield variability of corn growing with a clover mulch (Table 10). The significant variables in a similar model constructed from 1985 data were canopy ground cover, corn biomass, and clover biomass. In this model, the regression accounted for 87% variation in corn yield in presence of a clover mulch (Table 10). No other variables made a significant contribution to either model.

The purpose of the stepwise analysis was to identify management alternatives to maximize corn yield in the presence of clover. Therefore, correlated variables were not eliminated from the model since they represent different management options. The presence of colinearity, however, is a problem in predictive models when it modifies the regression coefficients (Neter and Wasserman, 1974).

In 1985, the stepwise regression procedure first selected the variable ground cover since it made the best contribution in terms of explaining yield variation. The reason that its contribution was more meaningful than that of corn leaf area or leaf area index may be that ground cover integrates more than one variable. Ground cover not only involves plant leafiness, but also the additional effect of row width which determined spatial canopy arrangements. The variable clover growth (or suppression) also was less meaningful than corn

9 Models with high coefficients of determination (R^2) and with low mean square errors.

ground cover to the regression model. Therefore, ground cover seems to imply something more than just shading and clover suppression. Ground cover also involves a certain planting arrangement capable of affecting the growth of corn. Consequently, chemical clover suppression, as a single management measure may not be able to provide highest corn yields, unless a favorable planting arrangement (as provided by the row width component of ground cover) is used. The planting arrangement should not only suppress clover, but also promote the growth of individual corn plants. It is clear, however, that clover suppression by chemical or competitive means is a key aspect for corn production in this system.

The field experiments previously discussed demonstrate that planting arrangement can be a practical tool to regulate crop and mulch growth. Within the range of treatments and growing conditions of these experiments, management to increase corn growth and leaf area should result in higher corn yields. The growth-yield response would follow an asymptotic trend.

2. Density experiments using systematic designs

Sweet corn, in a series of systematically arranged populations, was grown in a dead clover mulch. Two different planting arrangements were used. Sweet corn in an almost square or nearly equidistant planting pattern (Fig. 5), with a rectangularity[10] of 1.05, yielded more than when seeded in rows 76 cm apart (Fig. 11). In the row pattern, rectangularities ranged from 1.4 to 10.0 (Fig. 12.)

These experiments were well fertilized and irrigated. Therefore, light apparently was a main factor of intraspecific competition. Sweet corn plants seeded in wide rows (76 cm apart) were more crowded within the rows than when arranged equidistantly (Fig. 12). Therefore, plants in wide rows could have been at a disadvantage for light capture with respect to those in a more uniform planting pattern. Intraspecific interference among corn plants increased with density, and curvilinear yield-density relationships developed (Fig. 11). As densities increased, intraspecific interference within the wide rows depressed yields more than in the equidistant arrangement (Fig. 11). This observation agrees with Brown et al. (1970).

It can be concluded from Figure 11 that the yield advantage under the nearly equidistant arrangement must be related to better ear

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10 Rectangularity = length / width of a rectangle, where length refers to the distance between crop rows and width is the spacing between plants in the same row. For a given plant density, plants are almost equidistantly spaced when rectangularity equals 1, as opposed to a high rectangularity where row spacing is wider and plants are more crowded in the rows.

development per plant than that obtained with wide-row spacing. In spite of the variability, data in Figure 13 were best described by two statistically different ($p < 0.05$) regression lines. These curves suggest that high intraspecific interference in the rectangular planting (76-cm rows) may have lowered the assimilate distribution into secondary ears, thus increasing the proportion of small (non-marketable) ears. With a nearly equidistant plant spacing, however, the proportion of marketable ears was higher than in the rectangular planting (Fig. 13). Since crowding among almost equidistant corn plants was less than among those within wide rows, more light for photosynthesis, and less root interference could have favored ear growth in the equidistantly spaced plants.

However, it is not clear why the percentage of small ears decreased at corn densities higher than 120,000 plants/ha when using equidistant planting, unlike the wide-row arrangement response (Fig. 13). The variability of the data collected may be related to this effect.

A yield decline at high corn densities, as noted by Harper et al. (1980), by Moss and Mack (1979), and by Donald (1963) (Fig. 3), was not observed in these systematic experiments (Fig. 11). Yield reductions may occur when intense intraspecific competition at high densities reduces dry matter accumulation and increases corn sterility (Duncan, 1969 and 1975). Ghafar and Watson (1983), working with field corn, observed a linear relationship between corn yield and densities as high as 130,000 plants per ha. In the systematic experiments, nitrogen may have been released into the soil from the dead clover, providing an extra source of fertility (Vrabel, 1982) to support ear growth. Thus, some high density yield depressions may have been mitigated. Similarly Lang et al. (1956) observed that fertilizing with nitrogen reduced the decline of corn yields at high densities. It is also possible that intraspecific competition in the sweet corn variety used in the systematic designs may not have been intense.

In other experiments of this thesis, yields of corn planted with a living clover mulch did not change when corn density rose from 66,000 to 131,000 plants per ha (Table 4). However, corn yields in the systematic experiments (no clover) were significantly higher at 131,000 plants per ha than at 66,000 plants per ha (Fig. 11). Only intraspecific competition occurred in the systematic experiments. However, when corn grew with a clover mulch and its density increased from 66,000 to 131,000 plants per ha, it suffered interference from clover and from itself. The added effects of intra-and interspecific competition could explain why corn yields in the presence of clover leveled (Table 4), while corn yields in the systematic experiments (no clover competition) always increased with density (Fig. 11).

The systematic designs used in these experiments should further be conducted in the presence of a living clover mulch, as originally intended. Information on clover growth suppression by different corn densities could thus be obtained.

3. Replacement Series

Results from two replacement series experiments were analyzed following the conventional approach of Harper (1977), and de Wit (1960), and the methodology of Jolliffe et al. (1984).

3.a. Experiment with pots in the field

Small soil temperature differences existed between the pots and the field. The average soil temperature difference was 1.2 C (SE=1.5).

3.a.1. Conventional analysis

The interpretation of replacement series experiments is based on comparing the relative yields of each species to the diagonal lines of "expected yields" (Harper, 1977; Willey, 1979) in the replacement diagrams (Fig. 14). The "expected yield" lines represent situations where two species have equivalent intra- and interspecific competitive ability (Harper, 1977; Willey, 1979). If individuals of each species are equally competitive, they should substitute for each other in the mixture. Therefore, contribution of each species to final yields would be linearly related to species proportions in mixture (Harper, 1977), and plot as diagonal lines in the replacement diagram. The diagonals would be equivalence lines. Deviations from "expected yields" are interpreted as resulting from unequal competitive ability (Jolliffe et al., 1984; Willey, 1979)

The regression lines that best described the relative-yield data in Fig. 14a departed from the lines of equal interference. This departure from linearity indicated that unequal interference existed between corn and clover. Since the growth of clover was enhanced while that of corn was depressed (Fig. 14a), clover was considered to be the superior competitor for the same limiting resources as corn.

Competition for soil factors and light may have been more intense than for water because the experiment was irrigated. Clover shaded the emerging corn plants considerably, thus competition for light seemed most relevant during this experiment.

The relative yield total (RYT) of two species in mixture is obtained by adding the relative yields[11] of each species. A species competing successfully with another will preempt resources and increase its yield (relative yield) as much as the other species' relative yield is reduced. This concept occurs when RYT = 1 (McGilchrist and Trenbath, 1971), which indicates that two species compete for the same resources (Harper 1977)[12]. However, the RYT line in Figure 14a. departs from linearity (significant quadratic coefficient) indicating an RYT > 1 for all the proportions. This result suggests, according to Harper (1977) and Spitters (1980), that the two species partially avoided competition. A possible mechanism of competition avoidance could have involved some degree of niche diversification (Harper, 1977), in which case, clover could have had somewhat different resource requirements than corn or an independent source of one or more of the resources under competition. The fact that clover can

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11 Refer to Materials and Methods.
12 Refer to section 1.e. of the Literature Review.

utilize atmospheric nitrogen supports this idea. Clover also could have excreted nitrogenous compounds from its roots (Vrabel, 1980) that benefited corn to some degree. It can be concluded that the relationship between sweet corn and white clover was competitive (according to the relative-yield lines in Figure 14a). It also involved some mechanism of resource acquisition not subject to competition. The species thus seemed partly competitive and partly indifferent (Spitters, 1982).

3.a.2. Components of interference.

Jolliffe et al. (1984) proposed an alternative interpretation for replacement series results. In this approach, the importance of intra- and interspecific interference is quantified for the different proportions of the two species in mixture.

In Figure 15, Rm and Rx represent the response of a species to intra- and interspecific competition, respectively. Clover yield-density data could not be fitted to an asymptotic function, therefore Rm for clover was not calculated. The relative mixture response (Rx) varied with species proportions in the mixtures (Fig. 15b). The monoculture response of corn increased with density (Fig. 15a).

When the proportion of clover in the replacement mixtures increased, the interspecific effect of clover on corn growth also increased. When the proportion of clover declined the interspecific effect of corn on clover biomass yield increased (Fig. 15b).

From the conventional analysis of the replacement series (Fig. 14a), it was inferred that white clover was the superior competitor over the whole range of proportions. However, Jolliffe's analysis indicates that the interspecific influence of clover on corn yield becomes stronger than that of corn on clover yield only at clover proportions higher than approximately 35%. At less than 35% clover, the effect of corn competition on clover was highest (Fig. 15b). Consequently, more than approximately 35% clover was necessary for this species to behave as a superior competitor according to the analysis proposed by Jolliffe et al. (1984).

The partial discrepancy with the conventional interpretation of replacement series may be related to the different meaning that relative-yield lines (Fig. 14) and Rx lines (Fig. 15b) have. Relative yields represent the outcome of total competition, while Rx refers only to the interspecific component of interference. The outcome of total competition can not easily be inferred from Jolliffe's diagram (Fig. 15).

3.b. Growth chamber experiment

3.b.1. Conventional analysis

The replacement series experiment conducted in a growth chamber suggested that the two species were not competing for the same resources (Fig. 14b). The RYT line in Figure 14b departed from linearity indicating an RYT > 1 for all proportions. Clover in mixture with corn grew more than expected without depressing the relative yields of corn (Fig. 14b). These results could be interpreted as a commensalistic effect (Silvertown, 1982) where clover used resources derived from corn or from a corn-modified environment. However, as discussed for the field experiment, clover and corn may have escaped competition through some degree of niche diversification[13] (Radosevich and Holt, 1984; Harper, 1977). Figure 14b also supports this idea.

The experiment was irrigated and the canopies of corn and clover within the pots were separated by a vertical plate to avoid mutual shading[14]. Therefore, if there was any competition it presumably involved nutrients. Competition for nutrients must have been weak, however, since neither species experienced growth depression while growing in mixtures (Fig. 14b). This observation could be related to relatively low nutrient requirements by the still small plants of this experiment.

When competition for light was avoided in the growth chamber, the negative effects of interference seen in the field experiment (Fig. 14a) were removed (Fig. 14b). This suggests that light was a key factor of competition when corn grew in pots in the field in mixture with clover.

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13 According to Harper (1977) niche diversification occurs in a mixture of species when one or more species do not make heavy demands on the resources needed by the other(s). This process is also called annidation.

14 Shading effects by the plate were minimized (refer to materials and methods).

3.b.2. Analysis of interference components.

When data from the growth chamber experiment were interpreted as proposed by Jolliffe et al. (1984), clover response to interspecific competition (Fig. 16b) was similar to its response when growing in pots in the field (Fig. 15b). As in the field experiment, the yield-density response of clover was not asymptotic within the range of densities studied. Therefore Rm values for clover could not be calculated according to Jolliffe et al.(1984). The relative monoculture response of corn varied slightly with density (Fig. 16a).

Relative effects of interspecific interference (Rx) on both species were lower in the growth chamber than in the field pot experiment (Figs. 15b and 16b). This effect appeared to be related to a reduction in competition for light when canopy shading between species was avoided. The low response of corn to clover competition changed little over the range of proportions (Fig. 16b).

These results support the conventional replacement series diagram where neither species in the growth chamber had yields reduced by competition below the " expected yields" (Fig. 14b).

Clover Rx was higher than corn Rx at clover proportions less than 40%, in spite of the avoidance of interspecific competition for light (Fig. 16b). This observation suggests that even if light played an important role in defining competitive relationships in this system, it was not the only limiting factor under competition.

Reduction of relative response to interspecific competition in the growth chamber (where interspecific competition for light was minimized) was larger for corn than for clover, compared to the field experiment (Fig. 15b and 16b). This observation suggests that corn was the poorest competitor for light. Intraspecific stress on corn also was reduced in the growth chamber with respect to the field experiment (Fig. 16a). Such reduction can not be explained by the avoidance of interspecific interference for light in the growth chamber. Corn plants in the growth chamber were slightly etiolated and were harvested ten days earlier than in the field pots where plants exhibited normal growth. Interference for light among the slender corn plants of the growth chamber may have been less than in the field. Also, the duration of the experiment may have been short for the development of robust intraspecific interactions in corn.

The total densities of the experiments were below the point of constant final yield or density-independent yields (Harper,1977). Roush et al. (1988)[15] found significant effects of density on the yield response to different proportions by species in mixture.

3.c. Comments on the two interpreting approaches.

The alternative analysis of replacement series experiments proposed by Jolliffe et al. (1984) generally agreed with the conventional

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15 Roush, M.L, S.R. Radosevich, R.G. Wagner, B.D. Maxwell, and T.D. Petersen. A comparison of methods for measuring effects of density and proportion in plant competition experiments. Department of Crop Science and Department of Forest Science, Oregon State University, Corvallis, Oregon. Paper submitted for publication to Weed Science.

interpretation (Harper, 1977; Willey, 1979). Jolliffe's approach provided a quantitative assessment of the effect of species proportions on intra- and interspecific components of competition. The conventional replacement series diagram depicted the outcome of competition, and its interpretation provided a rather qualitative, but useful, description of general competitive relationships.

Jolliffe's approach showed that clover in the field experiment was affected by interspecific competition from corn (Fig. 15b). This cannot be concluded from the conventional replacement diagram (Fig. 14a). Similarly, in Figure 14b, interspecific competitive interactions are not evident as they are in Jolliffe's analysis (Fig. 16b). Recognizing these kinds of interactions is relevant to developing strategies to select the most compatible mixtures.

