AN ABSTRACT OF THE THESIS OF

Lori Jeannine Wiles for the degree of Master of Science
in Horticulture presented on July 3, 1986.
Title: MANAGING GROWTH AND COMPETITION OF A PERENNIAL RYEGRASS (LOLIUM PERENNE L.) LIVING MULCH IN A VEGETABLE CROPPING SYSTEM

Abstract approved: ______________________
Ray D. William

Vegetable production with a living mulch may reduce soil erosion and compaction, increase organic matter levels, and decrease the requirement for chemical inputs. Competition between the vegetable and mulch, however, has limited the development of successful living mulch systems to realize these benefits.

In a field study, interference between pak choi (*Brassica campestris* L.) and a living mulch of 'Manhattan II' perennial ryegrass (*Lolium perenne* L.) managed with mechanical, chemical, or no supression was investigated. In growth chamber and field studies, the effect of management on ryegrass dry matter production and allocation was studied by growth analysis of individual plants.

Results of the interference study suggest pak choi can be interplanted with ryegrass seeded at rates of up to 45 kg/ha. In a mixture of pak choi thinned to 36,000 plants/ha and ryegrass seeded at a rate of 90 kg/ha, the ryegrass competed and pak choi

yield was reduced 24%. Mowing twice or applying fluazifop-p-butyl ((±)-2-[4-[[5-trifluoromethyl)-2-pyridinyl]oxy]phenoxy]propanoic acid) reduced ryegrass dry weight, but did not affect competition with the pak choi.

In the growth analysis experiments, one application of fluazifop-p-butyl or withholding nitrogen altered dry matter allocation between roots and shoots and reduced dry matter production of the ryegrass. Shoot yield was affected more than root yield. Mowing subtly altered growth and did not consistently reduce grass dry weight.

Studying vegetable yield reductions in living mulch systems as competitive interactions and characterizing managed mulch growth with growth analysis may provide some insight into the competitive interactions. With greater insight into the competitive process, successful mulch management strategies may be efficiently developed.

MANAGING GROWTH AND COMPETITION OF A PERENNIAL RYEGRASS (<u>LOLIUM</u> <u>PERENNE</u> L.) LIVING MULCH IN A VEGETABLE CROPPING SYSTEM

by

Lori Jeannine Wiles

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed July 3, 1986

Commencement June 1987

APPROVED:

Professor of Horticulture in charge of major

Head of Deparment of Horticulture

Dean of the Graduate School

Date thesis presented July 3, 1986

Typed by Lori J. Wiles

This thesis is dedicated to the memory of
the serenity, courage, and wisdom of my grandmother,
Lena Cage

ACKNOWLEDGEMENTS

I would like to thank my committee, Drs. Ray William, Garvin Crabtree, and Steve Radosevich, for their assistance and support and for the freedom they gave me to follow a rather unusual program for either a horticulture or weed science student. There would not have been a cabbage patch, and then no field data, without the patience and assistance of Randy Hopson, Scott Robbins, and especially Dr. Jim Baggett. Also, I would like to thank the faculty, staff, and graduate students of the Horticulture Department, as well as the "Weed Group", for their encouragement, support, humor, and willingness to provide diversion when needed. In particular, the friendship of Patti, Mark, Karen, Wayne, Loretta, Fred, and Nancy was instrumental in completion of this thesis.

I would not have found my way to Oregon without the encouragement of Drs. R. D. Sweet and W. C. Kelly of Cornell University. Finally, my grandparents, Mr. and Mrs. D. M. Wiles, provided my early horticultural training during childhood summers in West Virginia. I have not since planted an onion upside-down.

TABLE OF CONTENTS

Page

Chapter 1. INTRODUCTION 1

Chapter 2. REVIEW OF THE LITERATURE 3

LIVING MULCH SYSTEMS FOR ROW CROPS 3
THE STUDY OF COMPETITION 9

Chapter 3. MANAGING COMPETITION OF A PERENNIAL RYEGRASS (LOLIUM PERENNE L.) LIVING MULCH IN A VEGETABLE CROPPING SYSTEM 12

ABSTRACT 12
INTRODUCTION 13
MATERIALS AND METHODS 15
RESULTS AND DISCUSSION 18

Chapter 4. MANAGING GROWTH OF A PERENNIAL RYEGRASS (LOLIUM PERENNE L.) LIVING MULCH 27

ABSTRACT 27
INTRODUCTION 28
MATERIALS AND METHODS 30
  1984 Growth Analysis 30
  1986 Growth Analysis 32
RESULTS AND DISCUSSION 35
  1984 Growth Analysis 35
  1986 Growth Analysis 46
  Growth and Competition 56

BIBLIOGRAPHY 63

LIST OF FIGURES

Figure | Page

Chapter 3

3.1 Pak choi interplanted with a 'Manhattan II' perennial ryegrass living mulch. 23

3.2 The effect of ryegrass seeding rate and management on ryegrass dry weight. 25

3.3 The effect of pak choi density, and ryegrass seeding rate and management on pak choi yield. 26

Chapter 4

4.1 The effect of management on unit leaf rate. 1984 experiment. 40

4.2 The effect of management on total dry weight. 1984 experiment. 41

4.3 The effect of management on root/shoot ratio. 1984 experiment. 42

4.4 The effect of management on root dry weight. 1984 experiment. 43

4.5 The effect of management on leaf area. 1984 experiment. 44

4.6 The effect of management on shoot dry weight. 1984 experiment. 45

4.7 The effect of management on unit leaf rate. 1986 experiment. 50

4.8 The effect of management on total dry weight. 1986 experiment. 51

4.9 The effect of management on root/shoot ratio. 1986 experiment. 52

4.10 The effect of management on leaf area. 1986 experiment. 53

4.11 The effect of management on shoot dry weight. 1986 experiment. 54

Figure Page

4.12 The effect of management on root dry weight. 1986 experiment. 55

LIST OF TABLES

Table Page

Chapter 3

3.1 Mean plant weight of pak choi weight in mixtures with a perennial ryegrass living mulch and in monocultures. 24

Chapter 4

4.1 Growth analysis definitions and formulas. 34

4.2 The effect of management on root, shoot, and total biomass duration, and leaf area duration. 1984 experiment. 39

4.3 The effect of management on relative growth rate and root and shoot component production rates. 1984 experiment. 39

4.4 The effect of management on root, shoot, and total biomass duration, and leaf area duration. 1986 experiment. 49

4.5 The effect of management on relative growth rate and root and shoot component production rates. 1986 experiment. 49

4.6 Predictions of the competitive ability of managed ryegrass by growth analysis parameters. 1984 experiment. 61

4.7 Predictions of the competitive ability of managed ryegrass by growth analysis parameters. 1986 experiment. 62

MANAGING GROWTH AND COMPETITION OF A PERENNIAL RYEGRASS (LOLIUM PERENNE L.) LIVING MULCH IN A VEGETABLE CROPPING SYSTEM

Chapter 1

INTRODUCTION

A living mulch planted between vegetable rows may reduce weed competition and soil erosion, increase soil organic matter, and diminish soil compaction by heavy equipment. These benefits may extend the period of cropping with a high value vegetable crop within a rotation or may reduce fertilizer and pesticide requirements. Interference between the vegetable and mulch, however, has been an obstacle in the development of systems to realize these benefits.

Interference in living mulch systems has been attributed most often to competition, yet little is known about the process leading to yield reductions. Efficient development of living mulch systems with minimal competition requires insight into the competitive interactions. For a better understanding of the competition, yield of both species must be measured and intraspecific and interspecific competition assessed. Studying mulch and crop resource utilization patterns with growth analysis may identify aspects of mulch growth crucial in the competitive process.

Interference in an annual living mulch-vegetable system with different mulch management regimes was studied. In a field experiment, interference between pak choi (Brassica campestris L.)

and a turf-type perennial ryegrass (_Lolium perenne_ L.), 'Manhattan II', managed with chemical, mechanical, or no suppression was assessed. The effect of management on mulch growth was studied with growth analysis of individual plants.

The purpose of this research was both applied and basic. The objectives were to identify mulch management options for optimizing vegetable yields in a newly planted perennial ryegrass mulch and to provide insight into the competitive interactions as a basis for extrapolation to different environments and mulch-crop combinations, or for development of alternate competition management strategies.

Chapter 2

LITERATURE REVIEW

LIVING MULCH SYSTEMS FOR ROW CROPS

In living mulch systems, a cover crop is grown simultaneously with the economic crop. Although the term 'living mulch' is of recent origin (2,29), the concept is not. As early as the 1930's and 1940's, intercropping corn (Zea mays L.) and legumes was studied to increase production efficiencies (31,32,37,39). Planting companion crops in soybeans (Glycine max L.) was examined in the 1950's as an inexpensive weed control method (49). Later, corn grown in an established living mulch grass or legume sod was proposed to enhance no-till systems (1,4,6,8,11,17,24,25,33).

Living mulch concepts for annual crops currently encompass the production of row crops in established or annually planted mulches. The mulch may be a legume or a grass, and mulch growth may be regulated during crop production. Spatial arrangement varies from no-till to a mulch planted only between some rows. Recently, living mulch production of corn (3,9,19,24,27,33), soybeans (18,27,48,46,58,59), and several vegetable crops including cabbage (Brassica oleracea L.) (29,36,41,51), sweet corn (Zea mays L.) (14,21,41), dry beans (Phaseolus vulgaris L.) (26), tomatoes (Lycopersicon esculentum Mill.) (21), peppers (Capiscum annuum L.) (34), and squash (Cucurbita spp.) (34,44) has been investigated.

The motive for adding a living mulch varies with the cropping system. The potential benefits of living mulch systems have been reviewed by several authors (2,14,28,40,46,57). A living mulch system may reduce soil erosion, stabilize organic matter levels, improve soil structure, reduce weed competition, and diminish soil compaction by heavy equipment. Some mulches may be harvested as forage. Pest problems may be reduced in some systems while legume mulches may supply nitrogen to the crop. These benefits may extend the cropping period for a high value row crop or may reduce fertilizer and pesticide requirements.

With few exceptions, adding a living mulch to a row crop system has reduced crop yields. The exceptions most often involve a newly planted mulch and include a winter wheat (*Triticum aestivum* L.) or winter rye (*Secale cereale* L.) mulch planted immediately following soybeans (49), a red fescue (*Festuca rubra* L.), tall fescue (*Festuca arundincea* Schreb.), or bentgrass (*Agrostis tenuis* Sibth.) mulch planted thirty days after dry beans (26), or legumes planted simultaneously with sweet corn (59). Yield reductions may depend on environmental conditions during the season (1,18,51,57) or the specific crop and mulch combination (1,6,16,34). Although benefits of the living mulch may have economic value (25,32), consistent maintenance of crop yields is critical for grower acceptance of this intensive system (54).

A plant may reduce the yield of a neighbor by several mechanisms. In agricultural systems, likely mechanisms for this interference include environmental modification (56), allelopathy

(23,47), and competition (23,47). Competition is the simultaneous demand by more than one plant for the same resources (15). Yield reductions in living mulch systems are attributed most often to competition. Allelopathy, however, was suggested as a mechanism in a soybean and rye (*Secale cereale* L.) system (48). Several living mulches, including perennial ryegrass (*Lolium perenne* L.), are believed to be allelopathic (20). Environmental modification may contribute to yield reductions by reduced soil temperatures which delay crop germination, or by increased pest problems (46,57).

The process of competition in living mulch systems, as in most intercropping systems, is poorly understood. Below-ground interactions are more important than above-ground interactions (1,6,10,11,19,24,33,34,36,44,51). Both nitrogen (6,10,11,31,36) and water (1,11,19,33,34,44,45,57) have been identified as limiting for crop growth in some systems. Competition for light may be important, however, with a crop planted into an established mulch (9,14,32).

The primary strategy for consistent reduction of competition between the mulch and crop has been suppression of mulch growth. The ideal living mulch is envisioned as becoming dormant during crop growth in response to an internal or external signal or condition (2,54). The validity of this concept is demonstrated by the minimal competition between a mulch of winter wheat (*Triticum aestivum* L.) or winter rye established simultaneously with soybeans (49). The winter grains rapidly produced a dense vegetative cover which competed against weeds, but in July when vegetative growth of the soybeans was vigorous, the grains were stressed and did not compete. Similarly, red fescue was observed to compete more severely with corn than cabbage (41). The growth period of the fescue overlaps more with the growth of corn than cabbage. In most cases, however, mulches must suppressed by chemical or mechanical means.

Chemical suppression is considered essential for successful production of corn in established crown vetch (*Coronilla varia* L.) (25), tall fescue (19), or Kentucky bluegrass (*Poa pratensis* L.) (19), or the production of sweet corn in established (46,57) or newly planted (14) white clover (*Trifolium repens* L.). Chemical suppression is necessary for soybean production in tall fescue (18).

Both plant growth regulators (1,3,14,18,19,34,48) and sublethal rates of herbicides (2,6,11,14,18,19,25,29,46) have been tested for mulch suppression. Triazine herbicides have been used successfully in corn-legume systems (14,46,57). Crown vetch in corn may be suppressed with dicamba (3,6-dichloro-2-methoxybenzoic acid) and a combination of glyphosate (N-(phosphonomethyl)glycine), atrazine (2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine), and 2,4-D ((2,4-dichlorophenoxy)acetic acid) (25). Elkins et al. outlined several herbicide and growth regulator treatments for minimal mulch-crop competition but sufficient mulch growth for forage with soybean (18) or corn (19) production in established tall fescue or

Kentucky bluegrass.

