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Title ECOTYPIC ADAPTATION OF SETARIA LUTESCENS (WEIGEL) F. T. HUBBARD, TO ALFALFA CULTURE IN CALIFORNIA

Abstract approved by Redacted for privacy
William W. Chilcote

Setaria lutescens (yellow foxtail) plants, grown from five seed sources were compared in California. Seed sources were: Connecticut, Iowa, Massachusetts, Pennsylvania and California. Morphological and physiological differences between biotypes include: plant size, growth habit, time required to mature and reproductive capacity. Most significant is the prostrate habit of the California biotype.

Biotype seed studies also indicate differences in dormancy and requirements for seed germination. After-ripening, stratification and temperature are implicated.

Growth and reproductive capacity of Connecticut, Pennsylvania and California Setaria lutescens biotypes are compared. Biotypes were grown with and without alfalfa (Medicago sativa) under California alfalfa forage production methods. The California biotype of

Setaria lutescens yielded 85% more seed than Connecticut and 71% more than Pennsylvania when clipped monthly to a height of 7.6 cm. When grown with alfalfa (Medicago sativa) and harvested monthly, the California biotype produced 98% more seed than Connecticut and 93% more than the Pennsylvania biotype. First-year forage yield of alfalfa was reduced 35% and the plant density of alfalfa reduced 48% when grown with California Setaria lutescens. Growth and reproductive capacity of Echinochloa crusgalli and Setaria lutescens were compared when grown with and without alfalfa under California forage production methods. When the two grass species were grown together at densities of 2300 plants/m^2 Setaria lutescens produced mature seed while Echinochloa crusgalli failed to reproduce. Echinochloa crusgalli plant density and seed production was reduced by second-year alfalfa. Setaria lutescens density was reduced but seed production averaged 10,000 seeds/m^2. Dry matter yields of first-year alfalfa and plant density of first- and second-year alfalfa were reduced when grown with Setaria lutescens.

Field studies of Echinochloa crusgalli and Setaria lutescens growing in commercially cultivated alfalfa were conducted. Transects of alfalfa strip checks showed field densities of Echinochloa crusgalli and Setaria lutescens to be largely dependent on the cultural practice of curing alfalfa forage in windrows.

Ecotypic Adaptation of *Setaria lutescens* (Weigel) F. T. Hubbard to Alfalfa Culture in California

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ECOTYPIC ADAPTATION OF *SETARIA LUTESCENS* (WEIGEL) F. T. HUBBARD, TO ALFALFA CULTURE IN CALIFORNIA

INTRODUCTION

Setaria lutescens Worldwide

Setaria lutescens (Weigel) F. T. Hubbard (yellow foxtail) is an annual plant species of worldwide distribution and agricultural importance. It is known throughout the temperate climates of the world as a weed of economic consequence in many cultivated crops. *Setaria lutescens* has become increasingly evident as an invader of cultivated alfalfa (*Medicago sativa*) in California during the past twenty years.

Setaria lutescens is an undesirable associate of alfalfa because of its aggressive growth habits, its low nutritional value and the mechanically damaging effect of its bristly head to livestock. Although frequently found in cultivated alfalfa, little is known regarding its growth characteristics in relation to the particular environment provided by irrigated alfalfa fields in the central valleys of California.

The purpose of this investigation was to study the ecology of *Setaria lutescens* in California and to discover the morphological or physiological assets that have enabled this species to become a successful invader of irrigated alfalfa in this semi-desert climate.

Echinochloa crusgalli (L.) Beauv. (watergrass) is also a weedy annual grass of widespread importance in cultivated crops of the world. It is an introduction from Europe and is found in almost all agricultural sections of California. Echinochloa crusgalli is a successful weed species in crops of the temperate climates including alfalfa. It is generally known as an opportunist rather than a primary invader of alfalfa, moving into portions of fields where crop plants have succumbed to excessive irrigation or diseases.

A portion of this overall investigation was a study of the competitive abilities of Setaria lutescens and Echinochloa crusgalli within an alfalfa stand. The objective was to determine possible morphological or physiological differences that may contribute to their success as weed species.

Setaria lutescens belongs to the tribe Paniceae of the family Gramineae. The genus Setaria includes about one hundred twenty-five species distributed throughout the temperate, subtropical and tropical regions of the world (Rominger, 1962). In North America the genus is represented by twenty-five species, ten introduced species from South America, and eight introduced species from the Old World (including Setaria lutescens, which was probably introduced from Europe). Rominger indicates the Type Locality as GERMANY: Pomerania, with the type not known.

> A common weed of cultivated ground in temperate North America, this species is called yellow foxtail, yellow bristle grass or pigeon grass (Rominger, 1962).

The species is widely known under the binomial Setaria glauca Beauvois; however, Rominger having thoroughly researched the nomenclature gives a convincing argument for using Setaria lutescens (Weigel) F. T. Hubbard (as proposed by Hubbard, 1916) as the correct binomial.

Setaria lutescens has a large range in the United States, and the species is cosmopolitan in temperate regions of both the old and new world.

> The following chromosome determinations have been made for Setaria lutescens. 2n = 36, Avdulov (1931); Kishimoto (1938). 2n = 72, Brown (1948. n = 18, Krishniswami and Rangaswami Ayyangar (1935). n = 36, Gould No. 76 (TAES), voucher examined (Rominger, 1962).

The genus Echinochloa also belongs to the tribe Paniceae of the family Gramineae. Echinochloa crusgalli (L.) Beauv. is an annual species introduced from Europe (Peck, 1961). Commonly known as barnyard grass or watergrass it is of worldwide distribution and is an economically important weedy species of most cultivated crops. Robbins (1940) said that Echinochloa crusgalli is found in almost all agricultural sections in California. He notes that Torry (1856) collected it on the Sacramento River in 1838-42.

Setaria lutescens in California

In the Eastern and Midwestern United States Setaria lutescens has received attention as a weed in corn, soybeans, sugarbeets, wheat, oats, grain sorghum and first-year plantings of forage crops. In California, Setaria lutescens is not considered an important weed of row and field crops; however, this species has become an increasingly serious problem in the important alfalfa growing areas of the State over the past twenty-five years. Yolo County, the largest alfalfa growing area in Northern California, has suffered rising economic losses due to Setaria lutescens infestations. Livestockmen refuse to knowingly purchase alfalfa hay containing "pigeon grass" because of the bristles, which cause "sore mouth" in animals, and its low nutritional value.

Setaria lutescens was first reported in California in 1838 according to Robbins (1940) who states:

> The species of Setaria growing without cultivation in California are all of European origin. Setaria lutescens (Weigel) F. T. Hubb. (yellow bristlegrass) was introduced early, Torrey (1856) collecting it on the Sacramento in 1838-1840. Brewer and Watson (1876) report it from Sacramento and elsewhere.

Setaria lutescens was collected from other areas of California during the late 1800s and early 1900s.

The species was first brought to the attention of this writer in 1954 when a dairyman near Woodland, Yolo County, reported "sore mouths" in his cattle from feeding a bristly grass in his hay. The weed was identified as Setaria lutescens by Dr. William Harvey, a University of California Agricultural Extension Service Specialist.

Unsuccessful attempts were made to control the weed chemically, then because this infestation was an isolated case the incident was forgotten.