In Jolliffe's approach, intraspecific effects (Rm) are one component of the total competition in the mixture of species (Jolliffe et al., 1984). In Jolliffe's analysis, intraspecific effects are nevertheless measured in monoculture, not on plants under intra- and interspecific interference, as it occurs with plants in mixtures (Jolliffe et al., 1984). The intraspecific response determined for a given species in monoculture may not be the same as the real intraspecific response occurring in a mixture with the same species and density. In mixtures, intraspecific shading could be interrupted or altered (quality of light) by the interposition of plants of another species. Intraspecific root contact may be reduced when plants of another species grow in the same space. Therefore, Rm and

Rx may not always be components of the same process given that Rm may not always represent the real intraspecific component of the total competitive pressure borne by plants in mixture.

The relative mixture response (Rx) as estimated by the approach of Jolliffe et al., (1984) seemed responsive to changes in resource (light) availability. This parameter should be useful in the identification of resources under competitive demand by plants. Jolliffe's approach could be further employed to assess the effect of corn planting arrangement on intra- and interspecific interference in mixture with clover, and to evaluate species to be used as living mulches.

In summary, these experiments demonstrated that clover and corn competed for the same resources when grown in mixture for 35 days after corn emergence, in pots in the field. Light was the probable factor limiting growth, and clover was the most aggressive competitor. Interspecific shading reduced corn growth early in its life cycle, because it emerged when clover already was 4 cm high.

Other limiting resources also may have been involved. The species partially avoided competition. Further knowledge on limiting factors and identification of resources involved in possible niche differentiations is required to establish management alternatives for the corn-clover intercropping.

4. Nitrogen release and nutrient uptake

When the foliage of many legumes is shaded or destroyed their roots and nodules suffer carbohydrate starvation. Such roots become senescent and mineralization releases N into the soil solution (Hoglund and Brock, 1978; Vrabel, 1982). The N thus released can enhance the growth of other intercropped species (Vrabel, 1982; Sweet, 1982). The mineralization process first produces NH_4-N, which is subsequently oxidized to NO_3-N (Mengel and Kirby, 1982). Therefore, ammonium-N should be the first product to accumulate around the senescent roots and nodules of legumes after their foliage is killed.

Thirty-seven days after spraying clover with atrazine, the NH_4-N concentration in the rooting depth of clover (first 30cm of soil) was higher in the sprayed than in the unsprayed plots (Fig. 17). Ammonium concentrations in the atrazine-sprayed plots were higher in the first 30cm of soil than in the 30-60cm interval (Fig. 18). Consequently, the accumulation of the first product of mineralization within the rooting depth of clover, following the spraying of atrazine on clover plots, suggested that ammonium had been released from the roots of the suppressed clover.

The rate of nitrification was low during the first 37 days after spraying (d.a.s.) clover (Fig. 19). Fifty-eight d.a.s., the nitrate concentration in the first 30cm of soil tended to be higher in the sprayed than in the unsprayed plots. However, the difference was not significant (Fig. 19). This trend could otherwise have been linked to the nitrification of the ammonium released by the sprayed clover; ammonium levels declined sharply in the treated plots after the 37th d.a.s. (Fig. 17). It is also probable that NO_3^- had been taken up by plants.

When the concentrations of ammonium and nitrate were added and averaged over the 0 to 60cm depth of soil, the amount of soluble nitrogen 24 d.a.s. was higher ($p<0.05$) in the sprayed than in the unsprayed plots (Fig. 20). Thirty-four days later, the concentration of NO_3+NH_4 was the same in treated and untreated plots.

The greatest release of nitrogen (NO_3+NH_4), measured 24 d.a.s., amounted to 14 mg/kg or approximately 31 kg N/ha (Fig.20). This quantity represents only 16% of the nitrogen required by corn in the Willamette Valley of Oregon (Mansour 1975). Nevertheless, nitrogen presumably released within a few weeks after spraying clover may have been responsible for partially reducing the differences in dry matter and N uptake between corn competing with a clover sward and clover-free corn 72 days after spraying atrazine (Table 11).

Twenty-four days after spraying atrazine on clover, when a significant release of N was first measured (Fig. 20), clover began to recover from the suppression treatment. Thus clover could have taken up part of the nitrogen it had released into the soil. For corn to fully benefit from the nitrogen released by the suppressed legume, clover suppression should last longer than it did in this experiment.

The release of nitrogen into the soil from the roots of a suppressed white clover mulch was not large. However, it still may have the potential to improve the growth of corn competing with this legume. Higher levels of nitrogen release can be expected from white clover. By treating white clover with atrazine, Sweet (1982) obtained N releases in the range of 50 kg/ha.

Concentrations of N, P, K, and S in corn tissue and corn dry matter production were measured to determine if differences in concentrations or uptake could be related to corn-clover competition.

In 1984, 48 days after planting corn, the nitrogen concentration (as percent of dry matter) in corn competing with a clover mulch was lower than in clover-free corn (Table 12). The dry matter values illustrate the intensity of the corn-clover competition (Table 12).

Vengris (1955) found that corn growing with weeds had lower nitrogen concentration in its tissues than when growing alone. This was particularly evident when corn plants were young.

The magnitude of the reduction in nitrogen concentration may seem too small to account for the large dry matter reduction when competition occurred (Table 12). Competition, however, occurs not only for nutrients but also for light and water (Zimdahl, 1979). The total competitive effect should be more detrimental than if competition involves only a single nutrient.

Intercropping with clover reduced the nitrogen content of corn without affecting concentrations of other nutrients (Table 12). If competition had impaired root development and thus reduced nutrient absorption, then the uptake of other nutrients should also have been affected.

The response of some nutrients to competitive uptake may be related to their mobility in the soil solution. Nitrate is considerably mobile in the soil, and is supplied to the roots by mass flow and diffusion (Barber, 1984). Phosphorus, however,has little mobility reaching the roots mainly by diffusion (Barber, 1984). The distance for diffusion through the soil to the roots is usually in the range of 0.1 to 15mm (Barber, 1984). Therefore, competition for P may be restricted to roots in intimate contact (Trenbath, 1976), and P may not become limiting under competition as readily as N. In the living mulch experiment, phosphorus concentration in corn was totally unaffected by competition from clover. Reductions in the concentrations of K and S (Table 12) were not significant ($p < 0.05$); the interactions of these nutrients with the presence of clover seems unclear.

When corn competed with clover, the uptake (concentration x dry matter) of N, P, K, and S was reduced in the same proportion as corn dry matter (Table 13). The data in Table 13 do not allow the conclusion that a reduction in the uptake of a given nutrient resulted from plant competition for that nutrient. Since the concentrations of at least P, K, and S seemed unaffected by competition, reductions in uptake probably resulted from a reduction of corn biomass when this crop competed with clover as opposed to growing alone (Table 13).

The multiple speculations illustrate that techniques employed in the above experiment may not be adequate to relate competition for a given nutrient to its effect on crop growth. A more adequate approach may involve experimental variation of nutrient availability, and the observation of the resulting plant responses. The use of replacement series or other more systematic designs may be useful here to define the type of the competitive interactions. Hall (1974), using replacement series and different levels of potassium availability demonstrated competition for this element between *Setaria anceps* and *Desmodium intortum*. The replacement series allowed for good comparisons of species behavior between mixtures and pure stands (Harper, 1977).

SUMMARY AND CONCLUSIONS

It was the primary objective of this investigation to study intra- and interspecific interference in a system involving sweet corn (*Zea mays* L) and a white clover (*Trifolium repens* L) living mulch. Effects of different densities and planting arrangements of corn growing with clover were studied in field experiments. Replacement series experiments were conducted in the field and in the growth chamber to evaluate the effect of relative species proportions on corn-clover interference. The response of corn to a range of planting densities was studied using systematic density experiments. The effect of clover competition on the nutrient content of corn was studied using plant analysis. Sequential soil sampling was conducted to assess the magnitude and timing of nitrogen release by senescent clover roots after spraying clover with atrazine.

The following conclusions can be derived from this study:

1. Sweet corn intercropped with a white clover living mulch yielded less than growing alone. Clover interference reduced corn growth and productivity. Therefore, for this cropping system to be a feasible sweet corn production alternative, clover interference needs to be managed. Since the clover mulch is intended as a perennial living cover to be used in more than one season, chemical suppression cannot be sufficiently severe to kill the clover. Therefore, chemical

treatments to suppress clover growth need to be complemented by vegetation management techniques aimed at enhancing corn growth, productivity, and ability to suppress clover growth.

2. A successful management alternative to reduce corn yield losses from clover interference was the planting of corn in narrow rows (38 cm) instead of seeding in 76-cm rows as is the current practice. Intra-row spacing of corn plants in narrow rows was higher than in wide (76-cm) rows. Intraspecific interference in the narrow rows was thus lower than that in the 76-cm row spacing. Consequently, with respect to plants in standard rows, single corn plants in narrow rows tended to grow more, developed higher leaf area indices, had a higher marketable output, and also reached a more complete canopy closure which resulted in better clover suppression. Modifying the planting arrangement of corn to obtain similar spacing between rows and between plants within a row was a key management option to reduce corn yield losses from clover interference. Corn growing with a clover mulch in narrow rows yielded as much as corn grown without clover in standard 76 cm rows.

The enhanced corn growth and productivity observed when corn grew in narrow instead of wide rows, was a measure of better resource capture by corn plants in a nearly equidistant planting pattern. The increase in resource capture by plants in narrow rows reflects their enhanced capacity to compete with clover.

3. The replacement series experiments demonstrated that white clover and sweet corn grown in mixture competed for the same limiting resources. Light was the probable factor limiting growth when corn grew with clover for 39 days after emergence. Clover appeared as the superior competitor during that period. Antagonism was not detected by the replacement series. However, corn and clover partially avoided competition. Perhaps this was because one or both of the species may not have made heavy demands on all the resources needed by the other species, or had some mechanism of resource acquisition not subject to interference. This may be a case of niche differentiation perhaps related to clover having an independent source of nitrogen. The presence of niche differentiation is a desirable feature in species to be intercropped.

The alternative analysis of replacement series proposed by Jolliffe et al. (1984) agreed in general with the conventional interpretation of such experiments (Harper,1977; Willey,1979). This alternative approach allowed quantification of the effects of species proportions on the intra and interspecific components of competition. It was, thus, shown that clover in the field experiment was affected by interspecific competition from corn. This effect was not apparent in the conventional replacement diagrams.

The relative response to interspecific interference (Rx in the analysis of Jolliffe et al.,1984) was sensitive to changes in levels of resource availability. Rx could, therefore, be a useful parameter to identify limiting resources for which species in mixture may compete. Quantification of the interspecific components of interference should also be helpful in selecting compatible species for living mulch systems.

In spite of having essentially eliminated competition for light, responses to interspecific interference were found using the approach of Jolliffe et al.(1984) for the interpretation of replacement series. Consequently, limiting factors other than light may have limited growth of corn and clover in the replacement series experiments.

Both interpretative approaches seemed to complement each other, enhancing the usefulness of replacement series in competition studies.

4. After the clover mulch was suppressed with atrazine, nitrogen was released into the soil from senescent clover roots. The amount of nitrogen released was not large with respect to corn requirements, and persisted approximately one month in the soil. However, this source of nitrogen presumably improved the growth of corn stressed by competition from clover.

Clover recovering from the suppression treatment might take up part of the nitrogen it released. In this study, clover began to recover twenty-four days after suppression, at the same time a significant N release was first measured. Therefore, clover should be maintained suppressed during the N release period to maximize corn's benefit from the legume's symbiotic nitrogen fixation. This may be achieved if the chemical suppression is complemented by a density and planting arrangement of corn such that provide early and significant canopy coverage of the ground.

5. Plant analysis indicated that when corn grew with clover, N concentration in corn tissue was reduced but the levels of P, K, and S were not affected. This observation may suggest that competition for nitrogen could have been more intense than for other nutrients. However, the procedure employed did not seem adequate to study competition for single nutrients. Measuring plant responses at different levels of nutrient availability may be a more adequate approach.

6. The response of sweet corn to density changes was affected by the presence of clover. Corn yield in monoculture always increased in response to density increments within a range from 25,000 to 170,000 plants/ha. Intraspecific competition was the main factor curbing yields at high corn densities. However, when the density of sweet corn (66,000 plants /ha) intercropped with clover was doubled, corn yield did not increase. In this case, the added effect of interspecific competition could have caused this lack of response. Clover suppression should thus affect the type of corn yield response to density increments.

7. Competition from clover or changes in corn density and planting arrangement did not affect the harvest index of corn, suggesting that carbohydrate allocation to vegetative or reproductive growth was not markedly altered by interference.

8. Long- and short-term advantages of living mulches growing with annual crops have been discussed (section 2.a. of the literature review). However, considering the corn yield losses observed, it seems that only few reasons may justify the use of a living mulch by sweet corn farmers in the Willamette Valley. Serious erosion and trafficability problems seem the strongest reasons for living mulch use. Use of the mulch as a forage to be sold or consumed in the farm, may also be of interest to growers. However, an economic analysis should define the usefulness of sweet corn-clover living mulch systems.

The use of living mulches is a new cropping approach that will require technical support and some changes in usual farming practices. Adapting the harvesting equipment to work in narrow rows will represent an additional factor over current farming practices.

Table 1. Treatments in the sweet corn density and distribution experiment in the presence of a white clover living mulch.

	Treatments			
Density (plants/ha)	66,000	131,000	79,000[1]	131,000
Row width (cm)	76	76	38	38
Seed spacing (cm)	20	10	33	20
Rectangularity[2]	3.8	7.6	1.2	1.9

[1] The corn planter used did not allow seeding at 66,000 plants/ha in rows 38 cm apart. The closest density was 79,000.plants/ha.

[2] Rectangularity = length / width of a rectangle.

Table 2. Sequence of tillage, sweet corn planting, fertilization, and clover suppression operations in field experiments 1 and 2.

1984

June 17:
Surface tillage in the treatment without clover.

June 25:
Strip tillage and planting: clover was mowed, and corn was planted in a 10 cm-wide planting band tilled in the clover sward. Surface-tilled plots were also planted on this date.
Fertilization: N, P, and K at, 3.5, 6.1, and 3.5 kg/ha respectively were applied 2.5 cm to one side and below the sweet corn seeds.
Clover suppression: atrazine + alachlor at 1.7 + 2.2 kg ai[1]/ha were sprayed[2] on a 15 cm band over the seeded rows.

August 1:
Fertilization: 100 kg N/ha were applied at the base of the sweet corn plants.

August 7:
Clover suppression: atrazine at 1.1 kg ai/ha was sprayed broadcast[2] .

1985

May 23:
Surface tillage in the treatment without clover

May 30:
Strip tillage and fertilization: a 15 cm-wide planting band was tilled in the clover sward. N and P (30 and 63 kg/ha) were applied 10 cm deep in the tilled band.