Few chemicals have been tested for the suppression of a grass mulch in broadleaf vegetables. Mefluidide (N-(2,4-dimethyl-5-(((trifluoromethyl)sufonyl)amino)phenyl)acetamide) at 0.28 kg ai/ha did not eliminate yield reductions of pepper or squash in established mulches of Kentucky bluegrass, creeping red fescue, and perennial ryegrass, or a mixture of these grasses and white clover (34). The rate used suppressed grass growth poorly. Suppression of rye, perennial ryegrass and spring-seeded oats (*Avena sativa* L.) in cabbage or beets (*Beta vulgaris* L.) was inadequate or too severe with HOE 29152 and diclofop (2-[4-(2,4-dichlorophenoxy)phenoxy]propanic acid) (29).

The potential of mechanical suppression of living mulches to reduce competition has not been fully investigated. Crop yields were reduced in earlier systems which included mowing up to three times during the season (32,45). Mowing white clover to a height of 2 cm in non-irrigated sweet corn did not eliminate yield reductions in dry years (57). Sweet corn yield also was reduced by an established (46) or newly planted (14) white clover mulch mowed twice during the season. Mowing when an established grass or grass and clover mulch attained a height of 15 to 20 cm did not maintain yields of squash or pepper (34). In contrast, season-long mowing or mowing for 8 weeks after planting and then killing any remaining mulch with sethoxydim (2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one) maintained soybean yield in a fall-seeded winter wheat mulch (48). In a spring-seeded winter rye, soybean yield was maintained with season-long mowing or mowing for 6 to 8 weeks and then killing the mulch (48).

The recent innovations of improved turfgrass cultivars and new postemergence grass herbicides may facilitate the management of competition between a broadleaf vegetable and a grass living mulch. In particular, improved perennial ryegrass varieties have several characteristics for recommendation as living mulches (13). Perennial ryegrass is competitive against weeds by rapid germination and establishment. As a bunchgrass, it will not creep into the crop row. The responsiveness of perennial ryegrass to nitrogen and soil moisture may allow growers to control ryegrass growth by manipulating these resources. New cultivars have a slower vertical growth rate (5).

Fluazifop-p-butyl ((±)-2-[4-[[5-(trifluoromethyl)-2-pyridinyl]oxy]phenoxy]propanoic acid) and sethoxydim are new postemergence herbicides for the control of annual and perennial grasses in soybeans and other broadleaf crops (12). These herbicides inhibit meristem growth of roots, shoots, and rhizomes (16). Growth of some perennial ryegrasses can be suppressed for several weeks with sublethal rates (61,63). A single application of fluazifop-p-butyl at 0.11 to 0.45 kg ai/ha or sethoxydim at 0.01 to 0.04 kg ai/ha suppressed growth of 'Manhattan II' perennial ryegrass for 8 weeks without stand reduction (63). In addition, tolerance of several broadleaf vegetables to these chemicals suggests selectivity at grass suppression rates

(7,38,42). Injury observed has been contact in nature (7,38) and may have been related to warm, humid conditions (7) or to the use of adjuvants (7).

These two technologies integrated may compose a useful management strategy for minimizing competition in living mulch production of broadleaf vegetables.

THE STUDY OF COMPETITION

Efficient development of management strategies for minimizing the competition between a row crop and a living mulch must ultimately be based on an understanding of the process of the competition. Most of our knowledge of living mulch competition is derived from studies in which resource levels are measured or controlled, or from observations of competition between species with different growth habits or the same species grown under different environmental conditions (1,6,16,18,34,51,57).

Replacement series experiments provide some insight into the interactions between two species (23,47). In this type of experiment, final biomass data of each species is collected from mixtures and monocultures with total density held constant while the proportion of the density contributed by each species is varied. With sufficient density for plants to interfere, competition can be identified as a mechanism of interference. The relative competitiveness of the species and the degree to which the species escape competition by exploiting different resources can be described. Unfortunately, the mixtures needed for this information do not correspond well with mixtures of pratical interest for crop production in a living mulch.

An addition series corresponds better with the pratical species mixtures of living mulch systems. Both total density and species proportion are varied systematically in this design (47,52). Recently, a model has been proposed for analyzing competitive interactions from the biomass yield of an addition series (52,53,64). The basis for this model is a hyperbolic relationship between density and biomass. Assuming all interference observed is competition, the relative abilities and the degree to which the species avoid competition can be estimated.

Replacement series and addition series experiments may identify competitive relationships, but provide no insight into how the relationships developed. Different experiments are needed to understand the process of the interaction (28,47,53). One approach for understanding and predicting competition has been mathematical growth analysis of the species grown in isolation (22,23,43,47). Since competition involves resource limitation and plant growth reflects exploitation of resources, growth of a plant in isolation may indicate the potential to compete. In growth analysis experiments, basic data from periodic destructive harvests are used to quantify dry matter production and partitioning over time (30).

Patterson (43) suggested several growth analysis parameters which may be relevant to the study of the competitive ability of a species. These parameters include leaf area duration (total amount of leaf area present during a particular period), relative growth rate (relative increase in plant material per unit time), and leaf area ratio (amount of leaf area per unit of total plant weight). Grime and Hunt (22) related a high maximum relative growth rate to the superior competitive ability of plants in some environments. Relative growth rate, however, was not correlated with the relative competitive abilities of four annual weeds (50). Plant size, net assimilation rate (unit leaf rate), and leaf area were better indicators of competitive ability.

The amount of living mulch growth has been related to competition with a row crop. Yield reductions have been associated with mulch regrowth after chemical suppression in several systems (6,14,54,55,58). Sweet corn and cabbage yield parameters were negatively correlated with the shoot yield of an associated legume or grass mulch (41). Deviations from this trend were tenatively attributed to temporal differences in growth. Mathematical growth analysis has not been used to study competition in living mulch systems.

Chapter 3

MANAGING COMPETITION OF A PERENNIAL RYEGRASS (LOLIUM PERENNE L.) LIVING MULCH IN A VEGETABLE CROPPING SYSTEM

ABSTRACT

Interference between pak choi (Brassica campestris L.) and a newly planted living mulch of 'Manhattan II' perennial ryegrass (Lolium perenne L.) was investigated in an addition series experiment. Mulch growth was managed by chemical, mechanical, or no suppression.

Ryegrass seeded at rates of up to 45 kg/ha did not compete with pak choi. In a mixture of pak choi thinned to 36,000 plants/ha and ryegrass seeded at 90 kg/ha, ryegrass competed and pak choi yield was reduced 24%. One application of fluazifop-p-butyl ((±)-2-[4-[[5-(trifluoromethyl)-2-pyridinyl]oxy]phenoxy]-propanoic acid) at 0.17 kg ai/ha or mowing twice reduced ryegrass dry weight, but did not alter the competition. The presence of pak choi did not affect ryegrass dry weight in any mixture.

The potential for intercropping a vegetable and a perennial ryegrass living mulch and effective suppression of mulch growth with fluazifop-p-butyl is indicated. Further, studying yield reductions in living mulch systems as competitive interactions may permit efficient development of management strategies for minimizing competition.

INTRODUCTION

A living mulch intercropped with a vegetable may reduce weed competition and soil erosion, increase soil organic matter, and diminish soil compaction by heavy equipment (2,14,28,40,46,56,57). These benefits may extend the cropping period with a high value vegetable crop within a rotation or may reduce fertilizer and pesticide requirements. Interference between the vegetable and the mulch, however, has limited the development of systems to realize these benefits. This interference has been attributed most often to competition.

The introduction of improved turfgrass cultivars and new postemergence grass herbicides may facilitate development of living mulch-broadleaf vegetable systems with minimal competition. Improved turfgrass cultivars have a slower vertical growth rate (5). In addition, growth of several perennial grasses may be suppressed for several weeks with low rates of the new postemergence grass herbicides (61,63). Growth of 'Manhattan II' perennial ryegrass (Lolium perenne L.), an improved variety, was suppressed for six weeks at low rates of sethoxydim (2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one) or fluazifop-p-butyl (63). Most broadleaf vegetables appear tolerant to these rates (7,38,42).

Interference was investigated in an annual living mulch-vegetable system incorporating an improved turfgrass as the living mulch and mulch suppression with fluazifop-p-butyl. Pak choi

(Brassica campestris L.) was grown between strips of 'Manhattan II' perennial ryegrass managed with chemical, mechanical, or no suppression. The effect of management on the interaction between the crop and mulch, rather than only the effect on crop yield, was assessed to provide insight into the competitive interactions.

MATERIALS AND METHODS

Interference in a system of pak choi planted two weeks after seeding a living mulch of 'Manhattan II' perennial ryegrass was assessed. The mulch was managed with no suppression, mowing two and four weeks after pak choi planting, or one application of fluazifop-p-butyl two weeks after pak choi planting.

To assess intraspecific and interspecific competition from final biomass data, an addition series of monocultures and mixtures. Both total density and species proportion are varied in an addition series. Three pak choi densities (0, 24,000, and 36,000 plants/ha) and four ryegrass seeding rates (0, 23, 45, and 90 kg/ha) were combined in a factorial arrangement. Four replications of this addition series were grown for each management treatment. The experimental design was a split plot with management treatments as main plots and density combinations as subplots. Plots were 2.7 by 4.6 m and consisted of two pak choi rows and three grass strips with a pak choi guard row separating adjacent plots.

The experiment was conducted at the Vegetable Farm, Horticulture Research Station, Corvallis, Oregon on a Chehalis silty clay loam with 2% organic matter and pH 6. The field was plowed, smoothed, and rolled. Fonofos was broadcast at 2.24 kg ai/ha. On June 13, fertilizer (N:P:K:S = 8:24:8:8) was banded at 1120 kg/ha to establish rows 90 cm apart for pak choi.

On July 4, 'Manhattan II' perennial ryegrass was planted in 60 cm strips between the prepared rows with a gravity seeder.

Ammonia sulfate was applied to the grass strip immediately after planting at a rate of 45 kg N/ha. 'Sakata #7' pak choi was planted in the previously prepared crop rows with a belt seeder on July 18.

Weeds were controlled in the crop row with a band application of propachlor (2-chloro-N-(1-methyl)-N-phenylacetamide) at 2.8 kg ai/ha before pak choi planting and by hand-weeding. Weeds were controlled in the grass strip with a directed application of bromoxynil (3,5-dibromo-4-hydroxybenzonitrile) at 0.42 kg ai/ha on July 19 and by hand-weeding. The monocultures were cultivated. All herbicides were applied with a lever-operated backpack sprayer.

Fluazifop-p-butyl at 0.17 kg ai/ha plus 1% (v/v) crop oil was applied on August 2 for chemical suppression of the ryegrass. For mechanical suppression, the grass was mowed at 3.5 to 4.0 cm on August 2 and again on August 15. The pak choi was hand thinned to the final densities on August 15 and sidedressed with 56 kg N/ha as ammonia nitrate on August 19. Sevin, diazinon, _Bacillus thurigensis_, and irrigation were applied when needed.

Pak choi was harvested on September 4 and 5 and ryegrass on September 8 and 9. Harvest area for pak choi was 3.7 m from the middle of each plot row and for ryegrass was 3.7 m of the center grass strip. The grass was mowed at 3.5 to 4.0 cm and the clippings were weighed. Grass samples of approximately 500g were dried for 48 hours at 60° C for dry weights.

All data were analyzed by an analysis of variance. To test for a significant interaction of pak choi and ryegrass densities, a second analysis of variance was conducted excluding the monoculture data.

RESULTS AND DISCUSSION

Mean plant weight is the best indicator of interference when comparing mixtures with different densities (23). Mean pak choi weight was independent of pak choi density and mulch management, but was influenced by ryegrass seeding rate. At the low pak choi density, ryegrass seeding rate did not affect pak choi mean weight (Table 3.1). At the highest pak choi density, pak choi mean weight decreased with increasing ryegrass seeding rate, but only mean weight at the highest ryegrass seeding rate was significantly different from the monoculture (Table 3.1).

Since ryegrass stand was not measured, interference experienced by ryegrass must be assessed less accurately from dry weight yield. Pak choi had no effect on ryegrass dry weight at any seeding rate or management. Ryegrass dry weight increased with ryegrass seeding rate for all managements (Figure 3.2). An insignificant ryegrass seeding rate by management interaction indicates that ryegrass suppression did not modify the yield response to density. Suppression reduced grass dry weight at all seeding rates with no difference between suppression methods being noted. Chemically suppressed grass developed stripe rust (*Puccina striiformis* West) 2 to 3 weeks after spraying which may have contributed to the reduced dry weights.

The mulch and crop interfered only in the mixture with the highest density of each. This threshold response to density suggests competition as the mechanism of interference. Competition in the system may have been underestimated in this experiment, however, as a result of the irrigation pattern. One replication of each suppression treatment while two replications of the no suppression treatment recieved less water than the remainder of the experiment. A reduction in plant growth rate may delay the onset and reduce the intensity of competition (23). Both crop and mulch yields were reduced in the dry replications, and differences in pak choi yield between mixtures and associated monocultures were observed only in the wettest replications. Competition may have been underestimated particularly in the no suppression management, since one half of these plots were in dry areas.

The competitive effects were to be analyzed following a model based on a hyperbolic relationship between yield and density (52,53,64). Yield responses at or below threshold densities for competition can not be described with this model, however, so relative competitive abilities and the degree to which the species avoid competition could not be assessed. Measurement of both crop and mulch yield still permits limited insight into the interaction. In the mixture, ryegrass was the superior competitor while pak choi had no influence on the ryegrass. The ability of a crop to suppress mulch growth has been indicated in other systems (4,10,14,26).