Within the past 15 years increasing numbers of livestockmen and alfalfa growers have reported Setaria lutescens in alfalfa fields. Growers have, upon occasion, destroyed otherwise productive alfalfa stands because of Setaria lutescens infestations. Once the weed becomes established in an alfalfa stand the infestation increases rapidly until Setaria lutescens is the dominant species.

Echinochloa crusgalli is an opportunistic invader, moving into locations where alfalfa stand has been thinned mechanically or by disease. This species has no mechanically damaging features but is low in nutritional value. Frequently the two species are found together in cultivated alfalfa, with Setaria lutescens seemingly the superior competitor.

Several questions have been raised relating to Setaria lutescens and Echinochloa crusgalli in California. Why has Setaria lutescens, a weed reported near Yolo County in 1840, recently become an important economic problem in alfalfa? Why is Setaria lutescens a serious competitor to row and field crops but not established alfalfa in the Midwest and Eastern United States? And, conversely, why does the weed offer serious competition to corn, wheat, grain sorghum, oats and similar crops in the other regions but not in California?

What types of cultural and climatic differences exist between California, the Midwest and East that allow these differences to occur? Is it possible that Setaria lutescens has, through selection, adapted itself to alfalfa culture in the central valleys of California? Have cultural practices changed in the central valleys to create a more favorable environment for Setaria lutescens? What morphological and physiological characteristics enable Setaria lutescens to compete more effectively with alfalfa than can Echinochloa crusgalli?

Several speculations are made concerning the recent, serious impact of Setaria lutescens on the cultivation of alfalfa as a forage crop. Many agronomic changes have occurred over the past hundred years, most since the advent of the internal combustion engine. Alfalfa harvest methods have been revised from; cutting with a sythe, curing flat or in the shock and stacking loose; to mowing with swathers, curing in the windrow, baling or cubing and mechanical removal to storage. Modern farmers moving equipment over wide areas have greater capability for spreading weed seeds. Insects and diseases have promoted changes to resistant cultivars of alfalfa and have increased need for modification of other cultural practices.

There are very large climatic and agronomic differences between the Eastern, Midwestern and Western States. Two potentially important differences, with respect to alfalfa, might be summer rainfall in the East and Midwest versus the hot, dry summer season of semi-desert California. Cultivars of alfalfa used in the Midwest and the East are generally of the winter dormant types, harvested two or three times per year, whereas the non-dormant alfalfa cultivars of California's central valley are harvested six to eight times per season.

Objectives of the Investigations

Many examples of ecotypic adaptation to environment have been described since the original work of Gotë Turesson in the 1920's (Turesson, 1925). Ecotypes have developed in response to selection pressures exerted by natural and artificial environments.

A general hypothesis was evolved to explain the speculations on *Setaria lutescens*. It was speculated that, from the original European introduction of the species to California, an ecotype has adapted to alfalfa culture in the central valleys of California.

The objectives of these investigations were (1) to learn whether *Setaria lutescens* had indeed developed a locally adapted ecotype; (2) to understand what types of adaptive morphological or physiological responses might have occurred; (3) to learn if changes (natural or artificial) in the alfalfa environment had enabled the species to increase its level of success; and (4) to learn if changes might be made to reduce the impact of *Setaria lutescens* on forage production.

Initial approaches were: (1) sampling of *Setaria lutescens* populations within California and from other areas of the United States by seed collections, then planting seed from collections in a uniform environment and noting morphological and physiological differences; and (2) investigating the competitive abilities of *Setaria lutescens*, *Echinochloa crusgalli* and *Medicago sativa* grown together under cultural conditions similar to those normally practiced in the irrigated central valleys of California.

SETARIA LUTESCENS BIOTYPES

Purpose of the Studies

These investigations entailed the collection of *Setaria lutescens* seed from seven locations in the United States and growing the resulting plants in a California environment. The objectives were to determine if ecotypic adaptation had occurred within the species, and to increase understanding of the ecology of *Setaria lutescens* by closely observing growth and development of individual plants.

During the fall of 1971 *Setaria lutescens* and *Echinochloa crus-galli* seed was collected from mature heads in several fields in each of three central valley counties of California--Yolo County (adjacent to Sacramento), Glenn County (60 miles north of Yolo), and Tulare County (200 miles south of Yolo). *Setaria lutescens* seed collected outside the State of California was contributed by: R. A. Peters, University of Connecticut; David Staniforth, Iowa State University; Jonas Vengris, University of Massachusetts; and William Gregg, Waterloo Mills Field Research Station, Pennsylvania.

Woodland Planting

In the spring of 1972 a site was selected in Woodland, Yolo County for preliminary comparisons of plants from the five states.

Methods

Meter square plots used for each collection were divided into sixteen equal 625 cm^2 subplots with seed planted in each subplot. Each collection was replicated twice for a total of ten, meter square plots. The soil type in the plot area was Yolo silt loam and irrigation was by basin flooding. A minimum of eight vigorous plants from each selection was established in each replication.

Variations in Development

Measurements reported are the mean of sixteen plants from each collection or biotype (Table 1). Measurements included qualitative observations of: color, waxyness of leaf surface and growth habit; quantitative measurements of days from emergence to heading, number of elongated internodes, vertical culm height, extended culm length. Culm height and culm length are reported at fifty-four days from planting and at maturity. The date of planting was May 2, and the duration of the experiment was 105 days.

Basic differences exist between the biotypes in several morphological and one physiological feature (Table 1). The only prostrate growth habit is exhibited by the California biotype. The Massachusetts biotype has no red coloring of culms, and the California biotype has a dull, waxy coat on both leaf blade surfaces. The Connecticut biotype is the earliest maturing as shown by the fewest number

Table 1. Variations in development between <u>Setaria lutescens</u> biotypes--Woodland--1972

Observation	Biotype				
	Calif.	Conn.	Iowa	Mass.	Penna.
1. Growth habit	Prostrate	Erect	Erect	Erect	Erect
2. Culm base color	Red	Red	Red	Green	Red
3. Abaxial leaf blade surface	Glaucous	Smooth	Smooth	Smooth	Smooth
4. Days-planting to heading	78	58	66	75	78
5. Number nodes per culm	5.3	4.1	5.0	5.0	5.3
6. Culm height 54 days (cm.)	15.0	31.0	48.0	38.0	37.0
7. Culm length 54 days (cm.)	36.0	36.0	51.0	54.0	45.0
8. Ratio culm length/height 54 days	2.4	1.1	1.1	1.4	1.2
9. Mature culm height (cm.)	62.0	101.0	140.0	130.0	129.0
10. Mature culm length (cm.)	97.0	107.0	148.0	135.0	133.0
11. Ratio culm length/height at maturity	1.6	1.0	1.0	1.0	1.0

Values are means of eight plants replicated twice.

of days from planting to heading. Pennsylvania, Massachusetts and California biotypes are the latest maturing, with Iowa being intermediate. The most striking difference in quantitative measurement is the culm height and the ratio of extended culm length to height. These measurements demonstrate the prostrate growth habit of the California biotype as opposed to the generally erect habit of other biotypes. Prostrate growth should be a distinct advantage under the frequent clipping schedules that occur in California alfalfa fields. The only physiological difference measured in this planting is the maturity difference between the biotypes. Maturity difference may be an expression of the different latitudes from which the seed was collected. There are differences in color and waxyness of leaf surface and some difficult to measure differences in pubescence. The adaptive significance of these features is less obvious.