June 3:
Planting: sweet corn was seeded 2 cm deep, into the band tilled in the clover, and also into the surface-tilled plots.

June 4:
Clover suppression: atrazine + crop oil at 1.5 kg ai/ha + 2 L/ha were sprayed broadcast[2] over 15 cm-tall clover.

June 13:
Clover suppression: clover was mowed between corn rows.

July 18:
Fertilization: 90 kg N/ha were applied at the base of the sweet corn plants.

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1 Active ingredient.
2 Spray volume was 200 L/ha.

Table 3. Effect of planting densities, row width, and clover mulch on mean crop growth rate (CGR) of corn. Data from two separate experiments (a and b) are averages over the first 119 (1984) or 116 (1985) days after corn emergence.

Treatments				CGR	
No.	Row width	Corn density	Clover Presence	1984	1985
	(cm)	(plants/ha)		----- ($g/m^2/day$)	-----
(a)					
1.	76	66,000	no	16.2a[1]	26.9a
2.	76	66,000	yes	6.7b	7.6c
3.	38	79,000	yes	-	13.5b
	LSD (0.05)			7.8	5.3
	CV (%)			30	19
(b)					
1.	76	66,000	yes	3.4d	15.2b
2.	38	79,000	yes	9.5b	20.9ab
3.	76	131,000	yes	7.1c	27.4a
4.	38	131,000	yes	13.4a	24.1a
	LSD (0.05)			1.9	8.5
	CV (%)			15	24

1 Values followed by the same letter are not statistically different according to Fisher's protected LSD (p=0.05).

Table 4. Effect of planting densities, row width, and a clover mulch on sweet corn yield and clover growth. Data are from two separate experiments (a and b).

Treatments No.	Row width	Plants per ha	Clover mulch	Yields of marketable ears 1984	1985[1]	Clover dry matter (Aug.6, 1985)
	(cm)			----(Kg/ha)----		(Kg/ha)
(a)						
1.	76	66,000	no	29,280a[2]	29,866a	---
2.	76	66,000	yes	17,760b	22,414b	1,811a
3.	38	79,000	yes	---	32,299a	711b
LSD (0.05)				8,552	4,828	323
CV (%)				16	10	11
(b)						
1.	76	66,000	yes	18,250b[3]		1,580ab
2.	38	79,000	yes	35,170a		1,090b
3.	76	131,000	yes	17,880b		2,030a
4.	38	131,000	yes	32,220a		1,090b
LSD (0.05)				3,739		623
CV (%)				9		27

1 Averages of two experiments in 1985.
2 Within columns, values followed by the same letter are not statistically different according to Fisher's protected LSD (p=0.05).
3 Data are averages for 1984 and 1985.

Table 5. Effect of planting densities, row width, and a clover mulch on sweet corn leaf area index. Data are from two separate experiments (a and b).

Treatments				Leaf area index 47 days after planting	
No.	Row width	Plants per ha	Clover mulch	1984	1985
	(cm)			--(cm^2/cm^2)--	
(a)					
1.	76	66,000	no	5.9a[1]	2.9a
2.	76	66,000	yes	1.2b	1.3b
3.	38	79,000	yes	---	2.6a
LSD (0.05)				2.3	1.1
CV (%)				29	29
(b)[2]					
1.	76	66,000	yes	0.84c	
2.	38	79,000	yes	1.45b	
3.	76	131,000	yes	1.29bc	
4.	38	131,000	yes	3.39a	
LSD (0.05)				0.53	
CV (%)				19	

1 Within columns, values followed by the same letter are not statistically different according to Fisher's protected LSD (p=0.05).

2 Data are averages for 1984 and 1985.

Table 6. Between-row ground cover by sweet corn canopies growing with clover in four planting arrangements or as conventional sweet corn monoculture, and its effect on sweet corn yield and clover suppression. Recorded from the ground by a 35 mm camera with a 7.5 mm fish-eye lens, eight weeks after planting sweet corn. Data are averages of four replicates in 1985.

Corn population	Row width	Clover mulch	Percent ground cover
(plants/ha)	(cm)		(%)
66,000	76	no	67a[1]
66,000	76	yes	28c
79,000	38	yes	53ab
131,000	76	yes	42b
131,000	38	yes	68a
LSD (0.05)			15
CV (%)			19

X	Y	Regression
Canopy ground cover (fraction)	Clover dry matter at corn harvest ($g/900\ cm^2$)	$Y = 4.3-6.2LN(X)$ $R^2 = 0.33$; $p = 0.02$

1 Within columns, values followed by the same letter are not statistically different according to Fisher's protected LSD ($p = 0.05$).

Table 7. Effect of planting density, row width, and a clover mulch on sweet corn yield per plant and ear size. Data are from two separate experiments (a and b).

Treatments				Marketable ear fresh weight per plant	Ears > 15 cm long
No.	Row width	Plants per ha	Clover mulch		
	(cm)			(Kg/plant)	(no./plant)
(a)[1]					
1.	76	66,000	no	0.51a[2]	1.38a
2.	76	66,000	yes	0.45a	1.23a
3.	38	79,000	yes	0.54a	1.43a
	LSD (0.05)			0.13	0.33
	CV (%)			16	14
(b)[3]					
1.	76	66,000	yes	0.28b	0.79b
2.	38	79,000	yes	0.44a	1.19a
3.	76	131,000	yes	0.14c	0.46c
4.	38	131,000	yes	0.25b	0.69bc
	LSD (0.05)			0.05	0.24
	CV (%)			11	19

1 Data from one experiment in 1985.
2 Within columns, values followed by the same letter are not statistically different according to Fisher's protected LSD (p=0.05).
3 Data are averages for 1984 and 1985.

Table 8. Effect of planting densities, row width, and a clover mulch on sweet corn dry matter partition. Data are from two separate experiments (a and b).

Treatments				Corn dry-matter partition[1] at harvest	
No.	Row width	Plants per ha	Clover mulch	1984	1985
	(cm)			----(%)----	
(a)					
1.	76	66,000	no	2.6a[2]	1.0a
2.	76	66,000	yes	1.3a	1.3a
3.	38	79,000	yes	---	1.2a
LSD (0.05)				1.5	0.5
CV (%)				34	26
(b)					
1.	76	66,000	yes	---	1.5a
2.	38	79,000	yes	---	2.1a
3.	76	131,000	yes	---	2.2a
4.	38	131,000	yes	---	1.8a
LSD (0.05)					1.2
CV (%)					38

1 (Ear dry weight / weight of above-ground vegetative dry matter)x100

2 Within columns, values followed by the same letter are not statistically different according to Fisher's protected LSD (p=0.05).

Table 9. Relationships between corn dry matter and the number of marketable ears per plant when sweet corn and white clover grew together.

Y	X	Date when X was recorded	Regression
Marketable ears/plant	Corn dry matter (g/plant)	July 19, 1985	$Y=1.6-11.5[1/(X+1)]$; $R^2=0.26$; $p=0.001$
Marketable ears/plant	Corn dry matter (g/plant)	August 6, 1985	$Y=-0.78+41LN(X)$; $R^2=0.3$; $p=0.005$
Marketable ears/plant	Corn dry matter (g/plant)	August 28, 1984	$Y=-1.07+0.5LN(X)$; $R^2=0.67$; $p=0.004$

Table 10. Multiple regressions of corn and clover dry biomass, and leaf area per plant on fresh weight of marketable sweet corn ears (1984 and 1985).

1984

$y^{a}=23626-0.12[1/(LA+1)]+0.50(BM_1)^2$

$R^2=0.78;\ p<0.01^{b}$

1985

$y=-9114+99368(GC)+124835[1/(Clov+1)]+0.569(BM_2)^2-81667(GC)^2$

$R^2=0.87;\ p<0.01$

[a] y = estimated yield of marketable ears (kg/ha, fresh weight); LA = corn leaf area (cm^2/plant), sampled 48 days after planting; BM_1 = corn dry biomass (g/plant) sampled 119 days after planting; BM_2 = corn dry biomass (g/plant) sampled 64 days after planting; Clov = clover dry biomass (g/900 cm^2) sampled 64 days after planting corn; GC = fraction of ground covered by corn canopies 52 days after planting.

[b] Significance of the regression coefficient according to the F test in the analysis of variance.

Table 11. Corn dry matter and nitrogen uptake following the application of 1 Kg ai/ha atrazine to an associated clover sward.

	Days after spraying atrazine			
	5		72	
	N	Dry matter	N	Dry matter
	(Kg/ha)			
Corn	302a[1]	7633a	308a	13517a
Corn + clover	31b	1207b	159a	6749a
LSD (0.05)	179	4301	231	9019

[1] Within columns,values followed by the same letter are not statistically different according to Fisher's protected LSD (0.05).

Table 12. Concentrations of four nutrients in corn leaves, 48 days after planting, when it grew alone or in competition with a white clover living mulch (1984).

	Nutrients				Corn Dry Matter
	N	P	K	S	
	---------- (%) ---------				(Kg/ha)
Corn	3.9a[1]	0.4a	2.6a	0.3a	7633a
Corn + clover	2.6b	0.4a	1.8a	0.2a	1207b
LSD (0.05)	0.5	0.08	1.54	0.13	4301

1 Within columns,values followed by the same letter are not statistically different according to Fisher's protected LSD (0.05).

Table 13. Corn uptake of four nutrients (concentration x dry matter), 48 days after planting, growing alone or in competition with a white clover living mulch (1984).

	Nutrients				Corn Dry Matter
	N	P	K	S	
	-------- (Kg/ha) -------				(Kg/ha)
Corn	302a[1]	31a	205a	23a	7633a
Corn + clover	31b	4b	23b	3b	1207b
LSD (0.05)	179	17	156	15	4301

1 Within columns,values followed by the same letter are not statistically different according to Fisher's protected LSD (0.05).

Figure 1. Biomass yield-density relationship (adapted from Radosevich and Holt, 1984).

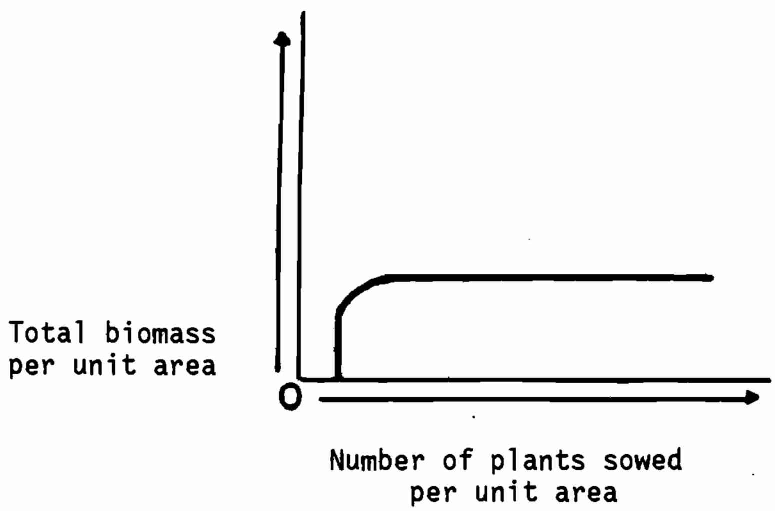


Figure 2. Effect of density (d) on mean single plant weight (w); for k = contant (adapted from Silvertown, 1982).

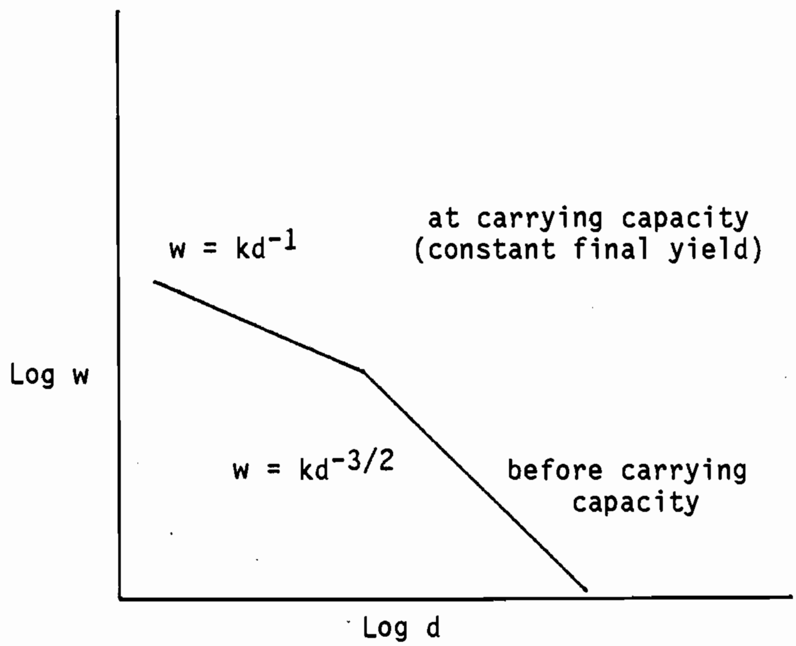


Figure 3. Biomass and grain yield-density relationship (adapted from Donald, 1963)

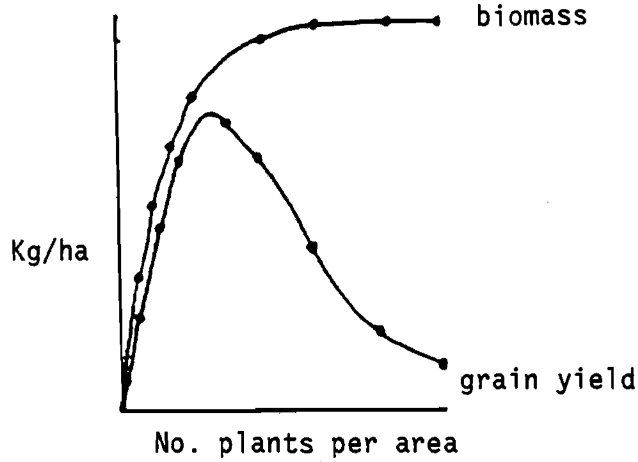
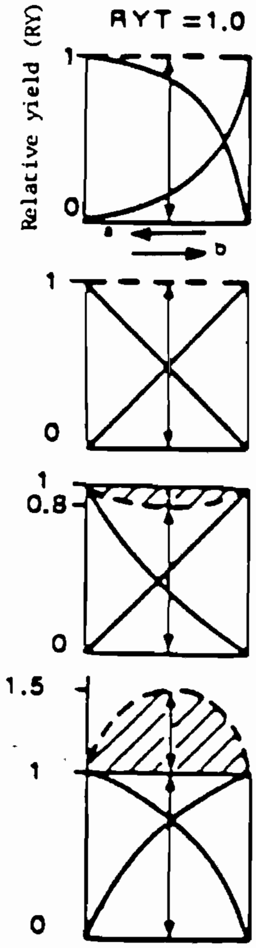


Figure 4. Models to interpret results in replacement series experiments (adapted from Harper, 1977).