These results indicate the potential for successful pak choi production in an establishing mulch of 'Manhattan II' perennial ryegrass seeded at a rates up to 45 kg/ha without suppression of mulch growth. Establishing grass mulches did not compete with the row crop in systems of sweet corn (Zea mays L.) interplanted with Chewings fescue (Festuca rubra L. var. commutata) or Kentucky bluegrass (Poa pratensis L.)(41), or dry beans (Phaseolus vulgaris L.) interplanted with red fescue (Festuca rubra L.), tall fescue (Festuca arundinacea Schreb.), or colonial bentgrass (Agrostis tenuis Sibth.)(26). Besides the advantage of minimal competition, annually planted mulches may minimize the problems with overwintering pests (57) or perennial weeds (47) observed with established mulches.

The growth form and short growing period of pak choi limits extrapolation of these results to other vegetables. Yield-density relationships for intraspecific competition change with time (23). With longer periods of interference, the threshold density is reduced and the intensity of competition increases until plant mortality begins. Assuming a similar relationship between time and interspecific competition, greater competition would be expected for vegetables with a longer growing period. In addition, pak choi biomass was equivalent to marketable yield. Competition may affect dry matter allocation and hence, marketable yield, independently from dry matter production (53). Shifts in dry matter allocation could alter marketable yield when only a plant part, such as fruit, is harvested. The information on management and competition in this experiment is insufficient to determine if mulch management could eliminate yield reductions from shifts in dry matter allocation or longer duration competition.

Mowing has not consistently eliminated competition between a mulch and a row crop (14,32,34,45,46,57) and mowing did not eliminate pak choi yield reduction in this experiment. Although final ryegrass dry weight was equivalent with mechanical and chemical suppression, grass biomass production with mowing was probably similar to biomass production without suppression. Resource use by mowed or unsuppressed grass then was similar if yield of the clippings is considered. Pak choi yield was reduced more with mechanical or no suppression than chemical suppression, but the differences between managements was not significant (Figure 3.3).

In contrast to mechanical suppression, chemical suppression has been effective in limiting competition in several systems (1,14,18,19,25,46,57). Chemical suppression reduced ryegrass biomass in the competitive mixture of this experiment, but did not influence the yield reduction of pak choi. Preemption of resources determines the outcome of many competitive interactions (23,47). The competitive advantage of ryegrass may have been established by the four weeks of grass growth before suppression. This growth was equivalent with all management treatments and would explain the failure of grass suppression to minimize the competition. Earlier suppression of grass growth may have maintained pak choi yield. Alternately, delaying grass planting could produce the same result.

An application of fluazifop-p-butyl was a simple method to suppress grass growth, with ryegrass dry weight reduced 37%

(Figure 3.2). With the success of chemical suppression in minimizing competition in other living systems, research on suppression of a grass living mulch with the new postemergence herbicides should be continued. However, the relative economies of suppression treatments must be evaluated in relation to potential benefits to crop yield and production costs.

Figure 3.1. Pak choi interplanted with a 'Manhattan II' perennial ryegrass living mulch.

Table 3.1. Mean plant weight of pak choi in mixtures with a perennial ryegrass living mulch and in monocultures.

Ryegrass Seeding Rate	Mean Plant Weight[1] (g) Pak Choi Density 24,000 plants/ha	36,000 plants/ha
0	848	880
23	875	865
45	822	848
90	816	676
	LSD (0.05) = 120	

[1] Means averaged over all management treatments.

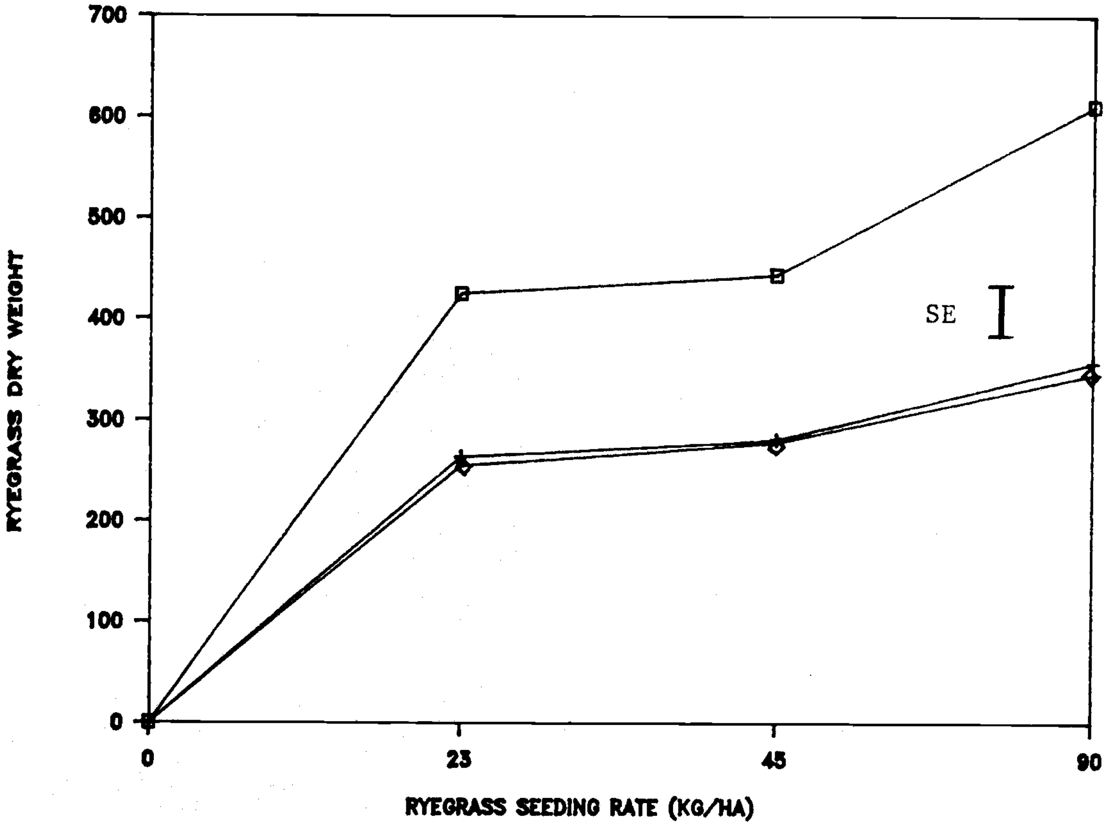

Figure 3.2. The effect of ryegrass seeding rate and management on ryegrass dry weight (g/m^2). No suppression (□), Mowing (+), Herbicide (◇). Means are averaged over pak choi densities.

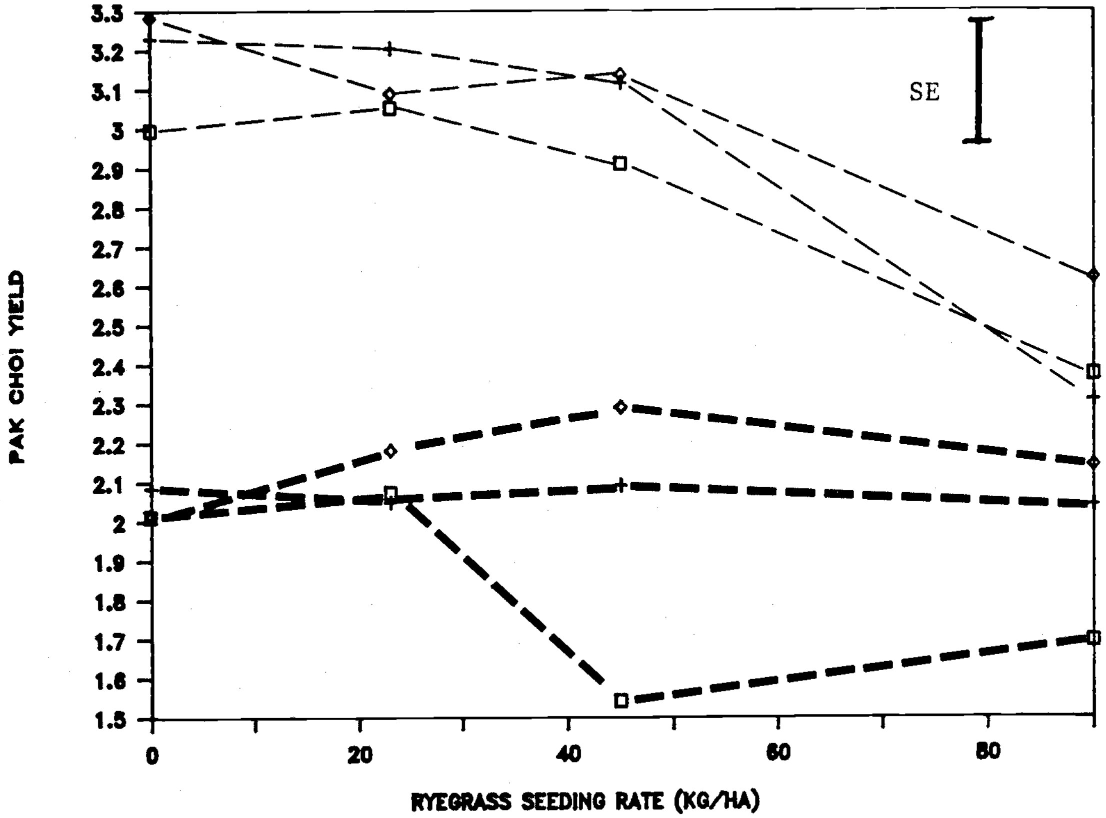

Figure 3.3. The effect of pak choi density, and ryegrass seeding rate and management on pak choi yield (kg/m^2). No suppression (□), Mowing (+), Herbicide (◇). Low density pak choi (▬ ▬ ▬), High density pak choi (— — —).

Chapter 4

MANAGING GROWTH OF A PERENNIAL RYEGRASS (LOLIUM PERENNE L.) LIVING MULCH

ABSTRACT

The effect of potential management strategies on growth of a perennial ryegrass (Lolium perenne L.) living mulch was studied with growth analysis to investigate the relationship between mulch growth and competition with a vegetable. One application of fluazifop-p-butyl ((±)-2-[4-[[5-(trifluoromethyl)-2-pyridinyl]oxy]phenoxy]propanoic acid) at 0.112 kg ai/ha or withholding nitrogen reduced dry matter production and altered dry matter allocation between roots and shoots. Withholding nitrogen reduced shoot and root yield 90% and 70%, respectively, while root and shoot yield were reduced 82% and 89% by applying fluazifop-p-butyl. Mowing reduced final biomass in only one experiment and did not change dry matter allocation.

Temporal differences in growth were apparent by growth analysis. Withholding nitrogen did not reduce root yield significantly until six weeks after planting. Fluazifop-p-butyl immediately reduced yield with most subsequent growth 4 weeks after spraying.

The results suggest measurement of only final shoot yield of a living mulch may obscure differences in growth which may be critical in determining competition with a vegetable.

INTRODUCTION

A living mulch grown in strips between vegetable rows is a potential solution to the problems of soil erosion and compaction, decreasing organic matter levels, and a dependence on chemical inputs (2,14,28,40,46,57). Management of competition between the vegetable and living mulch, however, has been an obstacle in the development of successful systems.

Strategies for minimizing competition between a living mulch and vegetable have focused on mulch growth suppression which reduces resource use. Chemical suppression is considered an essential component of several systems (14,18,19,25,46,57) while mechanical suppression has been used with less success (14,32,34,45,46,57).

Efficient development of systems with minimal competition requires insight into the competitive interactions. The current understanding of competitive interactions in living mulch systems is derived from comparisions between competition with different mulches or mulch management treatments in several crops or under different environmental conditions (1,6,16,18,34,51,57).

Quantitative, morphological, and temporal differences in living mulch growth, and hence, resource use, appear to determine the competitiveness of a mulch. Below-ground interactions appear more important than above-ground interactions (1,6,10,11,19,24, 33,34,36,44,51). Both nitrogen (6,10,11,31,36) and water (1,11,19,33,34,44,45,57) have been identified as limiting resources in living mulch systems. Competition for light may be important, however, with a crop planted into an established mulch (9,14,32) or with a mulch that climbs and shades the crop (3). Crop yield reductions have been associated with regrowth of a mulch after chemical suppression (6,14,54,55,58). On a more quantitative basis, vegetable yield has been negatively correlated with shoot dry weight yield of the associated mulch (41). Mulch growth concurrent with crop growth may be most critical in determining competitive ability (41).

Resource use determines competition (23,47). Since growth of a plant reflects its use of resources, studying the pattern of resource untilization by the interacting species may provide insight into competitive interactions. With growth analysis techniques, quantitative, morphological, and temporal aspects of growth can be described. Investigating competition with growth analysis techniques is not a new approach (22,23,43,47), but has not been applied to the study of living mulch systems.

The effect of potential management techniques on growth of a perennial ryegrass (Lolium perenne L.) living mulch was described with growth analysis of individuals. The growth of the mulch was managed by chemical, mechanical or no suppression, or withholding nitrogen. The objective was to define the relationship between mulch growth and competition with a vegetable as a basis for efficient development of management strategies.

MATERIALS AND METHODS

1984 Growth Analysis

The living mulch species was 'Manhattan II' perennial ryegrass, an improved variety with an intermediate growth habit. Three mulch management regimes were studied: no suppression, mowing once, and withholding nitrogen.

On August 12, 1984, ryegrass was seeded into 175 plastic 3.8 l pots to provide plants for 5 replications of each management treatment for seven harvests. Pots were set in a sawdust bed located in the courtyard of the East Greenhouses, Department of Horticulture, Oregon State University, Corvallis. The soil mix consisted of 1/3 soil, 1/3 peat based artificial soil mix, and 1/3 perlite. A complete fertilizer was incorporated into the soil mix, except nitrogen was omitted for the no-nitrogen treatment. Management treatments were arranged in a randomized complete block design within each harvest.