Davis Planting

In the spring of 1972 a site was selected on the University of California Experiment Station, Davis, for comparisons of the seven seed collections. Collections were from: Connecticut, Iowa, Massachusetts, Pennsylvania and California (Yolo County, Calif., Glenn County 60 miles to the north, and Tulare County 200 miles south).

Methods

Seeds of each of the seven collections were planted in a single 1.2 meter row, for a total of seven rows per plot. The plots were replicated four times. Between row spacing was 30 cm and within row spacing was 20 cm (between plants). The soil type was Reiff very fine, sandy loam with irrigation by basin flooding. The planting date was June 3, and the experiment continued for 105 days. Measurements reported are the means of twenty plants for each collection of each biotype. Measurements taken included qualitative observations of: color, waxyness of leaf surface and growth habit; quantitative measurements were: days from emergence to heading, number of elongated internodes, vertical culm height, and extended culm length.

Variations in Development

The three California biotypes (Yolo, Glenn, Tulare) were almost identical in every respect (Table 2). However, basic differences exist between the California biotypes and those from other states. Biotypes from Connecticut, Massachusetts, Iowa and Pennsylvania are erect in growth habit while the three California biotypes are prostrate. The Massachusetts biotype is of a tea-green color compared with blue-green of other biotypes. The three California specimens have a dull, waxy coat on both leaf surfaces in contrast to

Table 2. Variations in development between Setaria lutescens biotypes--Davis--1972

Observations	California Yolo	California Glenn	California Tulare	Conn.	Iowa	Mass.	Penna.
1. Growth habit	Prostr.	Prostr.	Prostr.	Erect	Erect	Erect	Erect
2. Culm base color	Red	Red	Red	Red	Red	Green	Red
3. Abaxial leaf blade surface	Glauc.	Glauc.	Glauc.	Smooth	Smooth	Smooth	Smooth
4. Days-planting to heading	77	75	83	63	63	75	81
5. Number nodes per culm	5.3	5.6	5.5	4.8	5.9	5.8	9.0
6. Culm height 55 days (cm.)	19.0	21.0	19.0	34.0	41.0	40.0	37.0
7. Culm length 55 days (cm.)	32.0	34.0	29.0	38.0	45.0	46.0	40.0
8. Ratio culm length/height 55 days	1.7	1.6	1.5	1.1	1.1	1.1	1.1
9. Mature culm height (cm.)	54.0	56.0	55.0	56.0	64.0	71.0	77.0
10. Mature culm length (cm.)	83.0	92.0	84.0	59.0	72.0	77.0	82.0
11. Ratio culm length/height at maturity	1.5	1.6	1.5	1.1	1.1	1.1	1.1
12. Overall plant color	Blue-green	Blue-green	Blue-green	Blue-green	Blue-green	Tea-green	Blue-green

Values are means of 20 plants.

the shiny lower leaf surface of other entries. In this experiment Connecticut and Iowa biotypes were the earliest maturing, Tulare and Pennsylvania the latest maturing entries, and the other biotypes intermediate. Pennsylvania exhibited a greater number of elongated internodes in this planting than other entires.

The three selections from California are similar in all respects, with exception of time to heading. It is speculated that time to heading differences may be due to the 250 mile, north-south variation in collection sites. Since the California biotypes were nearly identical, the Yolo entry was chosen to represent the California biotype in future experimentation.

The biotypes from Connecticut, Massachusetts, Iowa and Pennsylvania exhibited approximately 40 percent less height at Davis than in the Woodland planting. It is speculated this may be due to the later planting date at Davis (June 3 versus May 2) and cooler temperatures at the Davis site. Although Davis and Woodland are only ten miles apart there is a definite climatic difference between the two locations according to weather bureau records. Davis is under the influence of cooling ocean breezes from San Francisco Bay. As a result, both day and night temperatures are somewhat lower in Davis than at Woodland. The California biotypes did not exhibit the same response to later planting and cooler temperatures as did the out-of-state entries. Less genetic difference between the

California ecotypes through better overall adaptation to the California climate may explain this reduction in variability.

Woodland Planting 1973

Preliminary comparisons of *Setaria lutescens* from Connecticut, Massachusetts, Iowa, Pennsylvania and California at Davis and Woodland in 1972 indicated considerable variation between the entries. Of special interest was the difference in growth habit. It was deemed essential to undertake a more intensive, quantitative study of the five biotypes. For this purpose a third biotype comparison was developed in the Woodland area.

Methods

Large plastic pots with one plant per pot were used in this experiment. The pots (Union Produce No. 1108, 20 x 21 cm) were filled with a soil-sand mix and seeded to the five *Setaria lutescens* biotypes. Experimental design was a five by five latin square, replicated two times. The second five by five planted ten days following the first. Pots were sub-irrigated to germinate seed and then placed in the soil to minimize heat load and to facilitate irrigation. Pots were buried to the shoulder on 54 cm centers in the plot area. The top 4 cm of the pot remaining above the level of the soil surface. Each five by five planting was surrounded by an irrigation border and basin flooded. The plants were fertilized with 10-10-10 and Hoaglands solution several times during the experiment. Measurements taken at weekly intervals were: culm height, extended culm length, plant color, number of heads, width and length of leaf blades, number of nodes elongated, length of internodes and vertical distance of the internodes from the soil surface.

Dates of planting were: April 9 for Experiment I and April 19 for Experiment II (Latin squares I and II). The investigation was continued for 132 days. The plants were removed from pots, washed free of soil and oven dried when they were no longer producing seed heads.

Variations in Development

Variations in growth habit, color, leaf size and texture, number of nodes, maturity and final dry weight per plant existed between biotypes. Growth habit was documented by measurement of extended culm length, vertical culm height and the ratio of length/height.

The Connecticut biotype was the earliest maturing as shown by days from planting to heading; the Iowa biotype second; and the Massachusetts, Pennsylvania and California biotypes were later and similar in maturity. Significant differences exist between biotypes in many of the morphological features measured as shown in Tables 3 and 4. The taller entries generally had a greater number of elongated

Table 3. Variations in development between <u>Setaria</u> <u>lutescens</u> biotypes--Experiment I (4/9/1973)--Woodland

Observation	Biotype					LSD.01
	Calif.	Conn.	Iowa	Mass.	Penna.	
1. Growth habit	Prostr.	Erect	Erect	Erect	Erect	-
2. Culm base color	Red	Red	Red	Green	Red	-
3. Abaxial leaf blade surface	Glauc.	Smooth	Smooth	Smooth	Smooth	-
4. Days-Planting to heading	91 ± 14	63 ± 3	74 ± 9	89 ± 8	94 ± 3	-
5. Number nodes per culm	7.6	5.8	8.8	11.4	12.0	3.6
6. Heads/plant	289.0	58.0	152.0	246.0	169.0	75.0
7. Leaf blade width (mm)	11.4	12.2	10.8	11.4	11.6	1.1
8. Leaf blade length (mm)	266.0	244.0	320.0	458.0	362.0	80.0
9. Leaf ratio length/width	23.0	19.0	29.0	40.0	31.0	-
10. Culm height 6-28 (cm)	17.0	91.0	84.0	79.0	63.0	29.0
11. Culm length 6-28 (cm)	40.0	96.0	86.0	91.0	68.0	30.0
12. Culm ratio length/height	2.4	1.1	1.0	1.2	1.1	-
13. Mature culm height (cm)	53.0	91.0	116.0	119.0	105.0	21.0
14. Mature culm length (cm)	90.0	96.0	127.0	129.0	116.0	19.0
15. Culm ratio length/height	1.7	1.1	1.1	1.1	1.1	-
16. Final dry weight g/plant	111.0	28.0	61.0	113.0	101.0	55.0