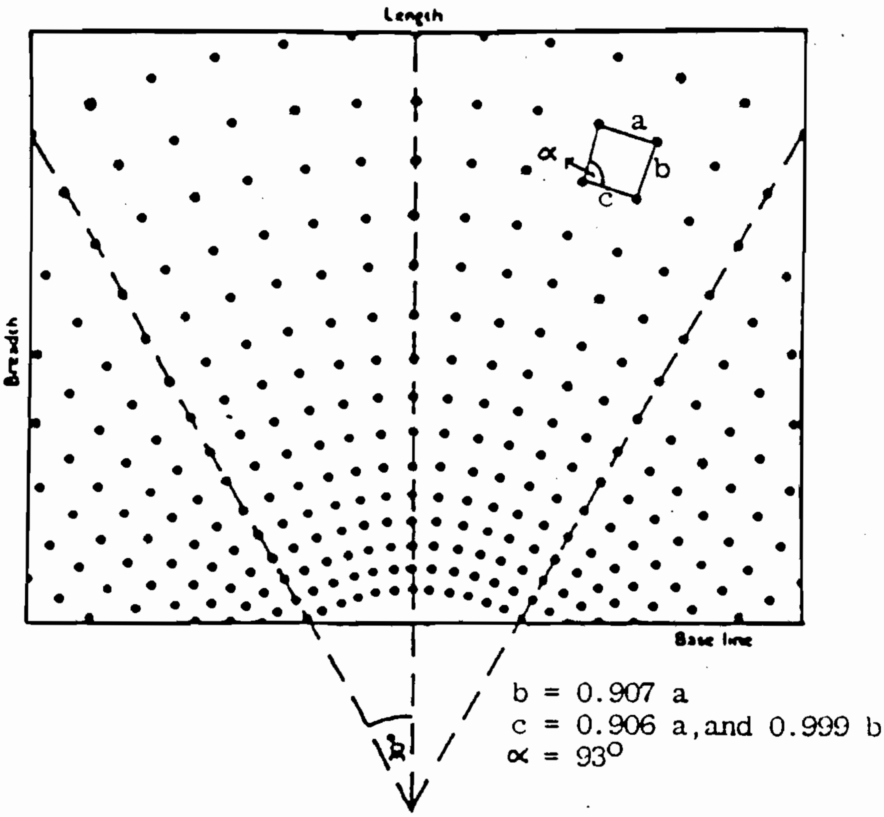
Competition for same resources; one species is more competitive.

Equivalent interference for both species.

Antagonism (such as allelopathy)

Competition is avoided (niche differenciation, also symbiosis).

Figure 5. A systematic fan design with an approximately square plant arrangement. The plant positions are represented by dots.



From: BLEASDALE, J.K.A. 1967. Systematic designs for spacing experiments. Expl. Agric. 3(1):73-84.

Figure 6. A fan design for spacing experiments with set row widths. The plant positions are represented by asterisks (adapted from Freyman and Dolman, 1971).

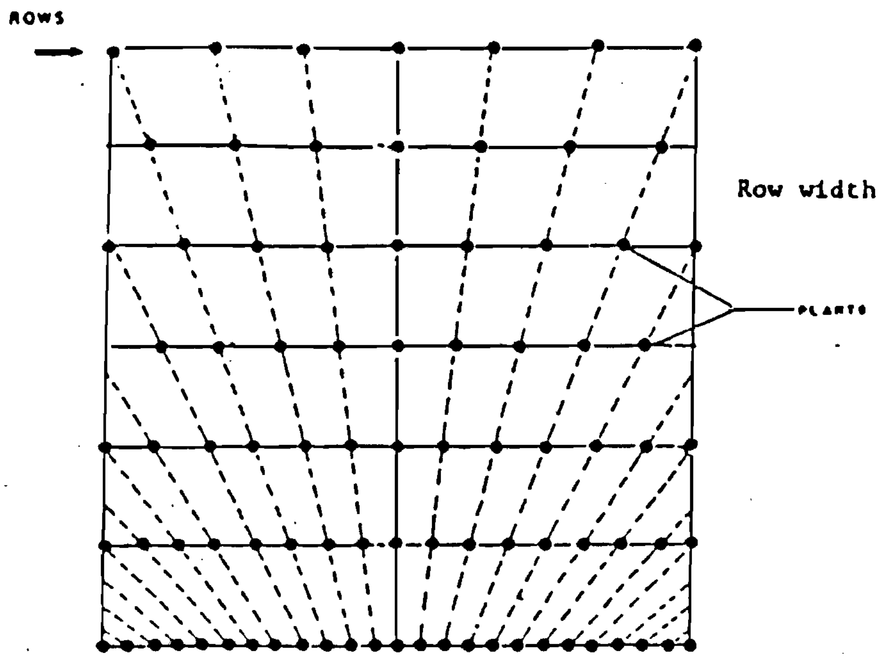


Figure 7. Diagrams of a replacement series (adapted from Roush and Radosevich, 1985).

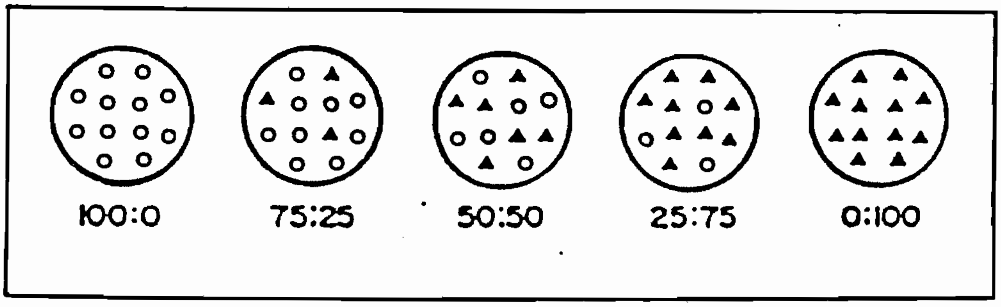


Figure 8. Soil moisture as indicated by readings from gypsum blocks (20 cm deep) on a KS-1 Delmhorst soil moisture tester, when corn grew associated with clover or in monoculture; high values indicate high soil moisture. Numbers represent standard deviations from the means.

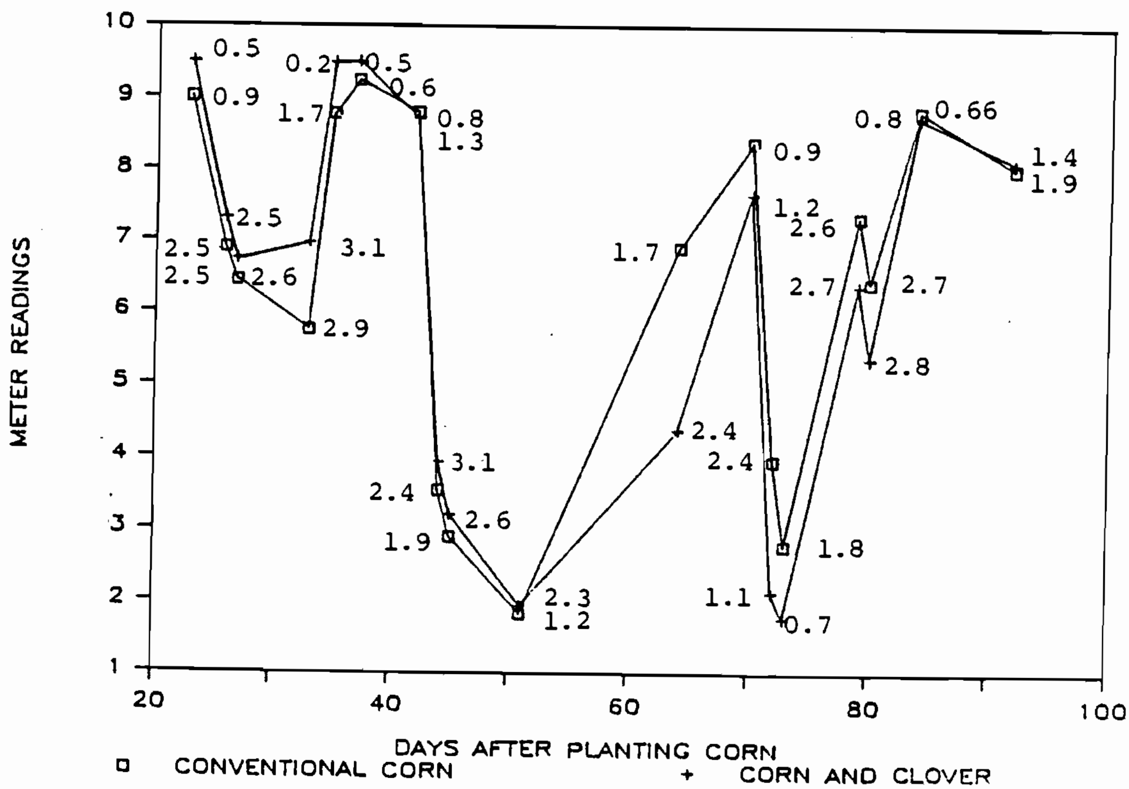
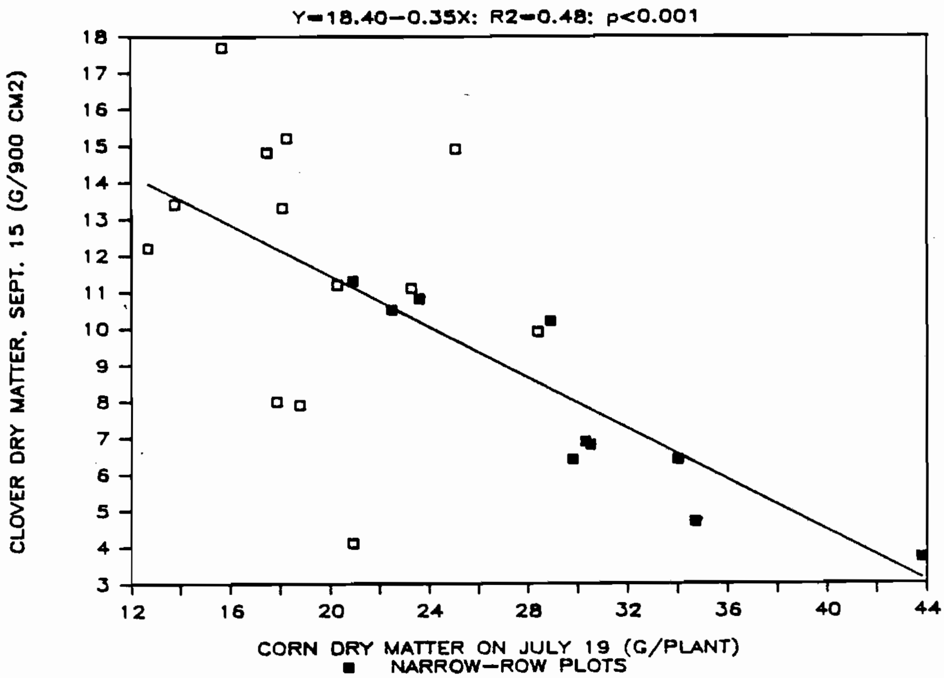


Figure 9. Effect of sweet corn dry matter and leaf area index (LAI), on July 19, 1985, upon white clover growth.



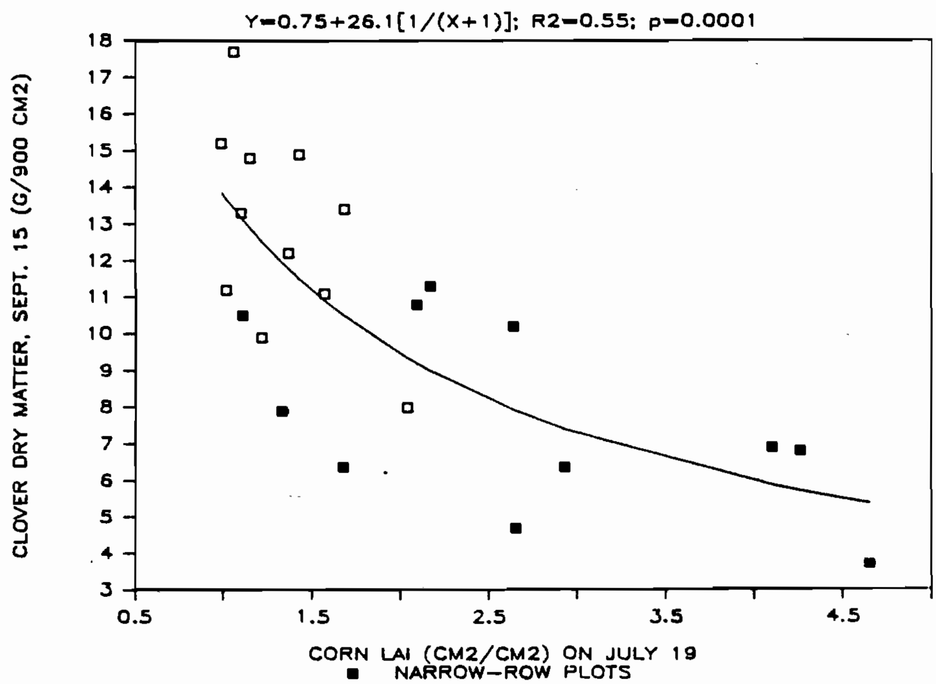


Figure 10. Effect of sweet corn dry matter (dm), leaf area (LA) and leaf area index (LAI) on final sweet corn yield. Crop sampled in August 1984, and in July and August, 1985.