Plants were thinned to two per pot on August 25. On September 1, the plants were thinned to one per pot and mechanically suppressed. The grass was 'mowed' by clipping at 3.2 cm with scissors. All treatments, except the no-nitrogen treatment, were fertilized with nitrogen at a rate of 196 kg/ha on September 12.

Harvesting began on September 5 (5 days after mechanical and chemical suppression and 25 days after planting) and continued at 5 day intervals for a total of seven harvests. The last harvest was 30 days after suppression and 55 days after planting. Leaf area and root and shoot dry weights were obtained at each harvest. Area was measured with a Li-Cor (model LI-300) leaf area meter, while dry weights were determined after drying at 60° C for 48 hours.

Parameters to characterize mulch growth were calculated from the basic harvest data with classical growth analysis techniques (30). Formulas used for the calculations are presented in Table 4.1. Analysis of variance was used to interpret the effect of management on each growth parameter. The basic data and calculated parameters for each harvest were analyzed independently. Relative growth rates and component production rates were analyzed as a split plot design with harvest intervals as subplots. Unit leaf rate was analyzed independently for each harvest interval while biomass durations were analyzed only for the last harvest interval.

1986 Growth Analysis

The 1986 experiment was conducted in a growth chamber. Parameters of the experiment were modified to simulate mulch management in a 1985 field experiment while adapting to space limitations. Three management regimes were studied: no suppression, mowing twice, and one application of a sublethal rate of fluazifop-p-butyl ((±)-2-[4-[[5-(trifluoromethyl)-2-pyridinyl]oxy]phenoxy]propanoic acid) plus 1% (v/v) crop oil.

Growth chamber conditions were a night temperature of 19° C, a day temperature of 32° C, and a 16 hour photoperiod. On December 6, 1985, grass was seeded into 4.8 l cardboard cartons. Plant material and soil mix were the same as the 1984 experiment. Six replications of each treatment were arranged in a randomized complete block design within each harvest. The plants were thinned to three per pot on December 19, 1985 and one per pot on December 31, 1985.

On January 3, 1986, first suppression treatments were applied. Plants were clipped at 3.0 cm. Pots were removed from the growth chamber for spraying with fluazifop-p-butyl at 0.112 kg ai/ha plus 1% (v/v) crop oil using a compressed air greenhouse sprayer with a 8006E fan nozzle. This rate was selected in a preliminary growth chamber experiment for suppression similar to the rate in the field of 0.17 kg ai/ha. On January 17, 1986, plants in the mechanical suppression treatment were clipped again and clippings were collected to estimate leaf area and biomass removed per plant.

Harvesting began on January 3, 1986 (0 days after suppression, 28 days after planting) and continued on a weekly basis for a total of six harvests. The last harvest was 35 days after the initial suppression treatments or 63 days after planting. At the first harvest, only plants of the mowing or no suppression treatments were harvested. No immediate effect of spraying was assumed.

Plants were harvested and growth analysis parameters were calculated and analyzed as described for the 1984 experiment.

Table 4.1. Growth analysis definitions and formulas.[1]

$\Delta T = T_2 - T_1$	length of harvest interval
W_1, W_2	total dry weight at beginning and end of harvest interval
R_{w1}, R_{w2}	root dry weight at beginning and end of harvest interval
S_{w1}, S_{w2}	shoot dry weight at beginning and end of harvest interval
A_1, A_2	leaf area at beginning and end of harvest interval

$\Delta W = W_2 - W_1$ $\Delta S_w = S_{w1} - S_{w2}$ $\Delta R_w = R_{w1} - R_{w2}$

R/S	Root/Shoot Ratio	R_w/S_w
LAR	Leaf area ratio	A/W
RGR	Relative Growth Rate (g/g day)	$(\ln W_2 - \ln W_1)/\Delta T$
R_r	Root Component Production Rate (g/g day)	$(\ln R_{w2} - \ln R_{w1})/\Delta T$
R_s	Shoot component Production Rate (g/g day)	$(\ln S_{w2} - \ln S_{w1})/\Delta T$
ULR	Unit Leaf Rate (g/cm^2 day)	$(W/ A)*(\ln A_2 - \ln A_1)/\Delta T$
LAD	Leaf Area Duration (cm^2 days)	$[A/(\ln A_2 - \ln A_1)]*\Delta T$
BMD	Biomass Duration (g days)	$[W/(\ln W_2 - \ln W_1)]*\Delta T$
Root BMD	Root Biomass Duration	$[R_w/(\ln R_{w2} - \ln R_{w1})]*\Delta T$
Shoot BMD	Shoot Biomass Duration	$[S_w/(\ln S_{w2} - \ln S_{w1})]*\Delta T$

---

[1] Adapted from Patterson (43).

RESULTS AND DISCUSSION

1984 Growth Analysis

Unit leaf rate (ULR) is an index of the physiological efficiency of the plant (30,47). Unit leaf rate only during the first harvest interval by mowing and during the last harvest interval by withholding nitrogen (Figure 4.1). The increased unit leaf rate immediately after mowing concurs with the use of stored carbohydrates to replace leaf area (5). Severe nitrogen deficiency symptons were apparent with the decreased unit leaf rate of the no-nitrogen management.

Final dry weight may reflect the quantity of resources used (47). Suppression significantly reduced final dry weight. Mowing and withholding nitrogen reduced yield by 40 and 73%, respectively (Figure 4.2). However, total resource use is only one aspect of growth which may determine competitive ability. Vegetable yield reductions in living mulch systems were negatively correlated to the shoot dry weight of mulches, but deviations from this trend were attributed to temporal differences in living mulch growth (41). Preemption of resources by rapid, early growth is associated with superior competitive ability (23,47). Studying the dynamics of yield with time then, may be useful in understanding competition.

Withholding nitrogen reduced yield at all harvests, with differences significant at the fourth, fifth, and seventh harvests (Figure 4.2). Yield of mowed plants was significantly reduced at the first, fifth and seventh harvests. This pattern in a mowed plant may be a consequence of a shift in dry matter allocation to replace leaf area at the expense of stored carbohydrates and, if necessary, root growth (5). Later when environmental conditions were less favorable for growth, unsuppressed plants may have sustained growth on a reserve of carbohydrates which was depleted in mowed plants.

A concise summary of yield incorporating a time dimension is biomass duration (BMD). Biomass duration, as the integral of the yield curve, accounts for magnitude and duration of biomass. Biomass duration is similar to the concept of leaf area duration which Watson (62) described as "the whole opportunity for assimilation." Biomass duration is a crude estimate of the whole opportunity of resource use, and may be especially appropriate for water and light. Alternately, since early growth is emphasized in the calculation, biomass duration may indicate competitive ability resulting from preemption of resources. Only the no suppression and no-nitrogen managements can be statistically separated with biomass duration (Table 4.2) with an intermediate value for mowing.

Relative growth rate (RGR) has been studied as a potential index of competitive ability (22,50). Relative growth rate describes the efficiency of dry matter production and may conveniently summarize the ability of a plant to exploit resources. Yield and biomass duration are related to relative growth rate by the equation YIELD = BMD X RGR (30). The mean relative growth rate (Table 4.3) was similar for the no suppression and mowed treatments. Withholding nitrogen reduced the relative growth rate by approximately 50 percent.

Other growth analysis parameters may describe resource specific characteristics of growth. Root growth indicates the potential to exploit nutrients and water, while shoot yield reflects water and light consumption.

Root/shoot ratio indicates that withholding nitrogen altered dry matter allocation with root growth being maintained at the expense of shoot growth (Figure 4.3). Root yield with no-nitrogen was significantly different from the no suppression management only at the final harvest (Figure 4.4). Root/shoot ratio was similar with mowing and no suppression (Figure 4.3).

Within each treatment, trends in leaf area (Figure 4.5) and shoot weight (Figure 4.6) were similar, suggesting no change in leaf physiology. Both parameters were reduced by withholding nitrogen beginning with the fourth harvest. Mowing had the same effect on shoot yield and leaf area as total yield.

Root and shoot components of biomass duration and relative growth rate may be resource specific analogies to biomass duration and relative growth rate. Root biomass duration was statistically equivalent with the three management treatments (Table 4.2). Withholding nitrogen significantly reduced leaf area duration (Table 4.2) and shoot biomass duration (Table 4.2), as did mowing, but root biomass duration was not significantly reduced.

Component production rates describe the rate of production of a plant part relative to the total weight of the plant. The root and shoot component production rates sum to the relative growth rate (RGR = $R_r + R_s$). Since the relative growth rate is an index of a plant's ability to exploit resources, component production rates reflect the ability to exploit specific resources. The root component production rate was not affected by management while the shoot component production rate was decreased by withholding nitrogen (Table 4.3).

Table 4.2. The effect of management on root, shoot, and total biomass duration, and leaf area duration. 1984 experiment.

Management	Biomass Duration Total	Biomass Duration Root (g/g day)	Biomass Duration Shoot	Leaf Area Duration (cm_2 days)
No suppression	25.2a[1]	7.7a	17.5a	1182a
No nitrogen	11.0b	5.6a	5.4b	251c
Mow	17.4ab	5.0a	12.4a	825b

[1] Means within columns followed by the same letter are not significantly different at the 5% probability level according to Duncan's multiple range test.

Table 4.3. The effect of management on relative growth rate and root and shoot component production rates. 1984 experiment.

Management	Relative Growth Rate (g/g day)	Component Production Rate Root (g/g day)	Component Production Rate Shoot
No suppression	0.126	0.041	0.086
No nitrogen	0.069	0.038	0.031
Mowing	0.128	0.038	0.090
LSD (0.05)	0.005	0.005	0.004

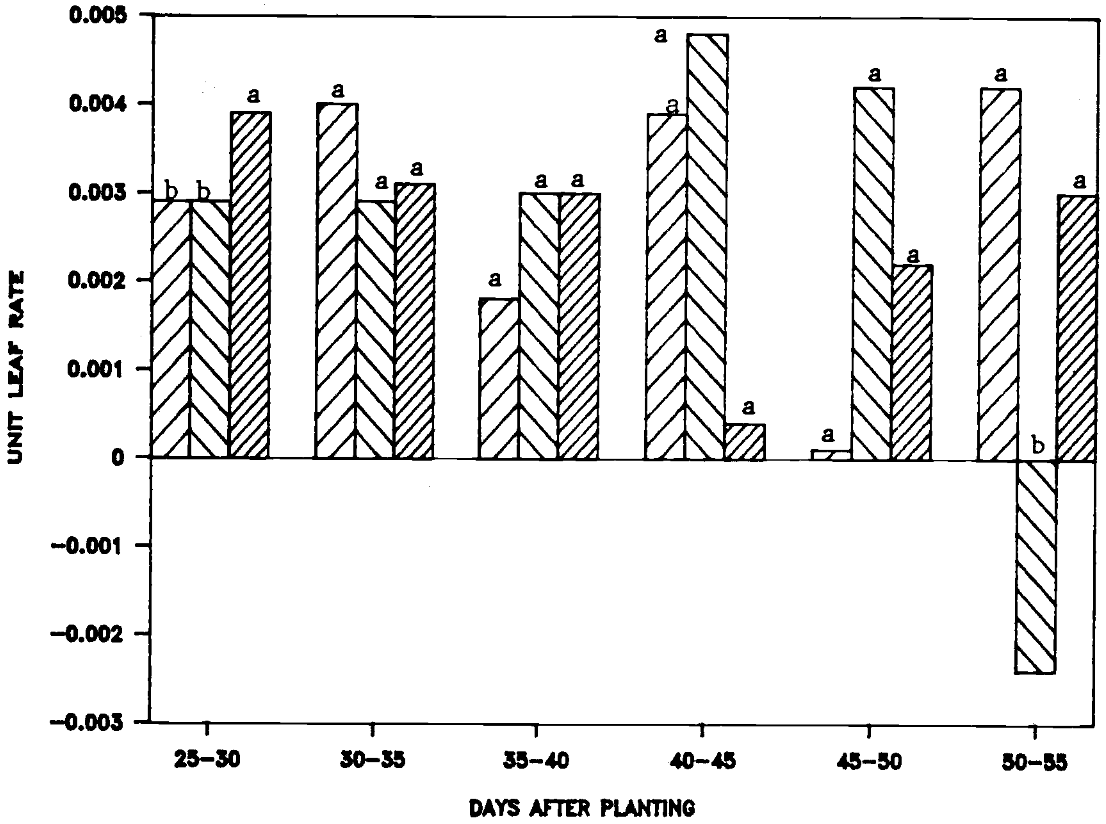

Figure 4.1. The effect of management on unit leaf rate (g/cm^2 day). 1984 experiment. No suppression (▨), No nitrogen (▧), Mowing (▩). Bars within a group with the same letter are not significantly different at the 5% probability level according to Duncan's multiple range test.