Table 4. Variations in development between _Setaria lutescens_ biotypes--Experiment II (4/19/1973)--Woodland

Observation	Biotype					LSD.01
	Calif.	Conn.	Iowa	Mass.	Penna.	
1. Growth habit	Prostr.	Erect	Erect	Erect	Erect	-
2. Culm base color	Red	Red	Red	Green	Red	-
3. Abaxial leaf blade surface	Glauc.	Smooth	Smooth	Smooth	Smooth	-
4. Days-Planting to heading	87 ± 8	52 ± 3	63 ± 3	85 ± 9	85 ± 5	-
5. Number nodes per culm	7.6	5.0	8.0	11.8	11.0	2.4
6. Heads/plant	262.0	81.0	188.0	287.0	163.0	56.0
7. Leaf blade width (mm)	11.8	12.6	10.8	12.0	12.2	0.8
8. Leaf blade length (mm)	272.0	214.0	334.0	444.0	354.0	64.0
9. Leaf ratio length/width	23.0	17.0	31.0	37.0	29.0	-
10. Culm height 6-28 (cm.)	19.0	79.0	77.0	77.0	55.0	19.0
11. Culm length 6-28 (cm.)	43.0	83.0	84.0	82.0	57.0	18.0
12. Culm ratio length/height	2.3	1.1	1.1	1.1	1.0	0.29
13. Mature culm height (cm.)	51.0	79.0	97.0	98.0	108.0	27.0
14. Mature culm length (cm.)	83.0	83.0	114.0	112.0	109.0	26.0
15. Culm ratio length/height	1.7	1.1	1.2	1.1	1.0	-
16. Final dry weight g/plant	125.0	28.0	61.0	140.0	107.0	30.0

internodes. California and Massachusetts biotypes far exceeded the others in numbers of heads per plant, the Pennsylvania and Iowa biotypes were intermediate, and the early maturing Connecticut biotype produced the least number of heads. Leaf blade length varied considerably between biotypes, California and Connecticut with the shortest and Massachusetts the longest, respectively. Culm length/height ratios in early season showed the California biotype to be relatively prostrate compared to the others, the prostrate habit continued through maturity. The final dry weight of plants included both top growth and roots. There was considerable variation between entries in production of dry weight during the life of the plant. Dry weight was related to the number of culms and seed heads produced.

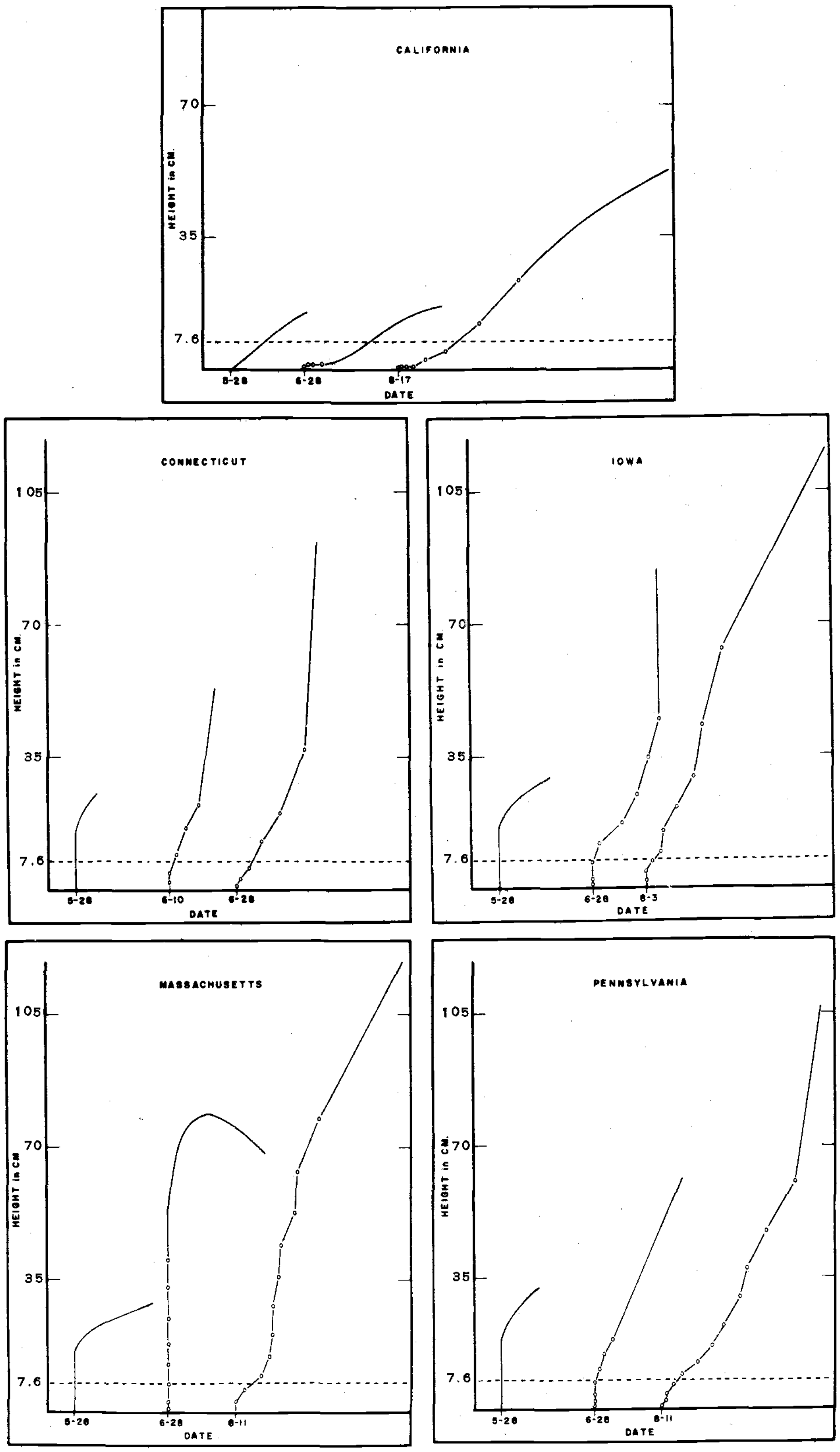
There were very few differences between Experiments I and II. For the most part the measurements could be combined. The major differences were in time to heading (with the later planting maturing more rapidly), and in culm height and length (the later planting had shorter culms).

Growth Patterns

Growth patterns of five *Setaria lutescens* biotypes at three dates are illustrated in Figure 1. Drawings were constructed from actual measurements taken on the dates shown. Each drawing represents the average culm position of plants of that biotype in Experiment I.

Figure 1. Growth patterns of Setaria lutescens biotypes at three stages in their life cycle. Drawings represent an average plant culm of each biotype on the date indicated. Each drawing is constructed from measurements of culm height, extended culm length, internode length and distance of nodes from the ground surface.