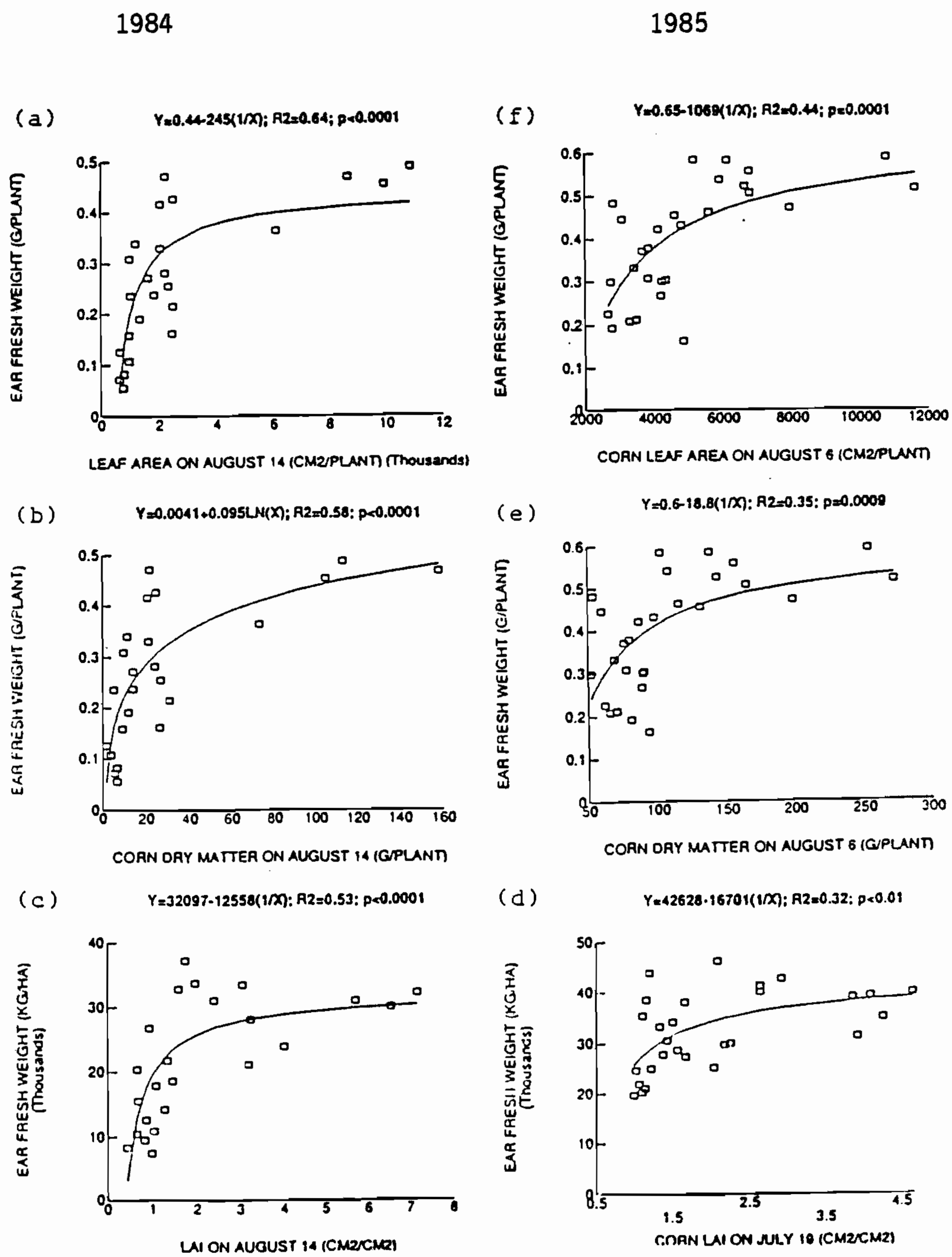
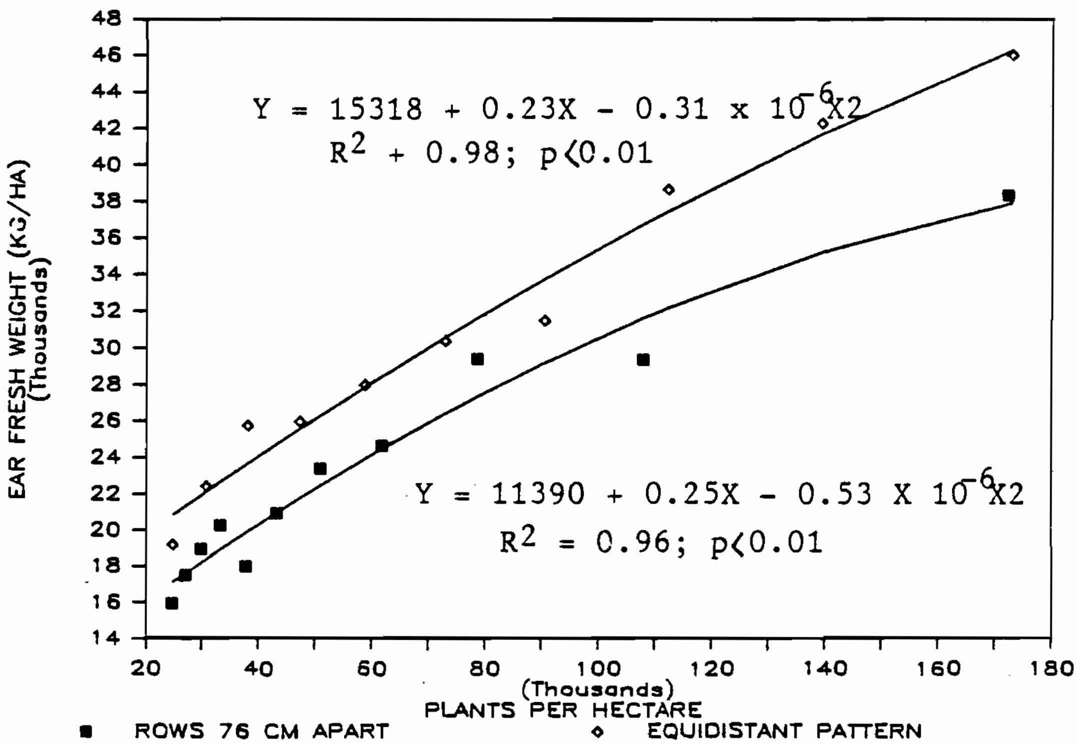
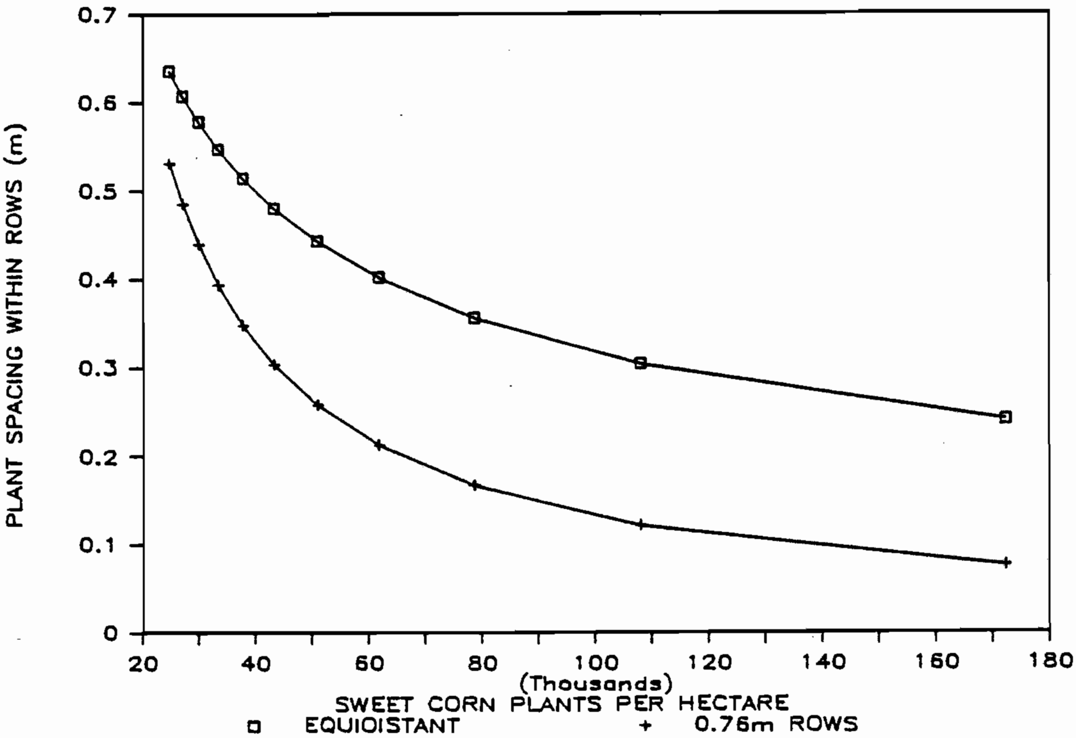


Figure 11 Yields of marketable sweet corn ears in 1985, when it was planted at different densities, in a nearly equidistant pattern or in rows 76 cm apart.[1]



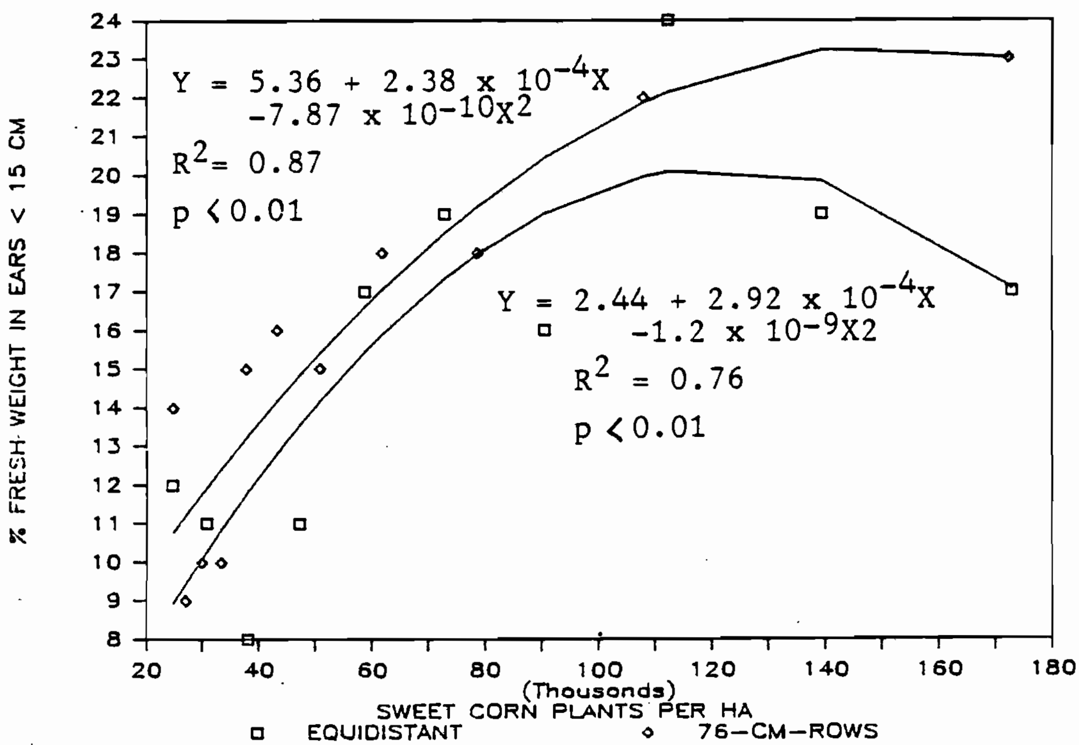
[1] The regression lines are statistically different ($p < 0.01$) according to an F test comparing all the coefficients in the models.

Figure 12 Spacing among sweet corn plants in an almost equidistant planting pattern or within rows 76cm apart when total density was systematically increased (1985).[1]



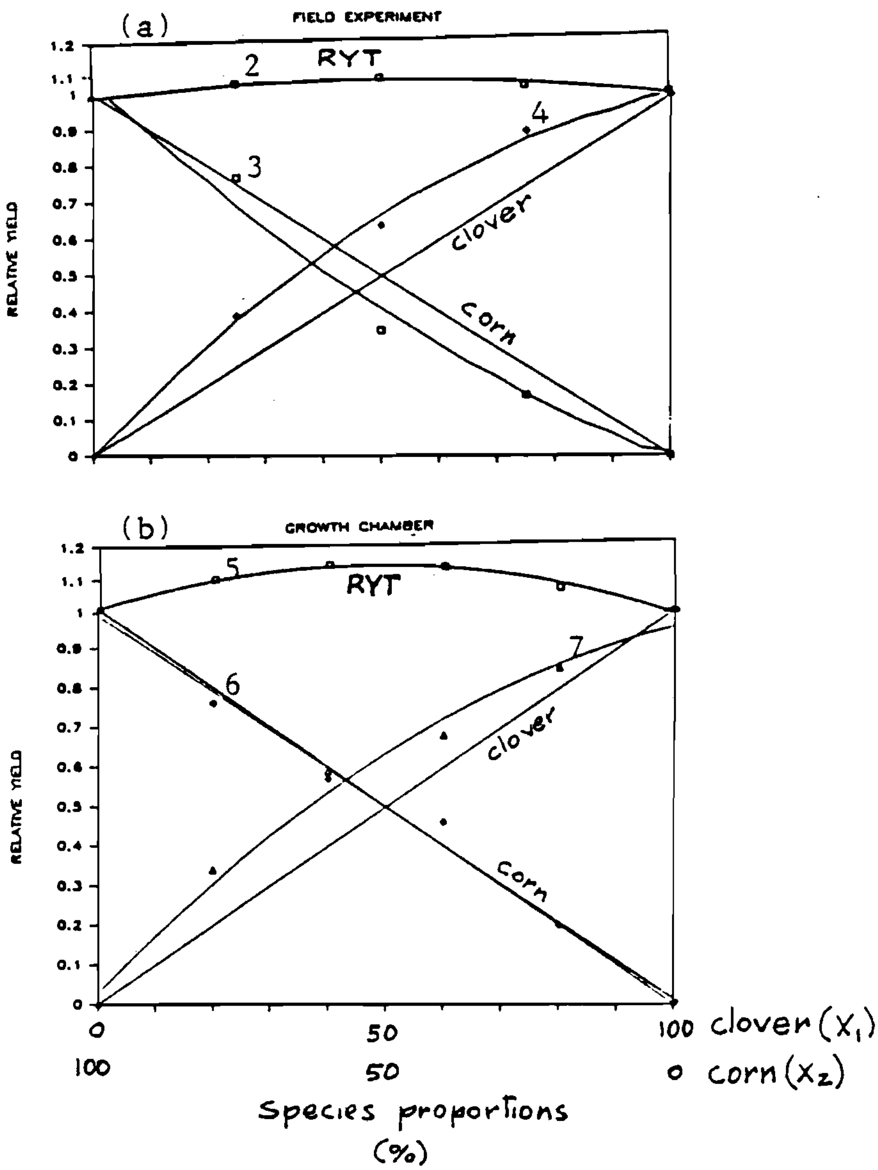
1 For each point in the graph, Rectangularity = distance between rows/plant spacing within rows. Distance between rows (in m) = 10,000/(spacing within rows (in m) x no. plants/hectare).