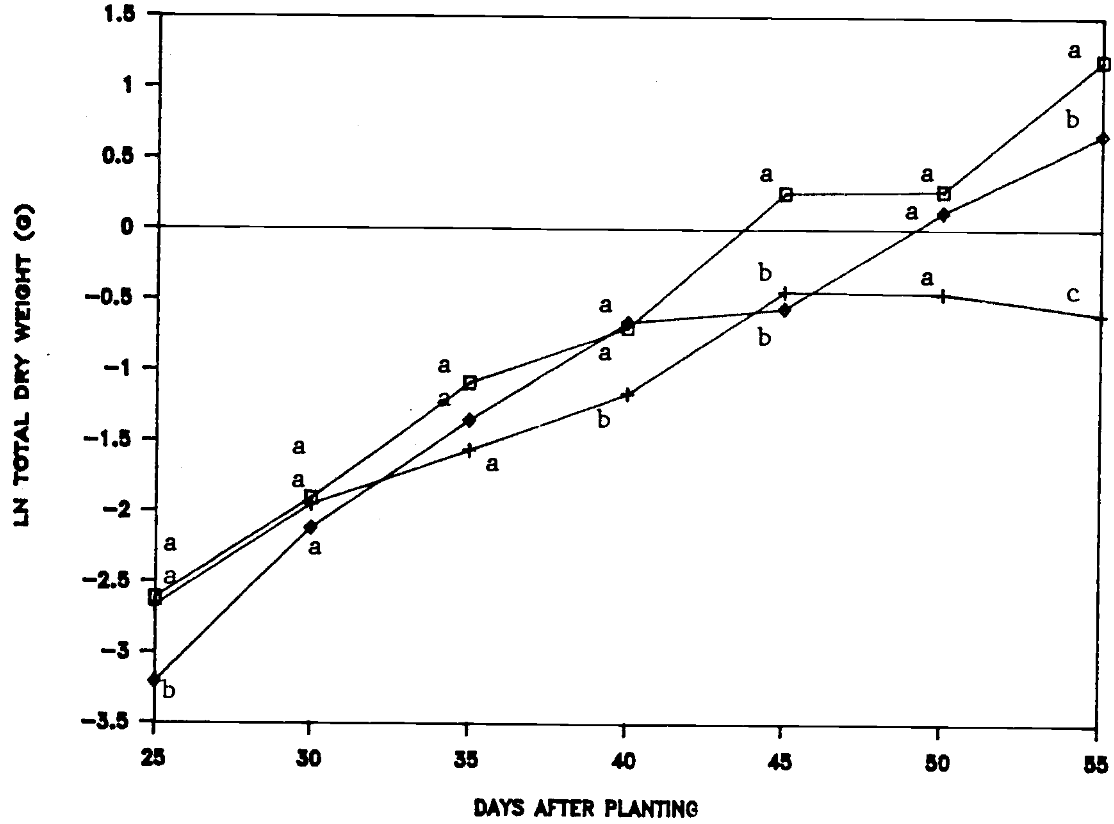

Figure 4.2. The effect of management on total dry weight. 1984 experiment. No suppression (□), No nitrogen (+), Mowing (◇). Weights within a harvest with the same letter are not significantly different at the 5% probability level according to Duncan's multiple range test.

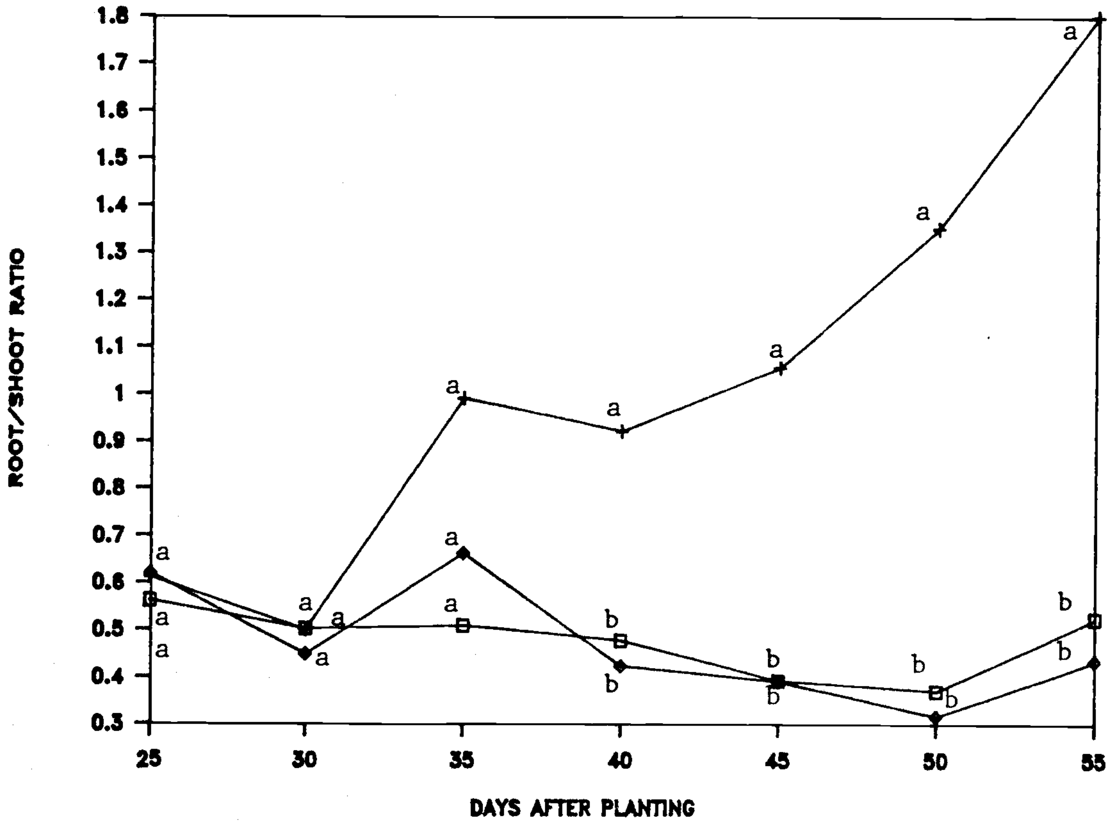

Figure 4.3. The effect of management on root/shoot ratio. 1984 experiment. No suppression (□), No nitrogen (+), Mowing (◇). Ratios within a harvest with the same letter are not significantly different at the 5% probability level according to Duncan's multiple range test.

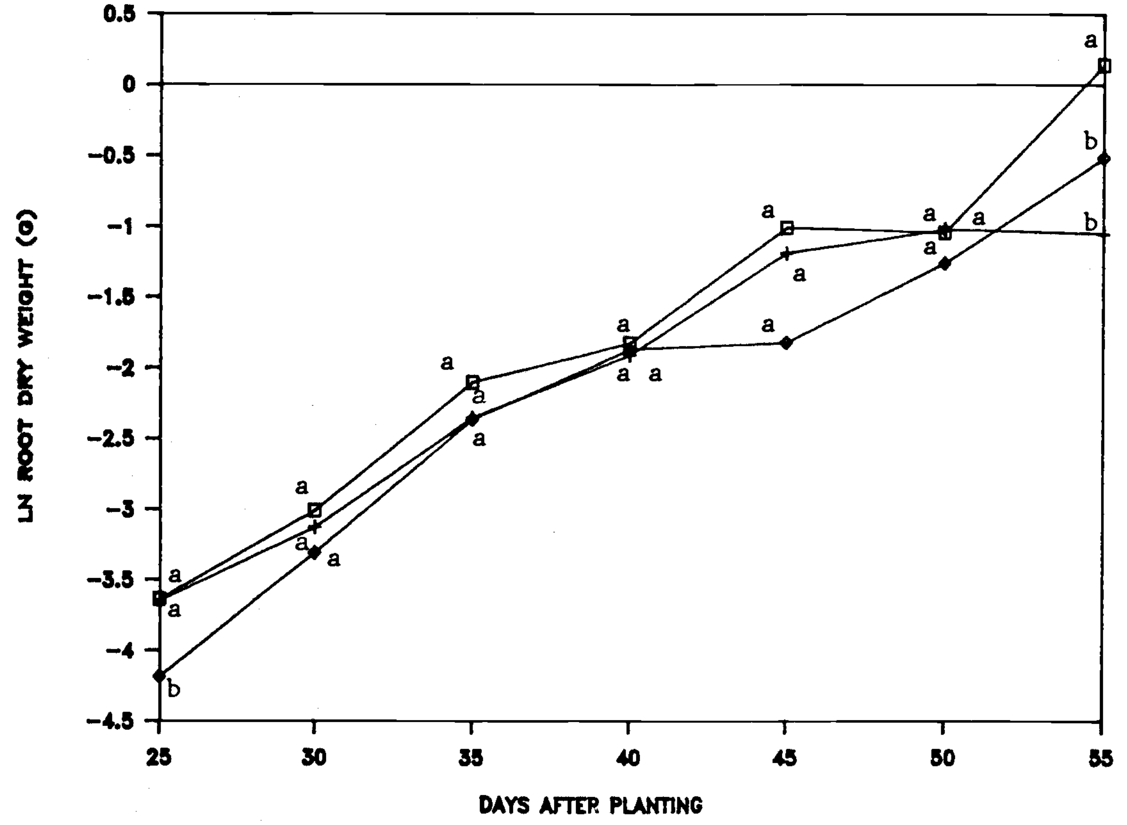

Figure 4.4. The effect of management on root dry weight. 1984 experiment. No suppression (☐), No nitrogen (+), Mowing (◇). Weights within a harvest with the same letter are not significantly different at the 5% probability level according to Duncan's multiple range test.

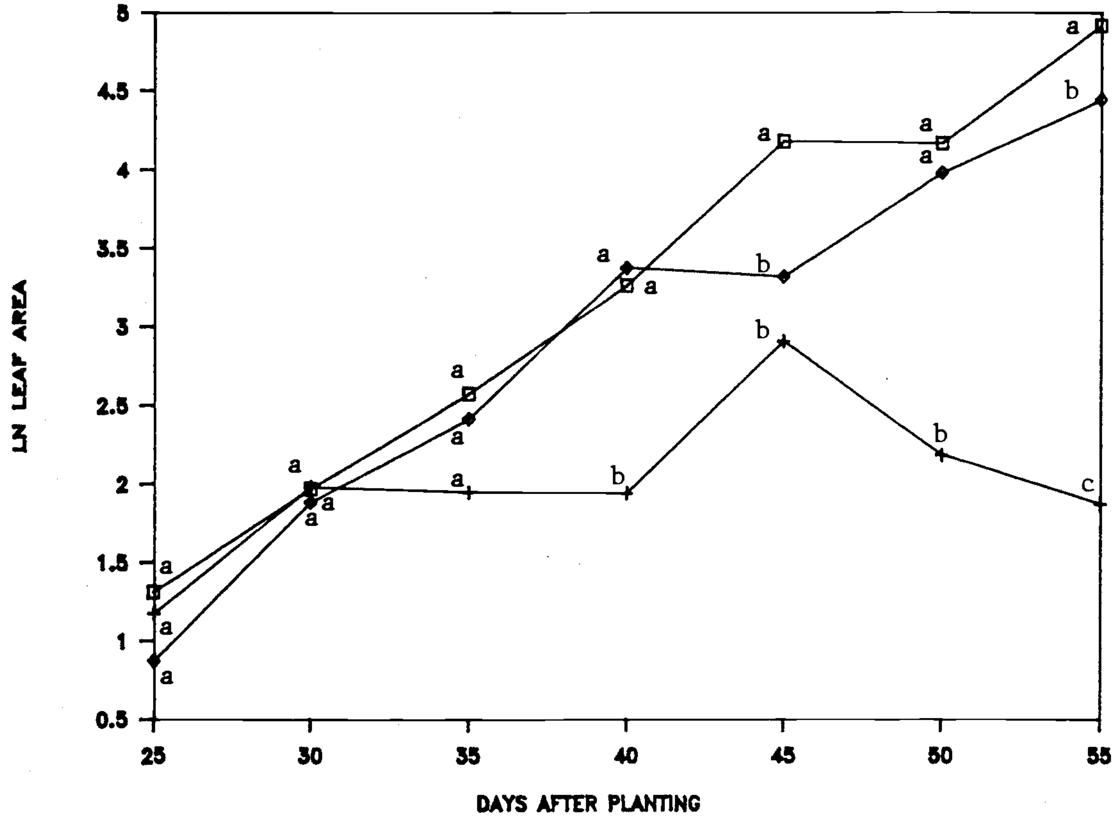

Figure 4.5. The effect of management on leaf area (cm^2). 1984 experiment. No suppression (□), No nitrogen (+), Mowing (◇). Areas within a harvest with the same letter are not significantly different at the 5% probability level according to Duncan's multiple range test.

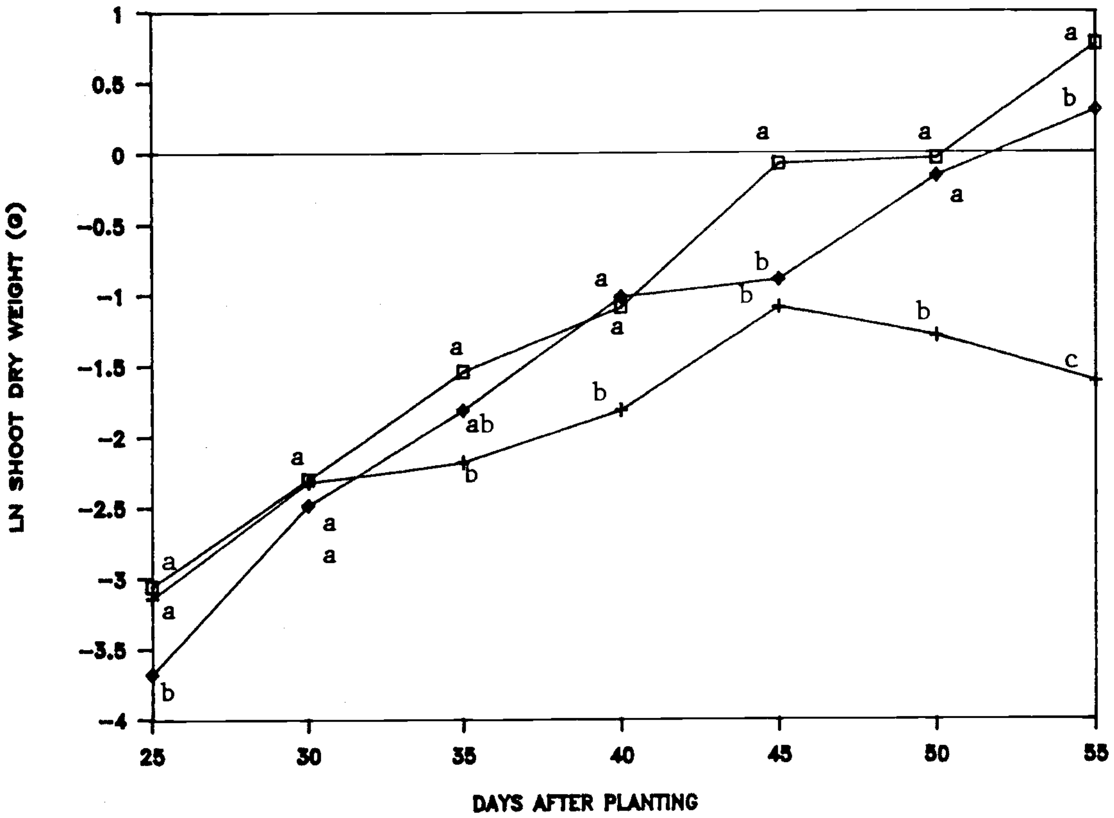

Figure 4.6. The effect of management on shoot dry weight. 1984 experiment. No suppression (□), No nitrogen (+), Mowing (◇). Weights within a harvest with the same letter are not significantly different at the 5% probability level according to Duncan's multiple range test.