GROWTH PATTERNS – *Setaria lutescens* BIOTYPE



An almost identical set of drawings could have been made from Experiment II. Measurements used were: extended culm length, culm height, the number of nodes, the vertical height of each node from the ground surface and the distance of each node from the culm base. Using these measurements it was possible to construct an average culm for each biotype on the dates listed (35 mm slides, taken weekly, aided in establishing a curve for the final internode). The dotted line represents 7.6 cm cutterbar height for clipping.

The first figure on each biotype graph (5-28) was constructed from measurements taken approximately five weeks after seedling emergence. This figure represents the plant foliage prior to heading. The California biotype, after initial upright seedling growth, bent downward at the ground surface to a horizontal position. Biotypes from Massachusetts, Connecticut, Iowa and Pennsylvania were erect. The figures on (6-28) represent plant culms nine weeks after emergence. Figures for Connecticut and Iowa represent headed culms. All biotypes, with the exception of California, have upright internodal elongation and show three to five nodes above 7.6 cm. The last figure in each graph depicts the biotypes headed and at maximum plant height. The Connecticut entry was at maximum height on June 28.

Considerable variation in color, maturity, growth habit and head production is evident between the five biotypes. Presumably, several of these differences are genetic in nature. The reproductive capacity, as indicated by number of heads, would certainly be an advantage from the standpoint of maintaining and increasing the population of that biotype (providing the seeds are viable). Plant height would be useful when growing among competing weeds or tall crop plants. Early maturity would be of advantage in areas where the growing season is short because of temperature or daylength. In this comparison the later maturing biotypes produce more total growth and have higher reproductive capacities.

Drawings in Figure 1 support speculation that prostrate growth of the California biotype is an adaptation to alfalfa culture in California. After initial upright seedling growth the California entry bends horizontally at ground level nodes and most foliage remains in a horizontal position until after heading. The foliage resembles a rosette type growth found in several broadleaf plants. On June 28 all biotypes except California would have been severely damaged by clipping to 7.6 cm. Connecticut, Massachusetts, Iowa and Pennsylvania are heading, with internodal elongation sending nodes and heads above cutterbar height. The heading and culm elongation of the California biotype is initially in a horizontal direction, the head does not assume an upright position until after pollination. After pollination the final two nodes bend in an upward direction and elongation of the final four internodes takes place rapidly. Many heads escape being clipped until seed is mature and ready to shatter.

Summary and Discussion

The existence of physiological strains or races among various species has been recognized since the early 1900s. If sufficient morphological differences exist in a given series of races within a species they generally have been designated subspecies or varieties. It was Göte Turesson (Turesson, 1925) who pointed out that the survival of a plant depends on its physiological fitness to its environment as well as its morphological characteristics. His studies revealed that species occupying large geographic areas are composed of ecological races, or as he termed them, "ecotypes." An ecotype constitutes those individuals which exhibit a distinctive type of inherited morphology or physiology which is adaptive in relation to a particular ecosystem. A more precise understanding of the ecotype concept has come from the experimental studies of Clausen, Keck and Hiesey (Clausen *et al.*, 1940, 1948). Their studies involve *Potentilla glandulosa* and several species of *Achillea*. Reciprocal transplant experiments of the individuals from each of the habitats showed that differences between them were hereditary. The populations had become genetically adapted to their own particular habitats; that is, they belonged to different races or ecotypes.

A number of possible sources of ecotypic development are described by King (1966). He lists regional, altitudinal, latitudinal, physiological, edaphic and agricultural ecotypes. If Setaria lutescens in California expressed true adaptive responses it might fall into two of King's classifications--regional and/or agricultural. A regional or geographic ecotype might develop because of the separation of a portion of a population by distance and/or geographical barriers. California fits into this category well, it is separated by long distances from Europe and also from the eastern and midwestern United States. Its mountain ranges and deserts on the inland side and the Pacific Ocean on the west provide physical barriers to migration and to genetic flow. Pritchard (1960) cited an example of another plant species, Hypericum perforatum, which also originated from Europe, migrating to California and through adaptation becoming a successful invader. Agricultural ecotypes have been described by E. J. Salisbury of England (King, 1966). Cited was a species of Ranunculus. The original species, or tall form, grew on the borders of the grain-field, while within the field a lower growing form had developed that flowered and set seed below the level of the reaping machine. Bunting (1960) points out the importance to a successful weed species of adaptation to the crop in which it is established.

> The more nearly a weed species resembles a crop in habit, ecological requirements, and in time relations, the more difficult it must be to control without damaging the crop itself.

Among the grasses (Gramineae) there are examples of ecotypic development. McKell (1962) investigated medusahead (Elymus caput-medusae) which has spread into the western coastal states since its introduction into Oregon eighty-five years ago. McKell describes development of ecotypes in this wide ranging species. Roche and Muzik (1964) working with Echinochloa crusgalli describes five bio-types in Washington. These biotypes differed in response to clipping, and in color, head type, seed morphology and growth habit.

A number of researchers have investigated and described varieties or selections within species of the genus Setaria. Hubbard (1915) reported many varieties of Setaria viridis (L.) Beauv. and Setaria italica (L.) Beauv. Rominger (1962) gives indications of polyploidy within the species Setaria lutescens in his description of the species, and Khosla (1972) describes six "agrobotanical morpho-types" and three cytological races within the species Setaria lutescens in India. Recently Schreiber and Oliver (1971) described two new varieties of Setaria viridis (L.) Beauv. found in Illinois. Biotypes of Setaria lutescens have been described by Santelmann et al. (1961 and 1963) in a study on the growth and development of Setaria lutescens in Connecticut and Maryland.

The most significant variation between biotypes originating from Massachusetts, Connecticut, Iowa, Pennsylvania and California was the prostrate growth habit of the California selection compared to erect growth and development of the others. There were other differences, such as the tea-green color with no reddening of culm base or nodes in the Massachusetts biotype versus the blue-green plant color and reddening of culms in all others. Differences in time of maturity were very evident with Connecticut maturing much more rapidly than all others. There were also variations in height, leaf width and length, number of elongating internodes and number of heads.

Biotypes showed close morphological and physiological similarity between years and experiments. The greatest observed difference between years was the shorter culm length and lesser node elongation in 1972 and the increased length of time to heading in 1973. This can be partially explained by later seasonal planting dates in 1972. Vengris (1963) demonstrated that plant yield, height, maturity and head length of Setaria lutescens were correlated to planting date. Early season plantings reaching the greatest height with the greatest dry matter yield when compared with mid-season or late season plantings. Vengris says this is related to photoperiodism, for Setaria glauca (lutescens) is a short day plant. Others have demonstrated the short day reproductive response of Setaria lutescens. Listowski and Jasmanowicz (1971) observed that the species is a short day plant with respect to flower initiation and that stem elongation, the number and size of leaves and rate of axillary shoot growth increased with increasing light. Peters et al. (1963) also attribute increased vegetative development to long periods of light and flower initiation to decreasing day length.

It appears from study of the morphology and physiology of individuals from the five biotypes that the California biotype exhibits characteristics that indicate possible agricultural adaptation to cultivation of alfalfa in California. The question is raised: Will what appears to be an adaptive response (viewed in isolation) actually be advantageous to a plant species growing under the conditions in which the adaptation may have evolved? It was with this question in mind that competition experiments of 1972 and 1973 were devised.