Figure 13. Percent ear fresh weight present in non-marketable ears (< 15cm), when a range of sweet corn densities were planted in rows 76 cm apart or in a nearly equidistant pattern (1985).[1]



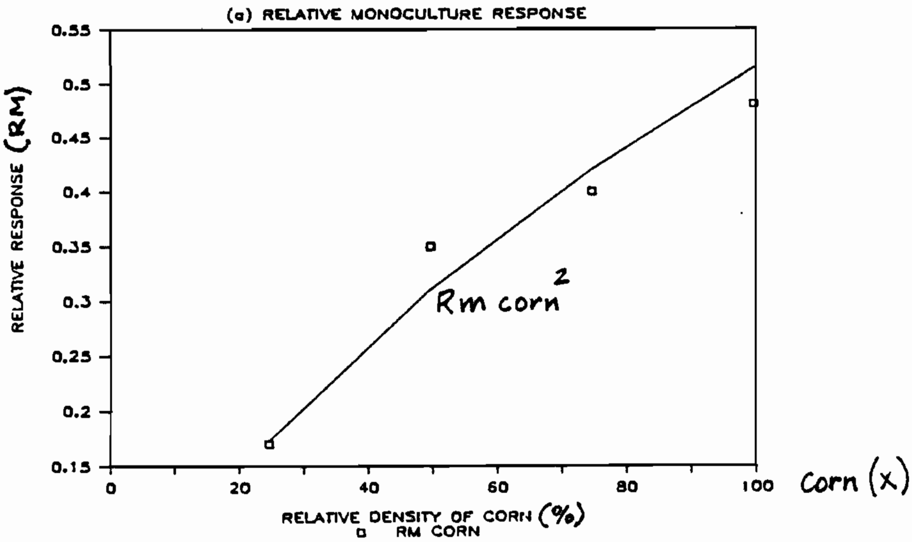
1 The regression lines are statistically different ($p<0.05$) according to an F test comparing all the coefficients in the model

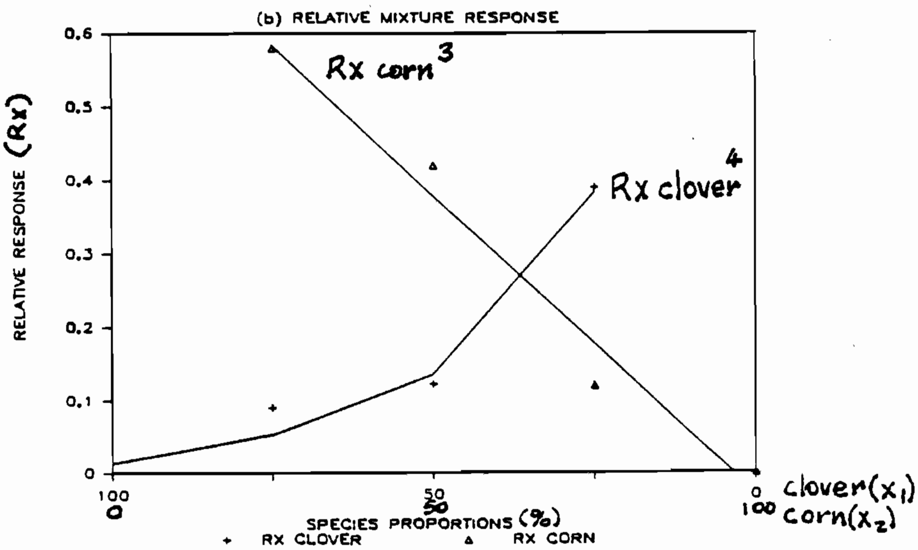
Figure 14. Biomass Relative Yields (RY) and Relative Yield Totals (RYT) of sweet corn and white clover seeded at different proportions (% of total) in replacement series with pots in the field or in a growth chamber (1985).[1]



1 Diagonal lines represent "expected yields" where competitive interactions betweeen and within species are equivalent or nonexistent.
2 $RYT(field)=1.03+0.002X_1-0.00002X_1^2$; $R^2=0.95$, $p<0.05$.
3 $RY(clover)=0.003+0.017X_1-0.65x10^{-4}X_1^2$; $R^2=0.99$, $p<0.01$
4 $RY(corn)=-0.01+0.63x10^{-2}X_2+0.41x10^{-4}X_2^2$; $R^2=0.99$, $p<0.05$
5 $RYT(gr.chamb)=0.97+0.0062X_2-0.58x10{-4}X_2^2$;$R^2=0.99$,$p<0.01$
6 $RY(clover)=0.03+0.02X_1-0.6x10^{-4}X_1^2$; $R^2=0.99$, $p<0.01$
7 $RY(corn)=0.01+0.9x10^{-2}X_2$; $R^2=0.99$, $p<0.01$

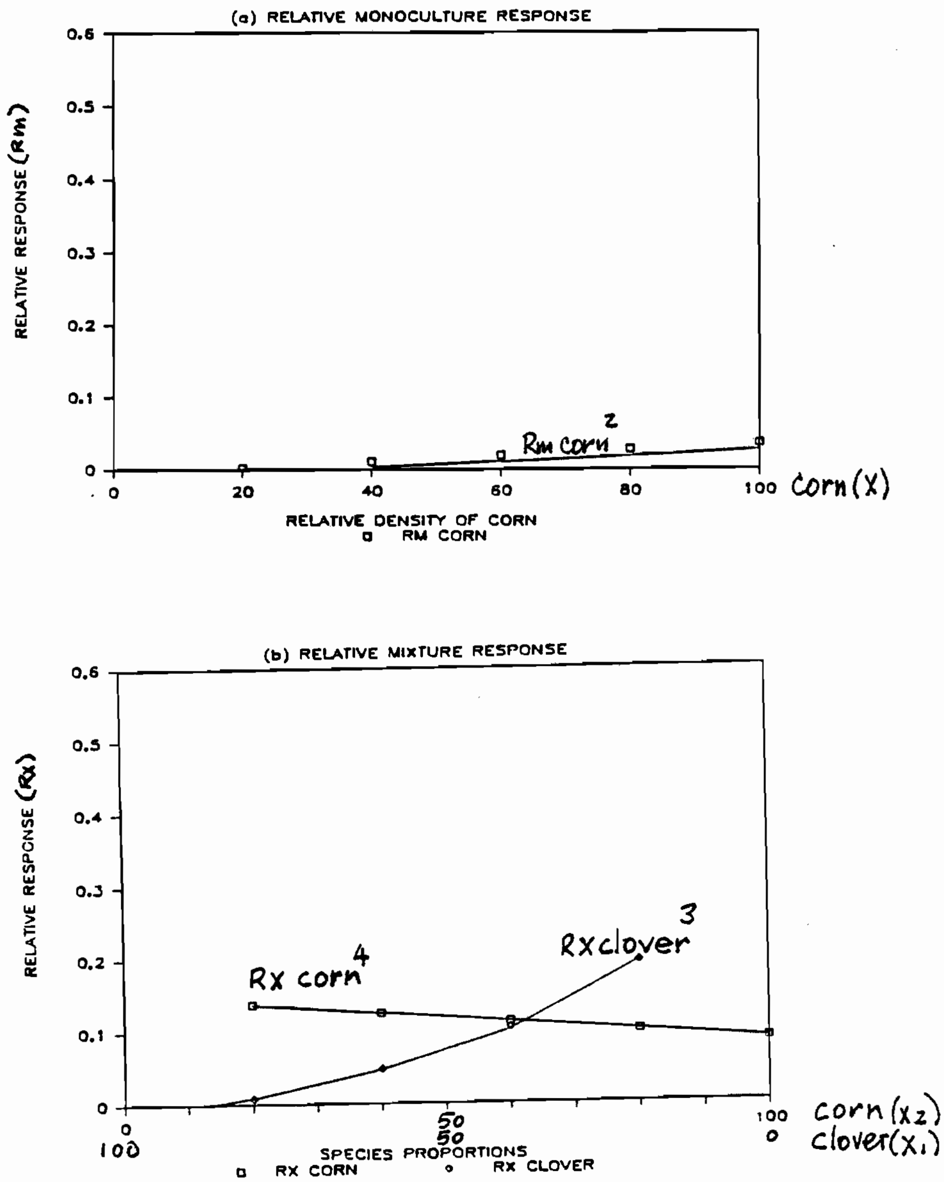
Figure 15. Relative monoculture (Rm) and mixture (Rx) responses (Jolliffe et al., 1984) when clover (+) and corn ( ) grew in replacement series with species at different proportions in the mixtures, or in monoculture at different relative densities[1]. Data are from a pot experiment conducted in the field.





1 Relative density = Yield at current density/yield at highest density x 100.
2 Y(corn Rm)=1/[0.66+220/(1.71X)]; R^2=0.98, p=0.0096
3 Y(corn Rx) = 0.8-4.8x10^{-3}($X_2$1.71); R^2=0.97, p=0.014
4 Y(clover Rx)=-0.1+106/($X_1$8.6); R^2=0.98, p=0.01

Figure 16. Relative monoculture (Rm) and mixture (Rx) responses (Jolliffe et al., 1984) when clover (+) and corn ( ) grew in replacement series with species at different proportions in the mixtures, or in monoculture at different relative densities[1]. Data are from a growth chamber experiment.



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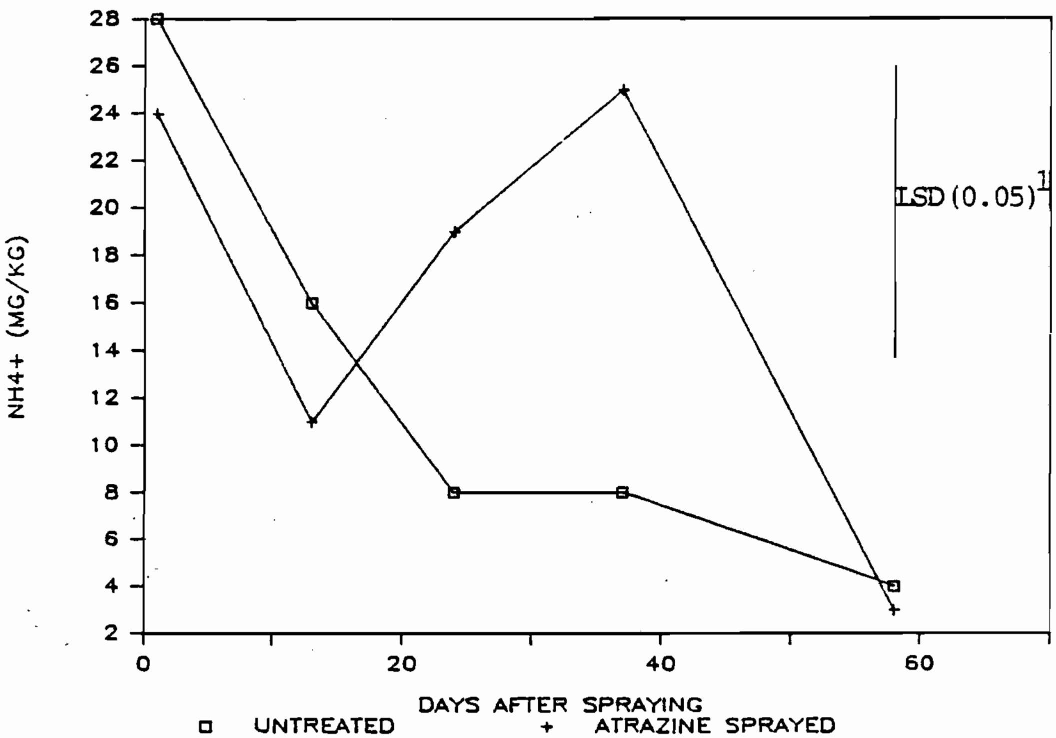
1 Relative density = Yield at current density/yield at highest density x 100.

2 $Y(\text{corn Rm})=0.01+2\times10^{-3}(0.2X)$; $R^2=0.99$, $p<0.0001$

3 $Y(\text{clover Rx})=0.6-0.13\text{LN}(X_1)$; $R^2=0.99$, $p<0.0001$

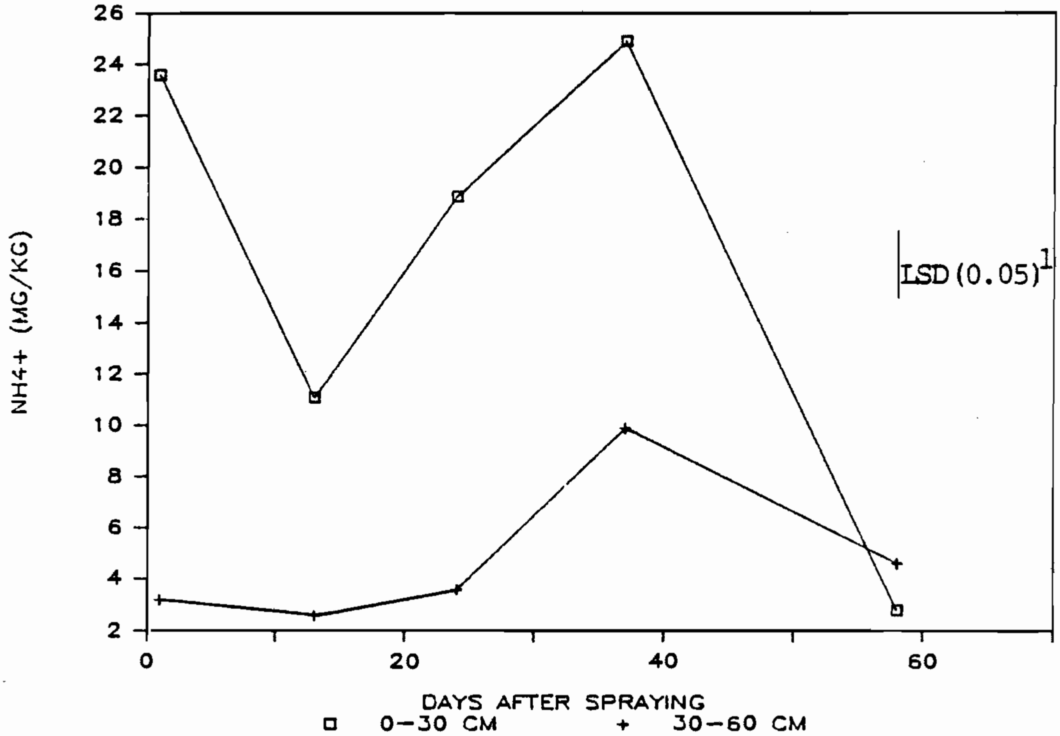
4 $Y(\text{corn Rx})=0.15-3.3\times10^{-3}(0.2X_2)$; $R^2=0.99$, $p<0.0001$

Figure 17. Ammonium concentration in the soil solution of the 0 to 30cm depth of soil under a white clover sward after it was sprayed with atrazine or left untreated (1985).