1986 Growth Analysis

In 1986, the effect of mowing twice or chemical suppression with one application of fluazifop-p-butyl was studied. In constrast to 1984, no change in unit leaf rate with mowing was evident (Figure 4.7). With chemical suppression, unit leaf rate was reduced beginning with the second harvest interval (7 days after spraying) and returned to a level similar to the first harvest by the last interval (35 days after spraying) (Figure 4.7). The increased unit leaf rate of the third harvest interval may be an artefact of the method of calculation since it is not reflected in increased growth. Suppressed plants were a lighter green color and had some dead leaf material.

Yield of chemically suppressed plants 42 days after treatment was 13% of the unsuppressed plants (Figure 4.8). Suppression was apparent beginning 2 weeks after treatment with most subsequent growth during the last harvest interval in two of the six plants. Yield of mowed plants was similar to yield of unsuppressed plants at the final harvest, but was significantly less at the three previous harvests. A decline in the growth rate of unsuppressed plants during the last harvest interval, rather than an increase in the growth rate of the mowed plants, may have resulted in the equivalent final yields. The amount of biomass removed per plant with mowing can be determined from the difference between shoot yield of unsuppressed and mowed plants at the first mowing and from the collected material at the second mowing. Total biomass production with mowing was 96% of the biomass production without suppression.

Yield with mowing was statistically equivalent to the no suppression management at the first two harvests (including the day of clipping), probably as a result of insufficient precision to measure differences. An estimate of total yield before clipping at the third harvest is lower than the 95% confidence interval for yield of the control, suggesting that the first clipping had some measurable impact on biomass production.

Biomass duration was reduced by suppression (Table 4.4). Mowing had a greater impact on biomass duration than yield. Relative growth rate with mowing and no suppression was similar while chemical suppression reduced the relative growth rate (Table 4.5).

As in the previous experiment, root/shoot ratio (Figure 4.9) indicates dry matter allocation between roots and shoots was similar with mowing and no suppression at all harvests. As a result, leaf area (Figure 4.10) and both shoot (Figure 4.11) and root (Figure 4.12) yield with mowing follow the pattern of total yield (Figure 4.8). Yields and leaf area were equivalent to no suppression at the final harvest and reduced at the three previous harvests. Leaf area duration and root and shoot biomass duration, like biomass duration, were reduced with mowing (Table 4.4). Relative growth rate, and root and shoot component production rates were similar with mowing and no suppression (Table 4.5).

The herbicide differentially affected root and shoot growth (Figure 4.9). Chemical suppression more severely reduced leaf area (Figure 4.10), shoot yield (Figure 4.11), leaf area duration (Table 4.4), and shoot biomass duration (Table 4.4) than root yield (Figure 4.12) or root biomass duration (Table 4.4).

Table 4.4. The effect of management on root, shoot, and total biomass duration, and leaf area duration. 1986 experiment.

Management	Biomass Duration Total	 Root (g days)	 Shoot	Leaf Area Duration (cm^2 days)
No suppression	198.1a[1]	49.9a	147.6a	12997a
Mow	131.7b	32.9b	97.9b	9765b
Herbicide	30.9c	14.4c	16.2c	1103c

[1] Means within columns followed by the same letter are not significantly different at the 5% probability level according to Duncan's multiple range test.

Table 4.5. The effect of management on relative growth rate and root and shoot component production rates. 1986 experiment.

Management	Relative Growth Rate (g/g day)	Component Production Rate Root (g/g day)	 Shoot
No suppression	0.121	0.034	0.087
Mow	0.121	0.029	0.092
Herbicide	0.056	0.026	0.030
LSD (0.05)	0.009	0.005	0.008

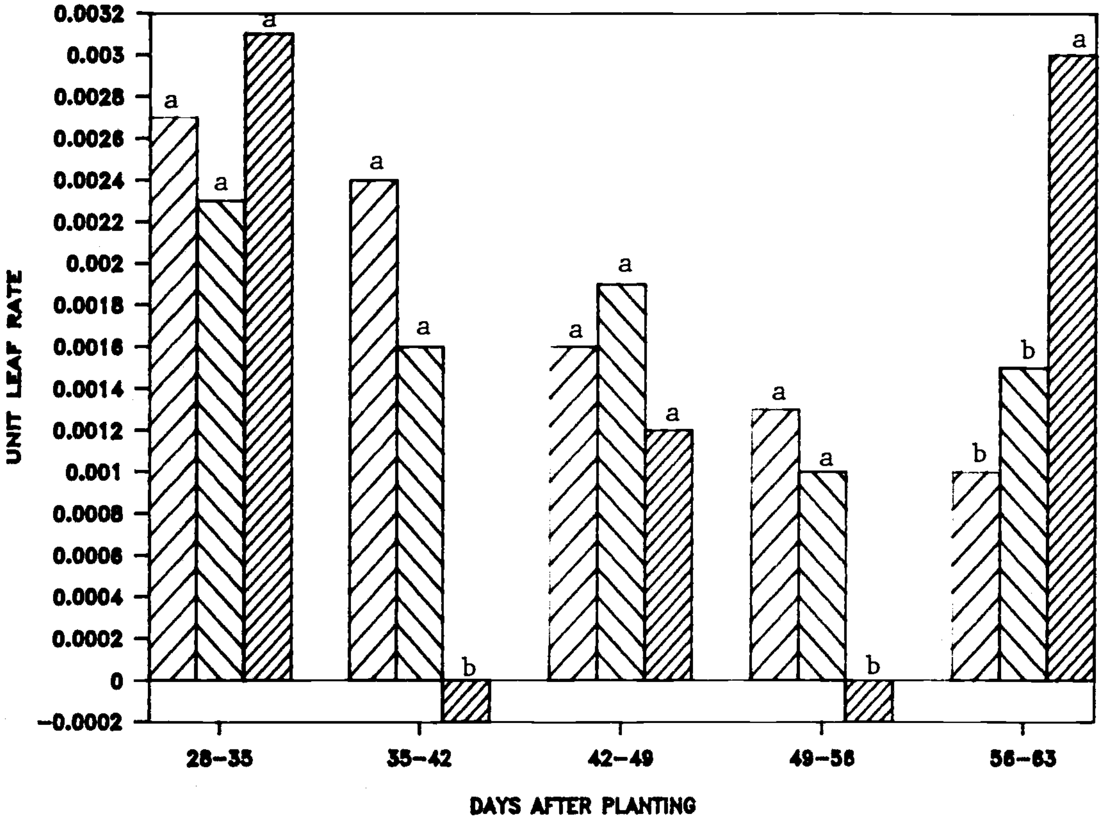

Figure 4.7. The effect of management on unit leaf rate (g/cm^2 day). 1986 experiment. No suppression (▨), Mowing (▧), Herbicide (▨). Bars within a group with the same letter are not significantly different at the 5% probability level according to Duncan's multiple range test.

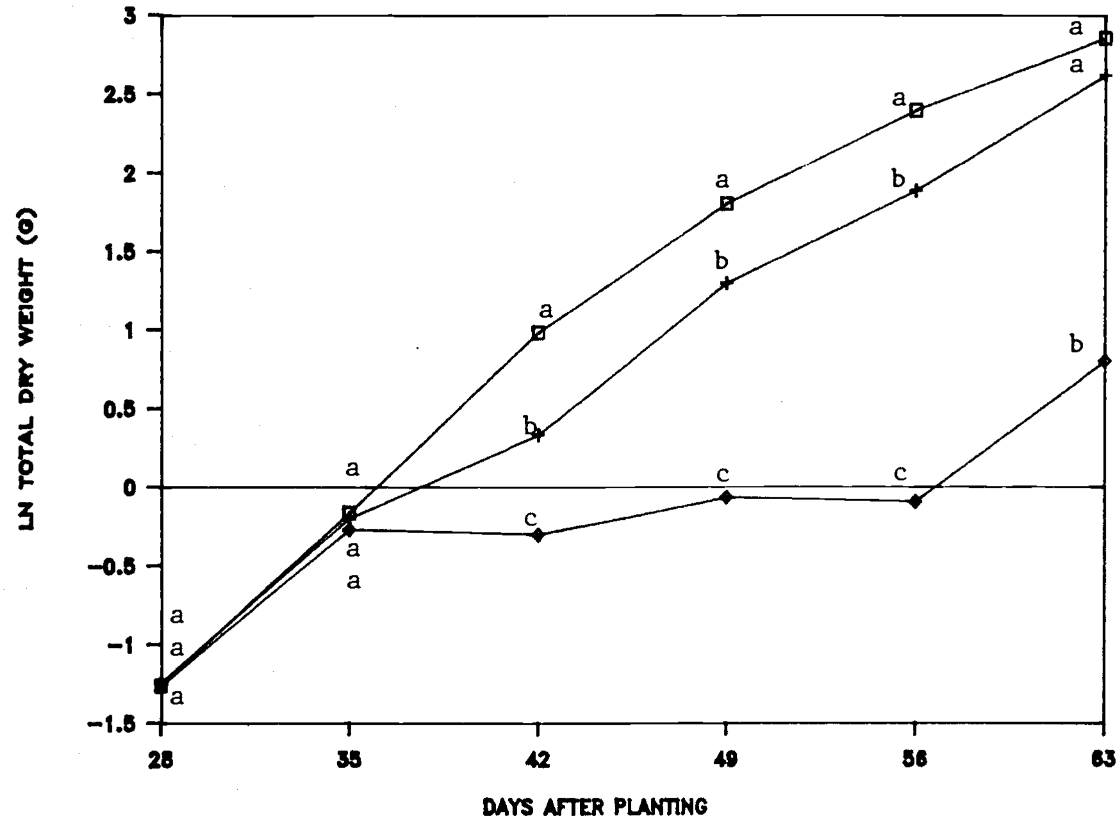

Figure 4.8. The effect of management on total dry weight. 1986 experiment. No suppression (□), Mowing (+), Herbicide (◇). Weights within a harvest with the same letter are not significantly different at the 5% probability level according to Duncan's multiple range test.

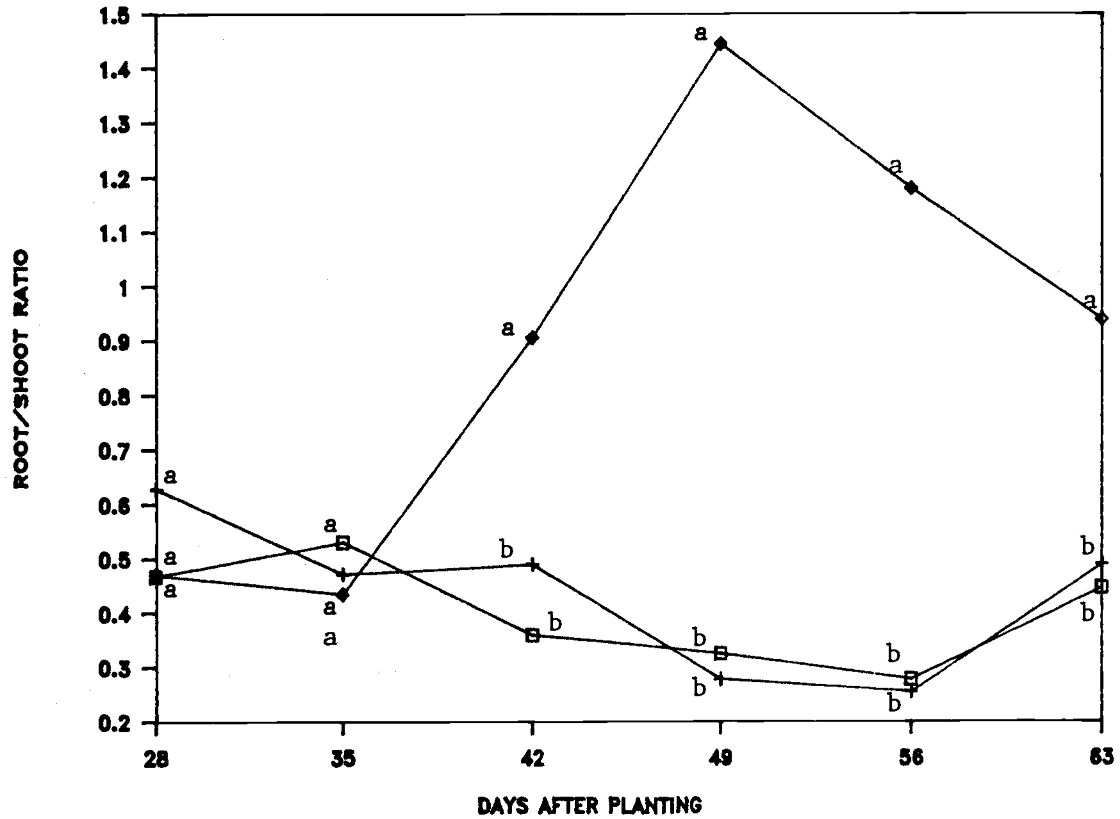

Figure 4.9. The effect of management on root/shoot ratio. 1986 experiment. No suppression (□), Mowing (+), Herbicide (◇). Ratios within a harvest with the same letter are not significantly different at the 5% probability level according to Duncan's multiple range test.