INTERSPECIES COMPETITION

Purpose of the Studies

These investigations included planting of *Medicago sativa*, *Setaria lutescens* and *Echinochloa crusgalli* in an environment simulating that of alfalfa cultivated for forage in California. Information to be gathered included dry matter production, stand density and estimates of seed production.

The purpose of the study was to collect information on morphological, physiological and cultural factors that might lead to the success of *Setaria lutescens* and/or *Echinochloa crusgalli* as invaders of alfalfa. The ultimate objective was to determine which factors contribute most to success of these weed species in cultivated alfalfa and to limit the success of weed species by a change in cultural methods.

Davis Competition Study (1972)

Methods

The three species in these studies will hereafter be referred to as: alfalfa-(*Medicago sativa*), *Setaria*-(*Setaria lutescens*), *Echinochloa*-(*Echinochloa crusgalli*).

A site thirty-six meters square, with no known history of *Setaria* or *Echinochloa*, was selected on the Experimental Farm,

U. C. Davis. The soil type was Reiff very fine, sandy loam, the irrigation method was basin flooding. A split plot with factorial arrangement of treatments was chosen to meet the objectives of the experiment. Main plots were AO (without alfalfa) and Al (with alfalfa). Subplots were three rates of Echinochloa and three rates of Setaria arranged factorially.

Seeding rates were: Alfalfa (Lahontan) 24.7 Kg/Ha (22 lb/acre)

Setaria	Echinochloa
S0 = 0 seeds/929 cm^2.	E0 = 0 seeds/929 cm^2.
S1 = 10 seeds/929 cm^2.	E1 = 10 seeds/929 cm^2.
S2 = 150 seeds/929 cm^2.	E2 = 150 seeds/929 cm^2.

(The treatment designation--E1 S2--for example, indicates a starting seeding rate of 10 Echinochloa seeds + 150 Setaria seeds per 929 cm^2. · one square foot.) Echinochloa and Setaria seed was collected from mature heads in Yolo County during the fall of 1971. Seed was broadcast in November 1971 at the predetermined rate and covered by raking. On March 10, 1972, alfalfa seed was broadcast and covered.

In early May, the low density seedings of Setaria (S1) and Echinochloa (E1) were hand thinned to one plant per 929 cm^2. High density seedings of Echinochloa (E2) and Setaria (S2) were counted but not thinned. Alfalfa stand density was counted at a uniform 35 plants per 929 cm^2. Harvests of green material were taken with a flail harvester, weighed and samples dried for moisture content. 1972 harvest dates were: May 31, June 30, August 1, and September 9. Prior to each harvest subsample quadrats were hand cut and separated for measures of weed content and seed head count of the two weed species. Vegetative weed material was not separated by species. Following the final fall harvest the plots were allowed to grow untouched as is common practice in the area.

Plant Density, *Echinochloa* and *Setaria*

Original weed density is listed in Table 5. Low density treatments (E1, S1 and combinations) were hand thinned to one plant per 929 cm^2. High density treatments (E2, S2 and combinations) were counted but not thinned. The result was considerable stand variation between high density treatments.

Dry Matter Yields, *Echinochloa* and *Setaria*

Weed yields by treatment, with and without alfalfa, are given in Table 6. The following statements apply to both with and without alfalfa main plots. The presence of absence of alfalfa had the most substantial impact on vegetative production of *Echinochloa* and *Setaria*. Presence of alfalfa reduced total weed yields by 82 percent (Table 6). Alfalfa had a greater effect on low density weed treatments than on high density treatments. *Echinochloa* and *Setaria* produced similar vegetative yields when grown at equal plant densities. Low density

Table 5. Beginning density (plants/929 cm^2) Echinochloa crusgalli and Setaria lutescens when alone, or together, with and without alfalfa

Treatment[1]	Without Alfalfa		With Alfalfa	
	Echinochloa	Setaria	Echinochloa	Setaria
E0 S1	-	1.1	-	1.0
E0 S2	-	20.1	-	10.8
E1 S0	1.1	-	.8	-
E1 S1	1.0	1.1	.7	.9
E1 S2	1.0	19.0	1.3	18.7
E2 S0	11.0	-	7.1	-
E2 S1	7.2	1.0	3.2	1.0
E2 S2	4.6	17.7	2.5	12.5

Data above are means of four replications.

Table 6. Dry matter yields (g/m^2) Echinochloa crusgalli and Setaria lutescens when alone, or together, with and without alfalfa

Treatment[1]	Without Alfalfa	With Alfalfa
E0 S1	671	28
E0 S2	823	190
E1 S0	645	36
E1 S1	776	67
E1 S2	863	213
E2 S0	828	200
E2 S1	855	165
E2 S2	822	241
Means	785	142
LSD.05	197	69
LSD.05 without alfalfa vs with alfalfa = 288		

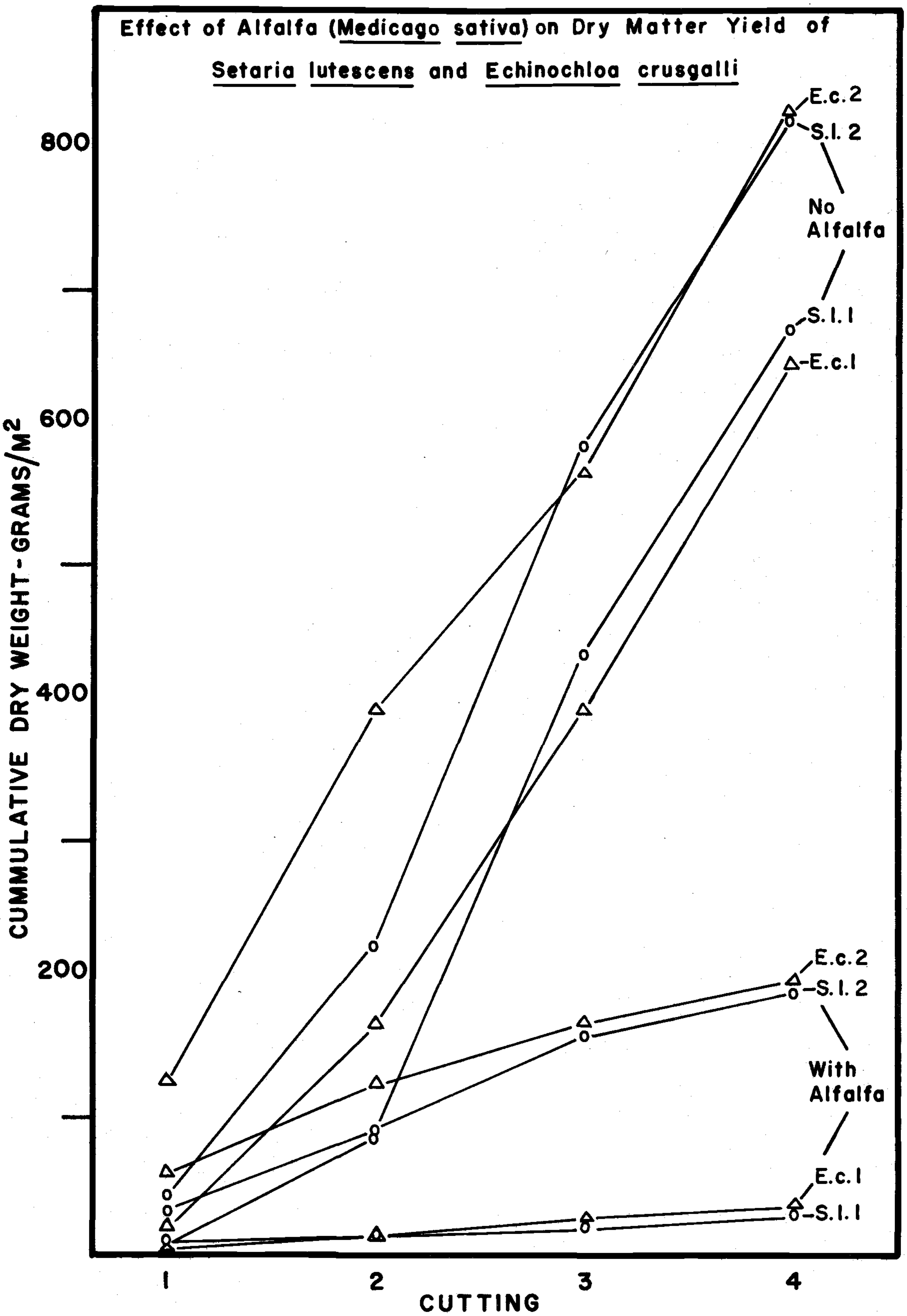
[1] E = Echinochloa crusgalli
S = Setaria lutescens
0, 1, 2 refer to seeding rates of 0, 10, 150 seeds/929 cm^2