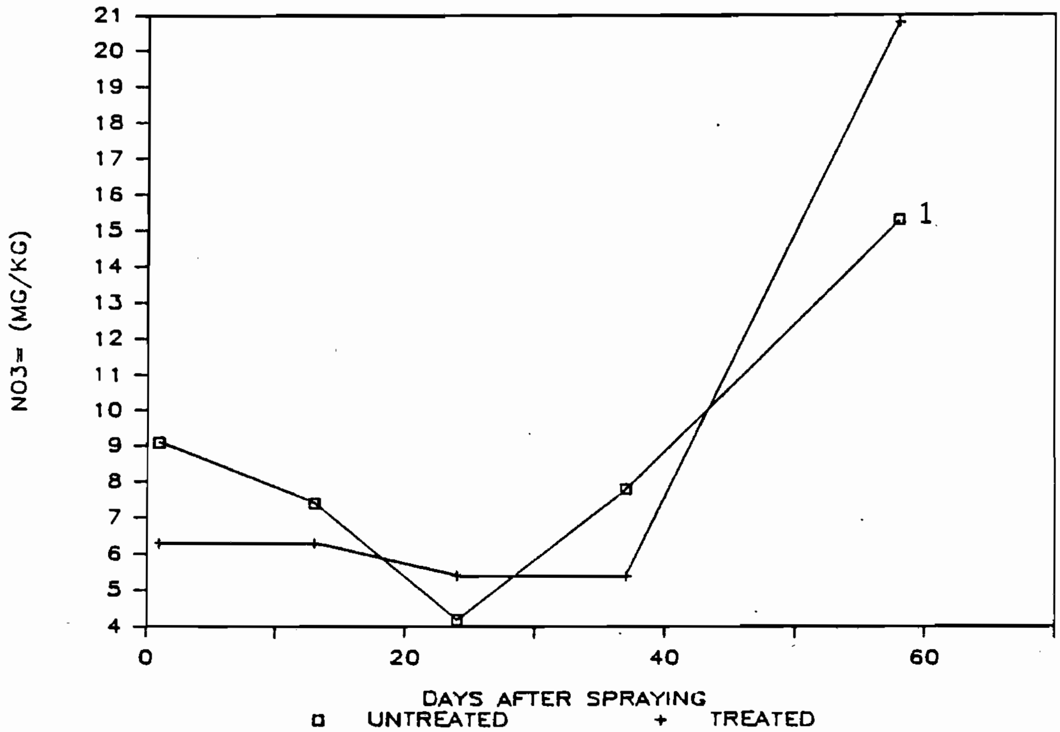
1 LSD bar is valid to compare points on different lines.

Figure 18. Ammonium concentration in the soil solution at two depths under a white clover sward after it was sprayed with atrazine (1985).



[1] LSD bar is valid to compare points on different lines.

Figure 19. Nitrate concentration in the soil solution of the 0 to 30cm depth of soil under a white clover sward after it was sprayed with atrazine or left untreated (1985).



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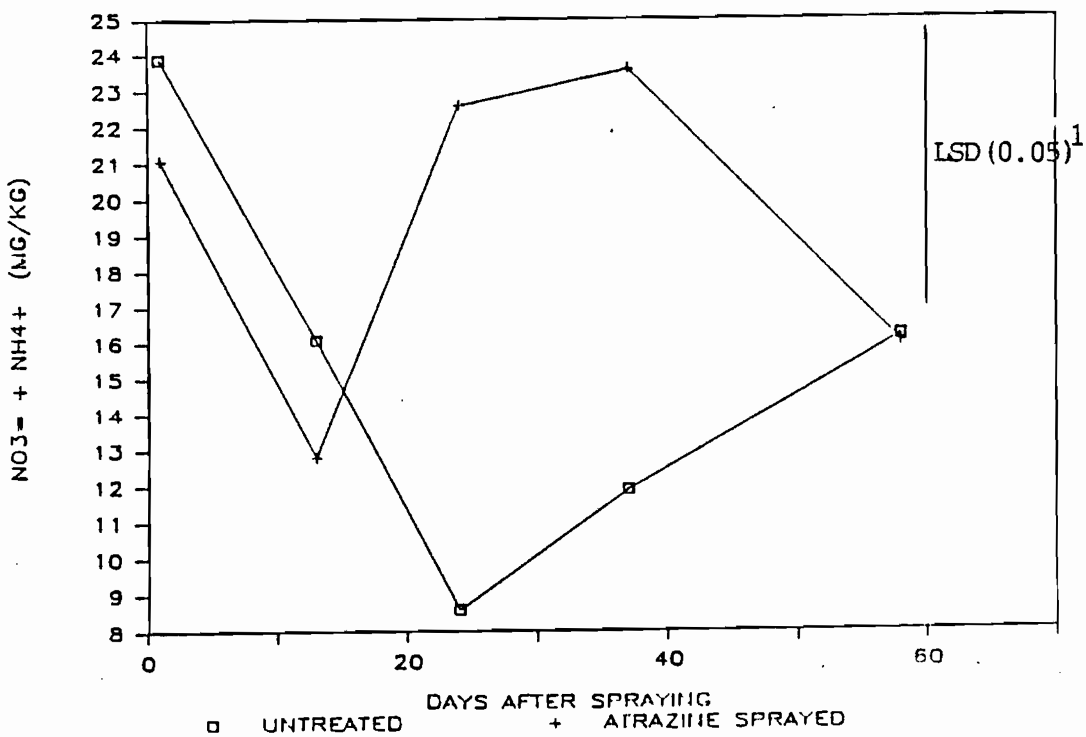
1 Differences between two means within a given sampling date (days after spraying)were not significant ($p > 0.05$) in the analysis of variance for a split plot-design.

Figure 20. Nitrate and ammonium concentration in the soil solution of the 0 to 60cm depth of soil under a white clover sward after it was sprayed with atrazine or left untreated (1985).



1 LSD bar is valid to compare points on different lines, within the same sampling date (days after spraying).

REFERENCES

Adams, W.E., J.E. Pallas, Jr., and R.N. Dawson. 1970. Tillage methods for corn-sod systems in the southern Piedmont. Agron. J. 62:646-649.

Akobundu, I.O. 1980. Live mulch: a new approach to weed control and crop production in the tropics. Proc. 1980 British Crop Prot. Conf. - Weeds 2:377-382.

Akobundu, I.O. and B.N. Okigbo. 1984. Preliminary evaluation of ground covers for use as a live mulch in maize production. Field Crops Res. 8:177-186.

Allen, J.R., and R.K. Obura. 1983. Yield of corn, cowpea, and soybean under different intercropping systems. Agron.J. 75:1005-1009.

Allen, L.H., Jr., T.R. Sinclair, and E.R. Lemon. 1976. Radiation and microclimate relationships in multiple cropping systems. Pages 171-200 in Multiple Cropping. Amer. Soc. Agron. 27.

Altieri, M.A., and M. Liebmann. 1986. Insect, weed and plant disease management in multiple cropping systems. Pages 183-218 in Francis, C.A. (Ed.). Multiple Cropping Systems. MacMillan Publishing Co. New York.

Assemat, L. 1986. Fan design and weed competition studies. Pages: 69-74 in Proc. Europ. Weed Res. Soc. Symp. Econ. weed control.

Atkinson, D., and M.G. Johnson. 1979. The effect of orchard soil management on the uptake of nitrogen by established apple trees. Sci. Food Agr. 30:129-135.

Baker, E.F.I. 1979. Population, time and crop mixtures. Pages 52-60 in International Crops Rresearch Institute for the Semi-Arid Tropics Internat. Workshop on Intercropping India.

Beale, O.W., G.B. Nutt, and T.C. Peele. 1985. The effects of mulch tillage on runoff, erosion, soil properties and crop yield. Soil. Sci. Soc. Amer. Proc. 19:244-247.

Bleasdale, J.K.A. 1967. Systematic designs for spacing experiments. Expl. Agric. 3:73-85.

Broughton, W.J. 1977. Effect of various covers on soil fertility under *Hevea brasiliensis* Arg. and on growth of the tree. Agro-Ecosystems 3:147-170.

Brown, R.H., E.R. Beaty, W.J. Ethredge, and D.D. Hayes. 1970. Influence of row width and plant population on yield of two varieties of corn (*Zea mays* L.). Agron. J. 62:767-770.

Burwell, R.E., D.R. Timmons, and R.F. Holt. 1975. Nutrient transport in surface runoff as influenced by soil cover and seasonal periods. Soil Sci. Soc. Amer. Proc. 39:523-528.

Butler, G.W., R.M. Greenwood, and K. Soper. 1959. Effects of shading and defoliation on the turnover of root and nodule tissue of plants of Trifolium repens, T. pratense, and Lotus uliginosus. N. Z. J. Agric. Res. 2(3):415-426.

Burnside, O.C. and W.L. Colville. 1963. Soybean and weed yields as affected by irrigation, row spacing,tillage and amiben. Weeds 12:109-112.

Caldwell, M.M., D.M. Eissestat, and J.H. Richards. 1985. Competition for phosphorus: differential uptake from dual isotope-labeled soil interspaces between shrub and grasses. Science 229:384-386.

Cantor, K.P. and A. Blair. 1986. Agricultural chemicals, drinking water and public health: an epidemiologic overview. Workshop paper No.2 at the 1986 meeting of the Soil Sci. Soc. of America.

Cardina, J. and N.L. Hartwig. 1982. The influence of nitrogen, corn population and crownvetch cover crop on weed-corn competition. Page 60 in Abstr. 1982 Meeting Weed Sci. Soc. of America. Abst. no. 115.

Chan, S.S., R.W. McCreight, J.D. Walstad, and T.A. Spies. 1986. Evaluating forest vegetative cover with computerized analysis of fisheye photographs. Forest Sci. December 1986.

Colville, W.L. 1968. Influence of plant spacing and popu- lation on aspects of the microclimate within corn ecosystems. Agron. J. 60:65-67.

Connolly, J. 1986. Our difficulties with replacement series methodology in mixture experiments. J. Appl. Ecol. 23:125-137.

Cook, T. 1982. The potential of turfgrass as living mulches in cropping systems. Pages 23-35 in Miller J.C. and S.M. Bell. Workshop Proc. Crop Production using cover crops and sods as living mulches. Oregon State Univ. IPPC Doc. 45-A-82.

Cooper, A.S. 1985. Sweet corn (Zea mays L) production in a white clover (Trifolium repens L.) living mulch: the establishment year. Ms Thesis. Crop Sci. Dept., Oregon State Univ. Corvallis, Oregon.

Cooper, C.S. 1977. Growth of the legume seedling. Adv. in Agron. 29:119-139.

Daniel, T.C., D.H. Mueller, R.C. Wendt, and G. Jackson. 1980. Conservation tillage of corn. Univ. of Wisconsin - Extension. Bulletin No. A3091.

De Calesta, D.S. 1982. Potential rodent problems in a living mulch system. Pages 36-43 in Miller, J.C. and S.M. Bell. Workshop Proc. Crop production using cover crops and sods as living mulches. Oregon State Univ. IPPC Doc. 45-A-82.

Donald, C.M. 1963. Competition among crops and pasture plants. Adv. in Agron. 15:1-118. Acad. Press, New York.

Duncan, W.G. 1969. Cultural manipulation for higher yields. In Eastin, J.D., F.A. Haskins, C.Y. Sullivan, and C.H.M. van Bavel (eds.). Physiological aspects of crop yield. Amer. Soc. Agron. Madison. 396pp.

Duncan, W.G. 1975. Maize. In Evans, L.T. (ed.). Crop physiology, some case histories. Cambridge University Press. London. 374 pp.

Ebelhaar S.A. and W.W. Frye. 1981. Legumes boost nitrogen for no-till corn. Crops and Soils Magazine. October. Pages 10-11.

Elkins, D.M., J.W. Van de Venter, G. Kapusta, and M. Anderson. 1979. No-tillage maize production in chemically suppressed grass sod. Agron. J. 71:101-105.

Fischer, R.A. and R.E. Miles. 1973. The role of spatial patterns in the competition between crop plants and weeds. A theoretical analysis. Math. Biosci. 18: 335-350.

Freyman, S. and D. Dolman. 1971. A simple systematic design for planting density experiments with set row width. Can. J. Plant Sci. 51:340-342.

Gaum, F.B., F.A. Seneca, and R.J. Lorenz. 1976. Multicropping in the Western United States. Pages 103-115 in Multiple Cropping. Amer. Soc. Agron. Special Publ. 27.

Ghafar, Z. and A.K. Watson. 1983. Effect of corn (Zea mays) population on the growth of yellow nutsedge (Cyperus esculentus). Weed Sci. 31:588-592.

Gliessman, S.R., R. Garcia E., and M. Amador A. 1981. The ecological basis for the application of traditional agricultural technology in the management of tropical agroeco-systems. Agroecosystems 7:173-185.

Gomez, A.A. and K.A. Gomez. 1983. Multiple cropping in the humid tropics of Asia. Internat. Dev. Res. Centre. Ottawa. 248pp.

Gray, B., M. Drake, and W.G. Colby. 1953. Potassium competition in grass-legume associations as a function of root cation exchange capactiy. Soil Sci. Soc. Amer. Proc. 17:237-239.

Gresshoff, P.M., D.A. Day, A.C. Delves, A.P. Matthews, J.E. Olsson, G.D. Price, K.A. Schuller, and B.J. Carroll. 1985. Plant host genetics of nodulations and symbiotic nitrogen fixation in pea and soybean. Pages 19-25 in Evans, H.J., P.J. Bottomley, and W.E. Newton. Nitrogen fixation research progress. M. Nijhoff Publ.

Hall, R.L. 1974. Analysis of the nature of interference between plants of different species. Nutrient relations in a Nandi Setaria and greenleaf Desmodium association with particular reference to potassium. Austr. J. Agric. Res. 25:749-756.

Hargrove, W.L. 1982. Proc. Minisymp. on legume cover crops for conservation tillage production systems. The Univ. of Georgia, Coll. of Agric. Exp. Stns. Sp. Publ. no.19.