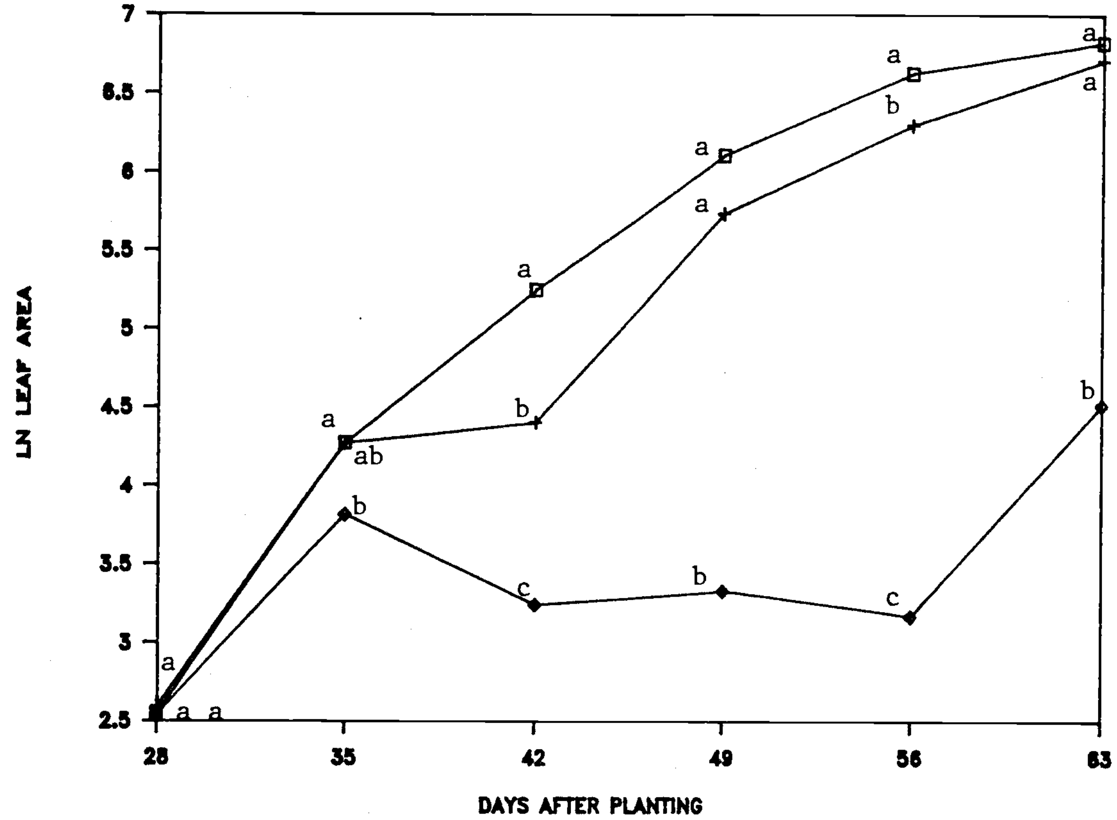

Figure 4.10. The effect of management on leaf area (cm^2). 1986 experiment. No suppression (□), Mowing (+), Herbicide (◇). Areas within a harvest with the same letter are not significantly different at the 5% probability level according to Duncan's multiple range test.

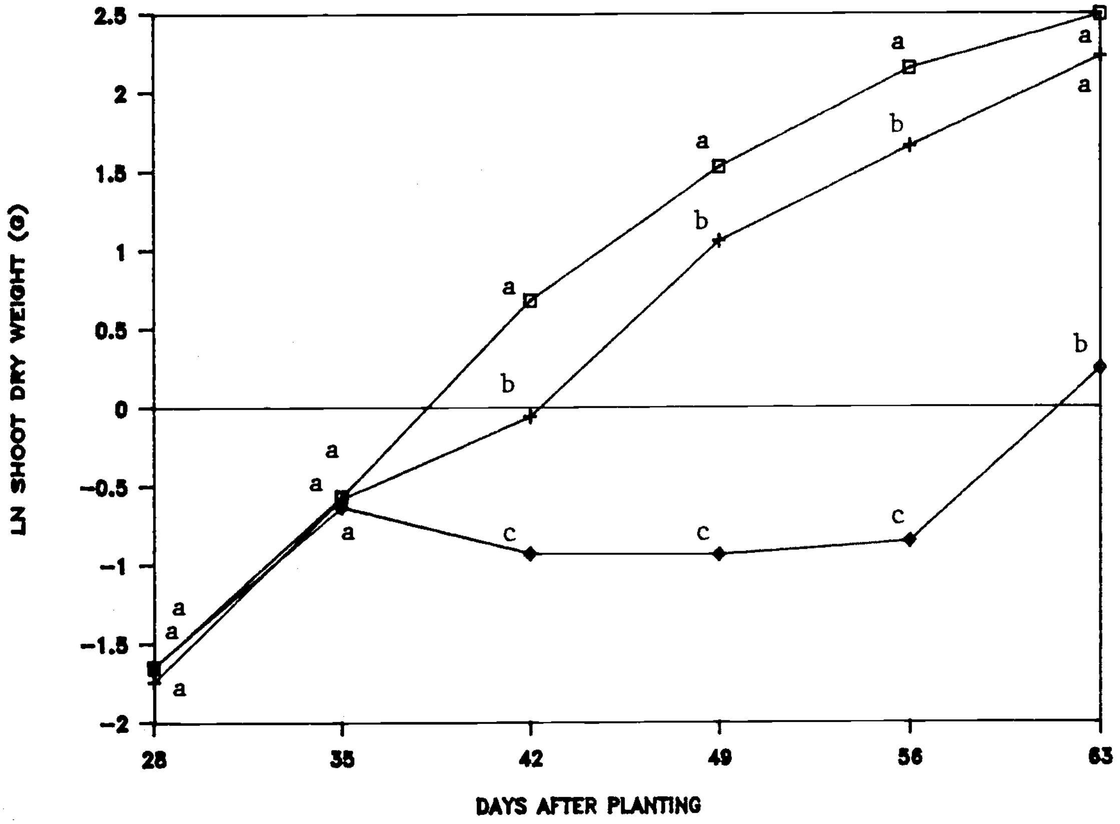

Figure 4.11. The effect of management on shoot dry weight. 1986 experiment. No suppression (□), Mowing (✚), Herbicide (◇). Weights within a harvest with the same letter are not significantly different at the 5% probability level according to Duncan's multiple range test.

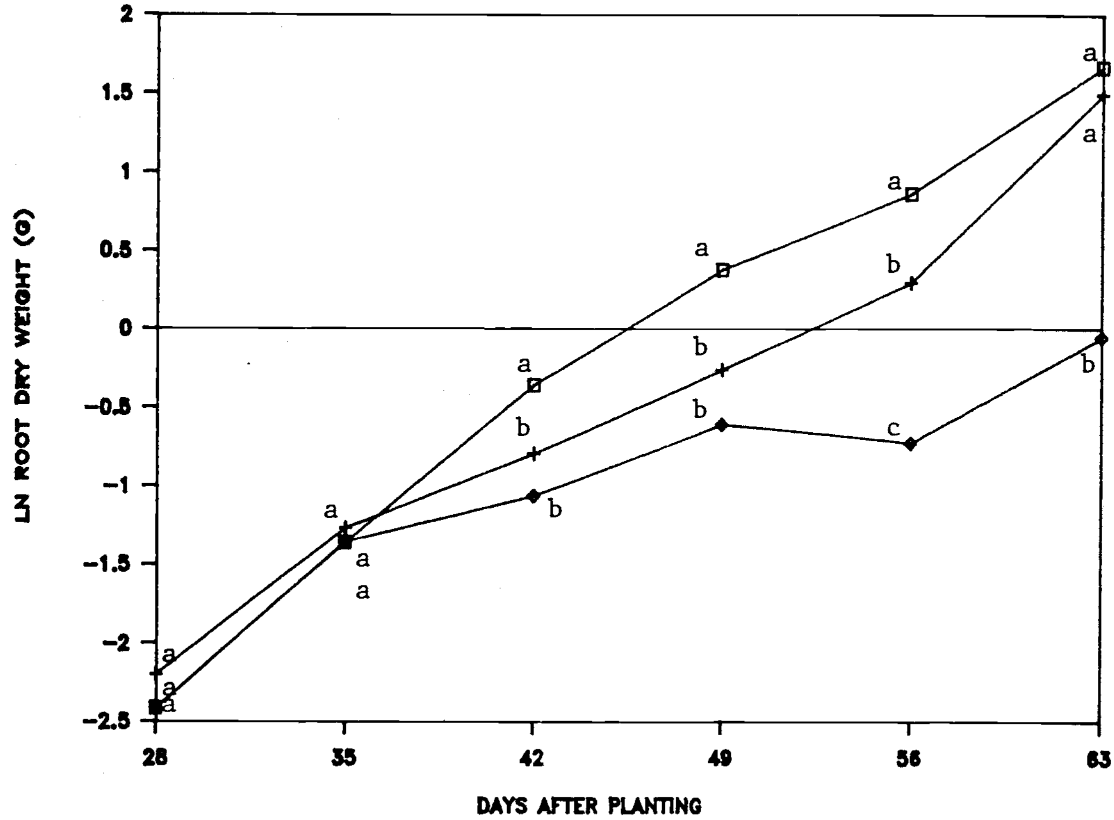

Figure 4.12. The effect of management on root dry weight. 1986 experiment. No suppression (□), Mowing (+), Herbicide (◇). Weights within a harvest with the same letter are not significantly different at the 5% probability level according to Duncan's multiple range test.

Growth and Competition

Extrapolation from growth of an individual ryegrass plant to competition with a vegetable as a living mulch must be done cautiously. The intense intraspecific competition a ryegrass plant experiences as a living mulch may modify the effect of management. For example, in the 1986 growth analysis experiment, chemical suppression reduced yield more than mechanical suppression. In a field trial, the same treatments produced equivalent yield. For this reason, qualitative rather than quantitative changes in living mulch growth with management are emphasized.

A second problem is the lack of information on competition in living mulch-vegetable systems with these management strategies. In a companion field study, the effect of the management strategies studied in the 1986 experiment on the competition between pak choi and a ryegrass mulch was investigated. Ryegrass reduced pak choi yield only in a mixture of 36,000 pak choi plants/ha and ryegrass seeded at 90 kg/ha. Management did not significantly modify the yield reduction, although there was a trend for greater competition with mowing or no suppression than chemical suppression.

Withholding nitrogen reduced resource use by the ryegrass, but nitrogen fertility may be difficult to effectively manage in the field. Further, root growth sustained for approximately 6 weeks after planting may allow the living mulch roots to grow into the nitrogen source of the crop and compete. If water use determines the competitive ability of a living mulch, the reduced shoot yield and leaf area suggests that withholding nitrogen is an effective management strategy.

Mowing has not consistently minimized competition in living mulch systems for row crops (14,32,34,45,46,47). Infrequent mowing, as in these experiments, subtly diminishes growth since leaf area removed is quickly replaced (5). The 1986 results suggest yield may not be reduced consistently with mowing and also the potential for increased biomass production with mowing. In 1986, final yield of mowed and unsuppressed plants was equivalent, probably as a result of the decline in the growth rate of unsuppressed plants during the last harvest interval. The reason for this decline is not known, but it suggests the potential for a mowed mulch to be more productive than an unsuppressed mulch in which the canopy closes and light limits further growth. Since clipping opens the canopy, the mowed mulch may consume more resources than the unsuppressed mulch in replacing leaf area.

If total biomass production determines competitive ability, these results suggest mowing might be a labor intensive strategy for minimizing competition. The interval between mowings influences the effect on growth (5), so the results may have been different with two mowings at either a shorter or longer interval than in this experiment. Limiting root growth would be less labor intensive than reducing total yield, however, since shoot growth under frequent mowing is maintained by a shift in dry matter allocation from roots to shoots (5).

If the competitive ability of a mulch is a function of water use, leaf area duration suggests a mowed mulch would be less competitive than an unsuppressed mulch. Although leaf area was reduced, water use may have increased with mowing by losses at the cut edges and an increased transpiration rate per unit leaf area (5).

These results suggest one application of fluazifop-p-butyl as a simple management strategy. Both root and shoot growth were severely reduced and regrowth did not begin until approximately six weeks after treatment. The suppressed grass probably used less resources, including water. Water use by three perennial grasses, smooth bromegrass (*Bromus inermis* Leyss.), Kentucky bluegrass (*Poa pratensis* L.), and Kentucky-31 tall fescue (*Festuca elatior* L.), treated with cyclocel (2-chloroethyltrimethylammonium chloride) or F-529 (N-pyrrolidinosuccinamic acid) was positively correlated with shoot yield in a greenhouse study (35).