treatments (E1, S1) produced 20 percent to 90 percent less than high density treatments (E2, S2). Any weed density with more than five plants/929 cm^2 gave near maximum vegetative weed yields per unit area. The original plant density variation (between high density treatments) is not reflected in weed yields. Individual plants compensated for thinner stand by increasing production per plant.

The seasonal growth patterns of eight treatments from the experiment are depicted in Figure 2. These eight treatments are: Echinochloa with and without alfalfa, Setaria with and without alfalfa. Setaria and Echinochloa yields are lower in the presence of alfalfa. Weed density (low versus high) has an impact on weed yield per unit area. However, plants at lower densities tend to compensate by producing more per individual. Setaria and Echinochloa produced essentially the same amount of vegetative matter under conditions of this experiment. Echinochloa dry matter yield was higher in early cuttings and Setaria yield higher in cuttings three and four.

Alfalfa was very competitive with Echinochloa and Setaria as shown by lower weed yields in presence of alfalfa. The number of Setaria and Echinochloa plants per unit area was important only at the very low densities. Both of these species show high plasticity or capability to take advantage of free space by increasing in size. Echinochloa showed high, early season yield because its early, erect growth was picked up by the harvester. Much of the early season

Figure 2. Dry matter yields of eight treatments from the 1972 Davis competition study are illustrated. E. c. represents Echinochloa crusgalli, S. l. represents Setaria lutescens, 1 and 2 represent Echinochloa and Setaria seeding rates of 10 and 150 seeds/929 cm^2.


Effect of Alfalfa (Medicago sativa) on Dry Matter Yield of
Setaria lutescens and Echinochloa crusgalli
CUMMULATIVE DRY WEIGHT - GRAMS/M²
800
600
400
200
CUTTING
1
2
3
4
E.c. 2
S.l. 2
No Alfalfa
S.l. 1
E.c. 1
E.c. 2
S.l. 2
With Alfalfa
E.c. 1
S.l. 1

Setaria growth was prostrate and below cutter bar height.

Dry Matter Yields, Alfalfa

Alfalfa yields were quite variable, increasing from first to last cutting as the season progressed (Table 7). Factorial analysis of yield data is shown in Table 7. Yields are given by level of Echinochloa and level of Setaria. There was no interaction effect between Echinochloa and Setaria. Setaria at high density (S2) decreased alfalfa yields at every cutting and caused a significant decrease in total yield of alfalfa over the season. Echinochloa at high density (E2) caused significant yield decreases by alfalfa at the first two cuttings, had no effect on cuttings three and four, and only slightly depressed alfalfa yields for the season. Neither weed species had a detrimental effect on alfalfa yield at low density (Sl, El).

The perennial alfalfa plants increased in size and vigor as the season progressed. As alfalfa gained maturity, the weeds had less effect on yield. By alfalfa grower standards, 35 plants/929 cm^2 is an exceptionally dense alfalfa stand and would be expected to compete strongly with weeds. It is not surprising to find that Echinochloa affected alfalfa most severely early in the year. Echinochloa grew rapidly before the first cutting, overtopping alfalfa, but later suffered from clipping and strong alfalfa competition. By seasons end Echinochloa had little effect on alfalfa yields. Setaria exerted its greatest

Table 7. Dry matter yields of alfalfa (g/m^2) Alfalfa yields at three densities of Echinochloa crusgalli or Setaria lutescens

Treatment[1]	Alfalfa Yield by Cutting and Treatment				
	Cutting				Total
	1	2	3	4	
E0[2]	159	218	296	273	947
E1	153	199	243	261	856
E2	127	167	273	276	842
LSD.05	25.3	36.2	NS	NS	NS
S0[3]	148	203	279	267	897
S1	158	209	299	284	950
S2	132	173	234	258	798
LSD.05	25.3	NS	47	NS	119

[1] E = Echinochloa crusgalli
S = Setaria lutescens
0, 1, 2 refer to seeding rates of 0, 10, 150 seeds/929 cm^2

[2] Yield according to Echinochloa density.

[3] Yield according to Setaria density.

impact at the third cutting, starting slowly but growing rapidly late in the season. Lower densities (E1, S1) had virtually no effect on alfalfa yields.

Alfalfa yield by treatment is summarized in Table 8. Yields by treatment were quite variable.

Seed Head and Seed Yield, *Echinochloa* and *Setaria*

The mean yield of *Echinochloa* and *Setaria* seed heads across all treatments is given in Table 9. The presence of alfalfa caused a 95 percent reduction in total *Echinochloa* seed heads and reduced numbers of *Setaria* seed heads by 80 percent (Table 9).

Information contained in Table 10 shows that when *Echinochloa* and *Setaria* are grown together, each affects seed production of the other. Competition from high plant density of *Setaria* reduces *Echinochloa* seed production from 60 percent to 80 percent. Conversely, high density *Echinochloa* reduces *Setaria* production from 3 percent to as much as 37 percent. The lowest level of *Setaria* seed production is 4,200 seeds/m^2 while *Echinochloa* produces only 88 seeds/m^2 at its lowest productive rate in this test.

Seed heads of both species were counted at fourth harvest. The numbers of seeds per head were counted in 30 head samples to obtain estimates of seed production. Since seeds per head is an extremely variable figure, the seed yield estimates may be high. The most

Table 8. Dry matter yields of alfalfa (g/m^2) Alfalfa grown alone, with *Echinochloa crusgalli* and/or with *Setaria lutescens*

Treatment[1]	Yield
E0 S0	925
E0 S1	1043
E0 S2	872
E1 S0	848
E1 S1	1001
E1 S2	718
E2 S0	920
E2 S1	805
E2 S1	803

[1]E = *Echinochloa crusgalli*
S = *Setaria lutescens*
0, 1, 2 refer to seeding rates of 0, 10, 150 seeds/929 cm^2

Table 9. 1972 seed head yields (heads/m^2) Echinochloa crusgalli and Setaria lutescens with or without alfalfa. Mean over all treatments.