Harper, J.L. 1977. Population biology of plants. Academic Press, New York. 892pp.

Harper, L.A., S.R. Wilkinson, and J.E. Box Jr. 1980. Row-Plant spacing and broiler litter effects on intercropping corn in tall fescue. Agron. J. 72:5-10.

Hartwig, N.L. 1977. Nutsedge control in no-till corn with and without a crownvetch cover crop. Proc. Northeast Weed Sci. Soc. 31:20-23.

Harvard, M.E., G.F. Kling, and J.D. Istok (eds.). 1980. Erosion, sediment and water quality in the high winter-rainfall zone of the northwestern United States. Oregon Agric. Exp. Stn. Special Report 602.

Hinton, A.C. and P.L. Minotti. 1982. Living mulch initial investigations in a grass sod-dry bean system. Proc. Northeast. Weed Sci. Soc. 36:110.

Hoglund, J.H. and J.L. Brock. 1978. Regulation of nitrogen fixation in a grazed pasture. N. Z. J. of Agric. Res. 21: 73-82.

Holliday, R. 1963. The effect of row width on the yield of cereals. Field Crop. Abstr. 16:71-81.

Hunt, R. 1982. Plant growth curves-the functional approach to plant growth analysis. University Park Press, Baltimore. 248pp.

Huxley, P.A. and Z. Maingu. 1978. Use of a systematic spacing design as an aid to the study of intercropping: some general considerations. Expl. Agric. 14:49-56.

International Institute for Tropical Agriculture (IITA). 1985. Pages: 41-43 in Annual Report and Research Highlights. Ibadan, Nigeria.

International Rice Research Institute (IRRI). 1974. Multiple cropping. Pages 15-34 in IRRI annual report for 1973. Los Banos, The Philippines.

Jenny, H. 1933. Soil fertility losses under Missouri conditions. Missouri Agr. Expt. Stn. Bull. 324. 10pp.

Jolliffe, P.A., A.N. Minjas, and V.C Runeckles. 1984. A reinterpretation of yield relationships in replacement series experiments. J. Appl. Ecol. 21:227-243.

Kass, C.L. 1978. Polyculture cropping systems: Review and analysis. Cornell Internat. Agr. Bull. 32. 69pp.

Keeley, P.E. and R.A. Peters. 1965. Proc. Northeast Weed Control Conf. 19:333-342.

Kurtz, T., S.W. Melsted, and R.H. Bray. 1952. The importance of nitrogen and water in reducing competition between intercrops and corn. Agron. J. 44:13-17.

Kurtz, T., M.D. Applemann, and R.H. Bray. 1946. Preliminary trials with intercropping of corn and clover. Pages 349-355 in Soil Science Proc. 1946.

Lang, A.L., J.W. Pendleton, and G.H. Dungan. 1956. Influence of population and nitrogen levels on yield and protein and oil content of nine corn hybrids. Agron. J. 48:284-289.

Langdale, G.W. 1983. Legumes in cropping systems - water conservation and use in the southeast. Pages 11- 13 in Report Work Planning Conf. on legumes in conservation tillage systems. Lincoln, Nebraska.

Ledig, F.T. 1974. Concepts of growth analysis. Pages 166-182 in Reid and Fechner (eds.). Proc. Third North American Forest Biol. Workshop. Coll. of For. and Nat.Res., Colorado State Univ., Fort Collins.

Lima, A.F. and L.H.O. Lopes. 1979. Plant population and spatial arrangement study on the intercropping of maize and beans (Phaseolus vulgaris L.) in northeast Brazil. Pages 41-57 in Proc. International Crops Research Institute for the Semi-Arid Tropics Internat. Workshop on Intercropping. India.

Lindemann, W.C., G.E. Ham, and G.W. Randall. 1982. Soil compaction effects on soybean nodulation, N_2 (C_2H4) fixation and seed yield. Agron. J. 74:307-311.

Mack, H.J. 1972. Effects of population, density, plant arrangement, and fertilizers on yield of sweet corn. J. Amer. Soc. Hort. Sci. 97:757-760.

Mannering, J.V., L.D. Meyer, and C.B. Johnson. 1968. Effect of cropping intensity on erosion and infiltration. Agron. J. 60:206-209.

Mansour, N.S. 1975. Commercial production of sweet corn for processing in Oregon. Extension circular 863. Extension Service, Oregon State Univ., Corvallis, Oregon.

McAuliffe, C., D.S. Chamblee, H. Uribe-Arango, and W.W. Woodhouse Jr.. 1958. Influence of inorganic nitrogen on nitrogen fixation by legumes as revealed by N^{15}. Agron. J. 50:334-337.

Mead, R. and R.D. Stern. 1980. Designing experiments for intercropping research. Expl. Agric. 16:329-342.

Medd, R.W., B.A. Auld, D.R. Kemp, and R.D. Murison. 1985. The influence of wheat density and spatial arrangement on annual ryegrass, Lolium rigidum Gaudin, competition. Aust. J. Agric. Res. 36:361-371

Mengel, K. and E.A. Kirby. 1982. Principles of plant nutrition. Internat. Potash Inst. Bern. 655pp.

Miles, S.D. 1986. 1985 Oregon Country and State Agricultural estimates. Oregon State Univ. Ext. Service Sp. Report 761. 13pp.

Miller, J.C., and S.M. Bell (eds). 1982. Crop production using cover crops and sods as living mulches. Workshop proceedings Internat. Plant Protect. Ctr. Oregon St. Univ. Corvallis, Oregon. 124 pp.

Mitchell, W.H., and M.R. Teel. 1977. Winter annual cover crops for no-tillage crop production. Agron. J. 69:569-573.

Moss, J.D. and H.J. Mack. 1979. Effects of plant density and nitrogen fertilizer on sweet corn. HortScience 14:176-177.

Movat, C.H. and T.W. Walker. 1959. Competition for nutrients between grasses and white clover. Plant and soil 11:30-40.

Nataranan, M. and R.W. Willey. 1979. Growth studies in sorghum-pigeonpea intercropping with particular emphasis on canopy development and light interception. Pages 181-201 in International Crops Research Institute for the Semi-Arid Tropics Internat. Workshop on Intercropping. India.

Nelder, J.A. 1962. New kinds of systematic designs for spacing experiments. Biometrics 18 (3):283-307.

Ogg, A. 1982. Vegetation management in peach orchards. Pages 44-45 in Workshop Proc. Crop Production using cover crops and sods as living mulches. Oregon State Univ. IPPC Doc. 45-A-82.

Okigbo, B.N. 1979. Evaluation of plant interaction and productivity in complex mixtures as a basis for improved cropping system designs. Pages 155-179 in International Crops Research Institute for the Semi-Arid Tropics Internat. Workshop on Intercropping. India.

Oliver, L.R. 1979. Influence of soybean (Glycine max) planting date on Velvetleaf (Abutilon teophrasti) competition. Weed Sci. 27:183-188.

Osiru, D.S.O., and G.R. Kibira. 1979. Sorghum/pigeonpea and finger millet/groundnut mixtures with special reference to plant population and crop arrangement. Pages 78-85 in International Crops Research Institute for the Semi-Arid Tropics Internat. Workshop on Intercropping. India.

Pant, M.M. 1979. Dependence of plant yield on density and planting pattern. Ann. Bot. 44:513-516.

Patterson, D.T. 1982. Effects of light and temperature on weed/crop growth and competition. In Hatfield and Thomason (eds.). Biometeorology in integrated pest management. Academic Press, New York.

Pavlychenko, T.K. 1940. Investigations relating to weed control in Western Canada. Imp. Bur. Pastures and Forage Crops. Herbage Publ. Serv. Bull. 27. Aberystwyth, Wales.

Pendleton, J.W., J.A. Jacobs, W. Slife, and H.P. Bateman. 1956. Establishing legumes in corn. Agron. J. 48:44-48.

Peterson, A.E. 1985. Establishing alfalfa in wide-row corn. Plt.Food Review 1:16-17, 30-31.

Phillips, R.E. and S.H. Phillips. 1984. No-tillage agricultural principles and practices. Van Norstrand Reinhold Co. 306pp.

Pons, T.L. and H.W.G. van Wieringen. 1985. Effect of nitrogen fertilizer on competition of (Marsilea crenata Presl.) with rice. Biotrop Bulletin 23:59-65.

Radosevich, S.R. 1987. Methods to study interactions among crops and weeds. Weed Technol. 1:190-198.

Radosevich, S.R. and J.S. Holt. 1984. Weed ecology implications for vegetation management. John Wiley & Sons, New York. 265pp.

Rajat De, and S.P. Singh. 1979. Management practices or intercropping systems. Pages 17-21 in Inernational Crops Research Institute for the Semi-Arid Tropics Internat. Workshop on Intercropping. India.

Rao, M.R. and R.W. Willey. 1978. Current status of intercropping research and some suggested experimental approaches. Pages 123-137 in Ahmed, S. and H.P.M. Gunasena (eds.) Proc. Sand. review meeting I.N.P.U.T.S. project. Hawaii.

Rogers, W.S., T. Raptopoulos, and D.W.P. Greenam. 1948. Cover crops for fruit plantations: IV. Long term lays and permanent swards. J. Hort. Sci. 24:280-270.

Roush, M.L., and S.R. Radosevich. 1985. Relationships between growth and competitiveness of four annual weeds. J. Appl. Ecol. 22:895-905.

Schweitzer, E.E. and L.D. Bridge. 1982. Sunflower (Helianthus annuus) and velvet leaf (Abutilon theophrasti) interference in sugarbeets (Beta vulgaris). Weed Sci. 30:514-519.

Silvertown, J.W. 1982. Introduction to plant population ecology. Longman, London. 209pp.

Snaydon, R.W. and P.M. Harris. 1979. Interactions below ground - the use of nutrients and water. Pages 188-201 in International Crops Research Institute for the Semi-Arid Tropics Internat. Workshop on Intercropping. India

Spitters, C.J.T. 1983. An alternative approach to the analysis of mixed cropping experiments. 2. Marketable yield The Netherlands J. Agric. Sci. 31:143-155.

Spitters, C.J.T. 1980. Competition effects within mixed stands. Pages 219-231 in Hurd, R.G., P.V. Briscoe, and C. Dennis (eds.). Opportunities for increasing crop yields. Pitman Publ. London.

Spitters, C.J.T. and J.P. van den Bergh. 1982. Competition between crop and weeds: a system approach. Pages 137-148 in Holzner, W. and N. Numata (eds.). Biology and ecology of weeds. Dr. W. Junk Publishers. The Hague.

Stivers, R.K. 1956. Influence of interplanting of corn and Ladino clover on the yields of corn. Agron.J. 48 (3):97-98.

Sweet, R.D. 1982. Observations on the uses and effects of cover crops in agriculture. Pages 7-22 in Miller J.C. and S.M. Bell Workshop Proc. Crop production using cover crops and sods as living mulches. Oregon State Univ. IPPC Doc. 45-A-82.

Taylor, H.M. 1980. Soybean growth and yield as affected by row spacing and by seasonal water supply. Agron. J. 72:543-547.

Trenbath, B.R. 1976. Plant interactions in mixed crop communities. Pages 129-161 in Multiple Cropping. Amer. Soc. Agron. Sp. Publ. 27.

Unger, P.W. and T.M. McCalla. 1980. Conservation tillage systems. Adv. in Agron. 33:2-58.

Vengris, J., W.G. Colby, M. Drake. 1955. Plant nutrient competition between weeds and corn. Agron. J. 47:213-216.

Voelkner, H. 1979. Urgently needed: an ideal green mulch for the tropics. World Crops 31:76-78.

Vomocil, J. 1977. Compaction of soil by agricultural equipment. Div. of Agr. Sci., Univ. of California. Bull. 1881. 53pp.

Vomocil, J. and W.J. Flocker. 1961. Effect of soil compaction on storage and movement of soil and water. Transactions of the ASAE 1961. Pages 242-246.

Vrabel, T.E. 1983. Effect of suppressed white clover (*T. repens* L.) on sweet corn (*Z. mays* L.) yield and nitrogen availability in a living mulch cropping system. PhD. thesis. Cornell Univ.. Ithaca, New York.

Vrabel, T.E., P.L. Minotti, and R.D. Sweet. 1981. Legume sods as living mulches in sweet corn. Proc. Northeast Weed Sci.Soc. 35:158-159.

Wahua, T.A.T. and D.A. Miller. 1978. Relative yield totals and yield components of intercropped sorghum and soybeans. Agron. J. 70:287-291.

Walker, T.W., H.D. Orchiston, and A.R.F. Adams. 1954. The nitrogen economy of grass-legume associations. J. Brit. Grassl. Soc. 9:249.

Walker, R.H. and G.A. Buchanan. 1982. Crop manipulation in integrated weed management systems. Weed Sci. 30 (Suppl.) :17-24.

Westoby, M. 1980. The place of the self-thinning rule in population dynamics. Amer. Naturalist 118:581-587.

White, A.W., Jr., E.R. Beaty, and W.L. Tedders. 1981. Legumes for supplying nitrogen and studies on legumes in pecan orchards. Pecan South. June. Pages 24-31.

Wiese, A.F., J.W. Collier, L.E. Clark, and U.D. Havelka. 1964. Effects of weed and cultural practices on sorghum yields. Weed Sci. 12:209-211.

Willey, R.W. 1979. A scientific approach to intercropping research. Pages 4-14 in Inernational Crops Research Institute for the Semi-Arid Tropics Internat. Workshop on Intercropping. India.

Wit, C.T. de and J.P. van den Bergh. 1965. Competition between herbage plants. The Netherlands J. Agric. Sci. 13:212-221.

Wit, C.T. de. 1960. On competition. Versl. landbouwk. Onderz. (Agricultural Research Reports) 66(8):1-82. Wageningen: Pudoc

Zimdahl, R.L. 1980. Weed-Crop competition: A Review International Plant Protection Center. Oregon State Univ. Corvallis, Oregon. 196pp.

APPENDIX

Appendix table 1. Soil characteristics.

	Location	
Series	Hyslop Woodburn[2]	Hort. Farm Chehalis[3]
Texture[1]	sl	scl
pH	6	6.3
Organic matter (g/kg)	25	25
Phosphorus (mg/kg)	122	25
Potassium (mg/kg)	254	160
Sulfur (mg/kg)	10.5	4.1

[1] sl = silty loam, scl = silty clay loam.
[2] Fine-silty, mixed, Aquultic Argixeroll.
[3] Fine-silty, mixed mesic Cumulic Ultic Haploxeroll.