Each growth analysis parameter emphasizes a different aspect of growth. Identification of the growth analysis parameters which predict the competitive ability of a living mulch with a vegetable may provide insight into the competitive interaction and may permit efficient development of management strategies. In 1984, a competitive ranking of no suppression > mow > no-nitrogen is predicted with both leaf area duration and total yield (Table 4.6). In the 1986 experiment, the ranking of no suppression = mow herbicide is predicted with relative growth rate and total yield (Table 4.7). A competitive ranking of no suppression > mow > herbicide is predicted with biomass duration and leaf area duration (Table 4.7).

Separating relative growth rate, yield, and biomass duration into root and shoot components may provide more resource specific information for understanding competitive interactions. In 1984, a different competitive ranking is predicted with the component parameter than the general parameter only with shoot yield (Table 4.6). Predictions with specific and general parameters are the same in 1986 except with root component production rate (Table 4.7).

The limited competition observed in a 1985 field trial suggests a competitive ranking of a managed ryegrass as unsuppressed = mow $>$ herbicide. Also, mowing has not been generally effective as a suppression treatment while chemical suppression has been effective. This result is predicted with root, shoot, and total yield, relative growth rate, and shoot component production rate (Table 4.7). Living mulch shoot yield has been negatively correlated with corn and cabbage yield parameters (41). Yield may indicate the importance of the quantity of resources consumed by the living mulch in determining competition.

Relative growth rate, as calculated in this experiment, may also indicate the the quantity of resources used. In constrast to these results, relative growth rate was not correlated with relative competitive ability of four annual weeds, redroot pigweed (Amaranthus retroflexus), common lambsquarter (Chenopodium album L.), barnyardgrass (Echinochloa crus-galli (L.) Beauv.), and black nightshade (Solanum nodiflorum Jacq.) (50). The four annual weeds represented greater variation in physiology and morphology than the managed living mulch in this experiment. Relative growth rate may best predict competitive ability of plants with similar patterns of resource use.

Biomass duration, yield, and relative growth rate are related by the equation Yield = RGR X BMD. While competitive ability of the managed mulch was correctly predicted with yield and relative growth rate, biomass duration, root and shoot components of biomass duration did not predict this ranking.

The information on competition is too limited to fully evaluate the potential of growth analysis for understanding the competitive interactions between a living mulch and a vegetable. The results indicate that measurement of only final biomass may obscure differences in growth. Whether these differences in growth are critical in competitive ability remains to be determined. Growth analysis may be valuable for both identifying living mulch growth characteristics which determine competitveness with a vegetable and understanding the effect of living mulch management. With this insight, management strategies for minimizing competition in living mulch-vegetable systems may be efficiently developed.

Table 4.6. Predictions of the competitive ability of managed ryegrass by growth analysis parameters. 1984 experiment.

Predictor	Competitive Ranking
Yield	no suppression > mow > no N
Root component	no suppression > mow = no N
Shoot component	no suppression > mow > no N
Relative growth Rate	mow = no suppression > no N
Root component	no suppression = mow = no N
Shoot component	mow > no suppression > no N
Biomass duration	no suppression > no N, no suppression = mow, mow = no N
Root component	no suppression = mow = no N
Shoot component	no suppression = mow > no N
Leaf Area Duration	no suppression > mow > no N

Table 4.7. Predictions of the competitive ability of managed ryegrass by growth analysis parameters. 1986 experiment.

Predictor	Competitive Ranking
Yield	no suppression = mow > herbicide
Root component	no suppression = mow > herbicide
Shoot component	no suppression = mow > herbicide
Relative growth Rate	no suppression = mow > herbicide
Root component	no suppression > mow = herbicide
Shoot component	mow = no suppression > herbicide
Biomass duration	no suppression > mow > herbicide
Root component	no suppression > mow > herbicide
Shoot component	no suppression > mow > herbicide
Leaf Area Duration	no suppression > mow > herbicide

BIBLIOGRAPHY

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

2. Akobundo, 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.

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

4. Beale, O.W. and G.W. Langdale. 1964. The compatibility of corn and coastal bermudagrass as affected by tillage. J. Soil Water Conserv. 19:238-240.

5. Beard, J.B. 1973. Turfgrass: Science and Culture. Prentice-Hall, Inc., Englewood Cliffs, N.J. 658pp.

6. Bennett, O.L., E.L. Mathias, and C.B. Sperow. 1976. Double cropping for hay and no-tillage corn production as affected by sod species with rates of atrazine and nitrogen. Agron. J. 68:250-254.

7. Bonnano, A.R. and T.J. Monaco. 1985. The influence of environmental conditions and adjuvants on the phytotoxicity of sethoxydim and fluazifop-butyl to selected horticultural crops. Abstr. Weed Sci. Soc. Am. Pages 27-28.

8. Box, J.E., S.R. Wilkinson, R.N. Dawson, and J. Kozachyn. 1980. Soil water effects on no-till corn production in strip and completely killed sod. Agron. J. 72:797-802.

9. Cardina, J. and N.L. Hartwig. 1980. Suppression of crownvetch for no-tillage corn. Proc. Northeast Weed Sci. Soc 34: 53-58.

10. Cardina, J. and N.L. Hartwig. 1982. The influence of nitrogen, corn population and crownvetch cover crop on weed-corn competition. Abstr. Weed Sci. Soc. Am. Page 115.

11. Carreker, J.R., J.E. Box, R.N. Dawson, E.R. Beaty, and H.D. Morris. 1972. No-till corn in fescuegrass. Agron J. 64: 500-503.

12. Colby, S.R., J.R. Bone, and A.A. Akhavein. 1982. PP009, a selective herbicide for control of perennial and annual grasses. Abstr. Weed Sci. Soc. Am. Pages 14-15.

13. Cook, T. 1982. The potential of turfgrasses as living

mulches in cropping systems. Pages 23-25. In Workshop Proc. Crop Production Using Cover Crops and Sods as Living Mulches. Oregon State Univ. IPPC DOC. 45-A-82.

14. Cooper, A.S. 1985. Sweet corn (*Zea mays L.*) production in a clover (*Trifolium repens L.*) living mulch: the establishment year. M.S. Thesis, Oregon State Univ., Corvallis, OR.

15. Donald, C.M. 1963. Competition among crop and pasture plants. Adv. Agron. 15:1-118.

16. Doty, C.H. and S.R. Colby. 1985. PP005 for postemergence grass control in broadleaf crops. Abstr. Weed Sci. Soc. Am. Page 13.

17. Elkins, D., D. Frederking, R. Marashi, and B. McVay. 1983. Living mulch for no-till corn and soybeans. J. Soil Water Conserv. 38(5):431-433.

18. Elkins, D.M., J.D. George, and G.E. Birchett. 1982. No-till soybeans in forage grass sod. Agron J. 74:359-363.

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

20. Fales, S.L. and R.C. Wakefield. 1981. Effects of turfgrass on the establishment of woody plants. Agron. J. 73:605-610.

21. Ganser, S. 1980. Vegetable production in a living sod. Horticulture Department., Organic Gardening and Farming Res. Ctr., Rodale Press, Inc. 24pp.

22. Grime, J.P. and R. Hunt. 1975. Relative growth rate, its range and adaptive significance in a local flora. J. Ecol. 63(2):393-422.

23. Harper, J.L. 1977. Population Biology of Plants. Academic Press, N.Y. 892pp.

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

25. Hartwig, N.L. 1984. Crownvetch - a perennial legume "living mulch" for no-tillage crop production. Dept. of Crop Sci., Penn. State Univ.

26. Hinton, A.C. and P.L. Minotti. 1982. Living mulch: initial investigations in a grass sod-dry bean system. Proc. Northeast Weed Sci. Soc. 36:110-111.

27. Hofstetter, R. 1978. Legume sod interplanting. Agronomy Dept., Organic Gardening and Farming Res. Ctr., Rodale Press, Inc. 17pp.

28. Horwith, B. 1985. A role for intercropping in modern agriculture. Bioscience. 35(5):286-291.

29. Hughes. B.J. and R.D. Sweet. 1979. Living mulch: a preliminary report on grassy cover crops interplanted with vegetables. Proc. Northeast Weed Sci Soc. 33:109.

30. Hunt, R. 1982. Plant Growth Curves. Edward Arnold (Publishers) Limited, London. 248pp.

31. 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.

32. Kurtz, T., M.D. Appleman, and R.H. Bray. 1946. Preliminary trials with intercropping corn and clover. Proc. Soil Sci. Soc. 11:349-355.

33. Lake, G.G. and R.G. Harvey. 1986. Use of living mulches for weed control in no-till corn. Abstr. Weed Sci. Soc. Am. Page 22.

34. Loy, S.J. 1984. Competition of bush winter squash and bell pepper with permanent cover crops in strip tillage cultural systems. M.S. Thesis, University of New Hampshire, Durham, NH.

35. Mathias, E.L., O.L. Bennett, G.A. Jung, and P.E. Lundberg. 1971. Effect of two growth regulating chemicals on yield and water use of three perennial grasses. Agron. J. 63:480-483.

36. Matthews, D.L., C. Orr, and S. Bacon. 1984. Summary of 1982 and 1983 flea beetle research. Entomology Dept, Organic Gardening and Farming Res. Ctr., Rodale Press, Inc. 17pp.

37. McClelland, C.K. 1940. Effects of interplanting legumes in corn. Univ. of Arkansas Agric. Exp. Stn. Bull. No. 393. 29pp.

38. Monaco, T.J. 1985. Influence of various rates of fluazifop-butyl and sethoxydim on yield of peppers and cucumbers. Abstr. Weed Sci. Soc. Am. Page 28.

39. Mooers, C.A. 1930. The effects of various legumes on the yield of corn. Tenn. Agric. Exp. Stn. Bull. No. 142.

40. Mt. Pleasant, J. 1982. Corn polyculture systems in New York. M.S. Thesis, Cornell University, Ithaca., N.Y.

41. Nicholson, A.G. and H.C. Wien. 1983. Screening of turfgrass and clovers for use as living mulches in sweet corn and cabbage. J. Amer. Soc. Hort Sci. 108(6):1071-1076.

42. O°Sullivan, J. 1986. Tolerance of twelve vegetable crops to sethoxydim and fluazifop-p-butyl. Abstr. Weed Sci. Soc. Am. Page 26.

43. Patterson, D.T. 1982. Effects of light and temperature on weed/crop competition. Pages 407-419. In Biometeorology in I.P.M. Academic Press.

44. Pedersen, R.C., R.D. Sweet, and P.L. Minotti. 1981. Squash spacing for weed control. Proc. Northeast Weed Sci. Soc. 35:132-133.

45. Pendleton, J.W., J.A. Jacobs, F.W. Slife, and H.P. Bateman. 1956. Establishing legumes in corn. Agron. J. 49:44-48.

46. Peterman, M.K. 1985. Sweet corn (Zea mays) production in a white clover (Trifolium repens) living mulch: the second year. M.S. Thesis, Oregon State Univ., Corvallis, OR.

47. Radosevich, S.R. and J.S. Holt. 1984. Weed ecology: Implications of vegetation management. John Wiley and Sons. New York. 300pp.

48. Regnier, E. and E.W. Stoller. 1981. A living mulch for weed control in soybeans. Proc. North Central Weed Control Conf. 36:60.

49. Robinson, R.G. and R.S. Dunham. 1954. Companion crops for weed control in soybeans. Agron. J. 46:278-281.

50. Roush, M.L. and S.R. Radosevich. 1985. Relationships between growth and competitiveness of four annual weeds. J. Appl. Ecol. 23(3):895-905.

51. Ryan, J., M.F. Ryan, and F. McNaeidhe. 1980. The effect of interrow plant cover on populations of the cabbage root fly, Delia Brassicae (Wiedemann). J. Appl. Ecol. 17:31-40.

52. Spitters, C.J.T. 1983. An alternative approach to the analysis of mixed cropping experiments. 1. Estimation of competition effects. Neth. J. Agric. Sci. 31:1-11.

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

54. Sweet, R. 1982. Observations on the uses and effects of cover crops in agriculture. Pages 7-22. In Workshop Proc. Crop Production Using Cover Crops and Sods as Living Mulches. Oregon State Univ. IPPC Doc. 45-A-82.

55. Treanor, L.L. and H.A. Andrews. 1965. Growing corn on sod in Tenessee. Proc. So. Weed Control Conf. 18:136-144.

56. Vandermeer, J. 1984. The interpretation and design of intercrop systems involving environmental modification by one the components: a theoretical framework. Biol. Agric. Hortic. 2(2):135-156.

57. Vrabel, 1983. Effect of suppressed white clover (T. Repens L.) on sweet corn (Z. Mays L.) yield and nitrogen availibility in a living mulch cropping system. Ph.D. Thesis, Cornell Univ., Ithaca, N.Y.

58. Vrabel, T.E., P.L. Minotti, and R.D. Sweet. 1980. Seeded legumes as living mulches in sweet corn. Proc. Northeast Weed Sci. Soc. 34:171-175.

59. Vrabel, T.E., P.L. Minotti, and R.D. Sweet. 1982. Suppression of legume sods in sweet corn living mulch systems. Proc. Northeast Weed Sci. Soc. 36:108-109.

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

61. Warren, S.L. and W.A. Skroch. 1986. Tolerance of five perennial grasses to fluazifop and sethoxydim as influenced by growth stage and rate. Abstr. Weed Sci. Soc. Am. Page 32.

62. Watson, D.J. 1947. Comparative physiological studies on the growth of field crops. I. Variation in net assimilation rate and leaf area between species and varieties, and within and between years. Ann. Bot. 11:41-76.

63. William, R.D. and L.K. Brenner. 1985. Living mulch suppression using postemergence grass herbicides. Abstr. Weed Sci. Soc. Am. Page 32.

64. Wright, A.J. 1981. The analysis of yield-density relationships in binary mixtures using inverse polynomials. J. Agric. Sci. 96:561-567.