	Setaria lutescens		Echinochloa crusgalli	
	With Alfalfa	Without Alfalfa	With Alfalfa	Without Alfalfa
	158	807	17	389
LSD.05	306		134	

Table 10. 1972 seed head and seed yields (per m^2) Echinochloa crusgalli or Setaria lutescens yields when related to density of the other species.

Setaria lutescens			Echinochloa crusgalli		
Treatment[1]	Heads	Seeds	Treatment	Heads	Seeds
Heads/m^2 without alfalfa					
E0	1210	29,000	S0	940	57,000
E1	1273	30,000	S1	548	33,000
E2	747	18,000	S2	132	8,000
LSD.05	201			278	
Heads/m^2 with alfalfa					
E0	201	4,700	S0	35	280
E1	255	6,000	S1	20	160
E2	178	4,200	S2	11	88
LSD.05	NS			NS	

[1]Please refer to Table 7.

startling information gleaned from the measurements was the severe impact of alfalfa on overall seed yield of both weed species. This was not unexpected but the 80 percent reduction for Setaria and 95 percent reduction for Echinochloa demonstrates effectiveness of the perennial alfalfa plant as a competitor. A reason Echinochloa is especially adversely affected is that dense alfalfa forces erect growth that is vulnerable to clipping. Large portions of foliage and all seed heads are removed at each harvest. The prostrate habit of Setaria is an advantage in that most of the foliage and immature seed heads are below cutter bar height.

Stand Density, Alfalfa

Information in Table 11 shows small but consistant reductions in stand of alfalfa in treatments with high density of Setaria (S2). When alfalfa stand is analyzed by individual weed density across all treatments, there is a statistically significant reduction in alfalfa density in the treatments with high density Setaria. There is a slight reduction in alfalfa density with increasing Echinochloa populations, but the difference is not statistically significant. No particular reason can be given for stand reduction in alfalfa by Setaria other than competitive effects of a weed on seedling alfalfa plants.

Table 11. 1973 alfalfa stand density (plants/929 cm^2) Alfalfa density with Echinochloa crusgalli or Setaria lutescens or both.

By Weed Treatment

Setaria[1] Density	Echinochloa Density E0	E1	E2
S0	26.4	26.8	24.4
S1	26.4	24.0	26.8
S2	24.5	24.0	22.8

By Echinochloa Density and By Setaria Density

Echinochloa Density	Alfalfa Density	Setaria Density	Alfalfa Density
E0	25.7	S0	25.8
E1	24.9	S1	25.7
E2	24.6	S2	23.7
LSD.05	NS		1.51

[1] S = Setaria lutescens
E = Echinochloa crusgalli
0, 1, 2 refers to seeding rate of 0, 10, 150 seeds/929 cm^2

Davis Competition Study (1973)

Methods

Seed produced by Echinochloa and Setaria during 1972 resulted in seedling grasses for 1973. Alfalfa plots were all counted for grass stand density, and Echinochloa and Setaria plants were removed from the E0 and S0 treatments.

Treatments "without alfalfa" had extremely dense stands of both grasses. As a result, plant density counts were taken only in the E2 S0, E0 S2, and the E2 S2 treatments. All Setaria was removed from the E2 S0 treatment. No other hand thinning was undertaken.

The harvest method changed following the first 1973 harvest. Cutting with a mower, hand raking into windrows, drying in the windrow and weighing dry was substituted for green chopping with a flail machine. Preliminary quadrats were hand cut and separated to determine weed content. Seed head counts were made from these sub samples and 100 head samples of each species weighed to arrive at a seed production estimate.

Plant Density, Echinochloa and Setaria

1973 plant density was extremely high in plots "without alfalfa." Plant density of those plots counted was ten times greater than in 1972 (Table 12). The E2 S2 treatment count "without alfalfa" is a

Table 12. 1972 and 1973 plant densities (plants/m^2) Echinochloa crusgalli and Setaria lutescens when alone, or together, with and without alfalfa.

Treatment[1]	Echinochloa		Setaria	
	1972	1973	1972	1973
Without Alfalfa				
E0 S1	-	*	12	*
E0 S2	-	*	216	2357
E1 S0	12	*	-	*
E1 S1	11	*	12	*
E1 S2	11	*	205	*
E2 S0	119	947	-	*
E2 S1	76	*	11	*
E2 S2	50	(2551 Combined)	190	(2551 Com-bined)
With Alfalfa				
E0 S1	-	-	11	47
E0 S2	-	-	116	43
E1 S0	9	14	-	-
E1 S1	8	4	10	45
E1 S2	14	6	201	88
E2 S0	76	18	-	-
E2 S1	34	10	11	58
E2 S2	27	3	135	66

[1] Please refer to Table 6.

*No stand count taken due to extreme density.

Stand counts have been converted to plants per square meter for ease of comparison.

combination of Echinochloa plus Setaria.

The overall Echinochloa stand with alfalfa was reduced 67 percent from 1972. Setaria plant density was 28 percent less than in 1972 (overall means). 1973 Echinochloa stand count was less than 1972 in five of six original treatments. Setaria plant density increased in the three original low density (S1) treatments and decreased from 1972 in the original high density (S2) treatments.

The 1972 weed seed production "without alfalfa," of ten to sixty thousand seeds/m^2, favored an extremely dense second year weed stand. In addition, seed had (apparently) floated from plot to plot with irrigation water. The result was a high density mixture of Echinochloa and Setaria. This development was unexpected but not entirely unwelcome. It provided an opportunity to speed up the end result of interspecies competition, although original treatments were blurred. Except for the E2 S0 (high density Echinochloa) treatment no attempt was made to thin or weed these plots. Plots were not thinned because of considerable difficulty in differentiating between Echinochloa and Setaria seedlings this small and this dense and a lack of time required to thin large plots with very high plant density.

Second-year alfalfa was very competitive with grass seedlings. Echinochloa plant density was reduced to a much greater extent than Setaria. Germination of seed and seedling response to shade may be speculated as part of the difference.

Dry Matter Yields, *Echinochloa* and *Setaria*

The overall 1973 weed yield "without alfalfa" was reduced by 85 percent from 1972 (Table 13). The only substantial difference between treatments is due to the hand thinned E2 S0 (high density *Echinochloa*).

Total 1973 weed yields "with alfalfa" were reduced by 71 percent from 1972. There were no statistically significant differences between treatments in 1973, as is shown by data in Table 13. Seed mixing did not occur in these plots.

Comparing main plot effects on total weed yields shows the presence of alfalfa reduces weeds by 64 percent as compared to no alfalfa (Table 13).

Echinochloa and *Setaria* plants in all treatments "without alfalfa" were stunted with light yellow color and red tinges on leaves. These plants were too short to be harvested with the 7.6 cm cutter bar until after head emergence. It is speculated that stunting was due to extreme density and nutrient deficiency. The 1972 dry matter yields from these plots was very high and most available nitrogen may have been removed from the soil. The mixture of *Echinochloa* and *Setaria* resulting from floating seed made the original treatments invalid. Forage yields were not separated by plant species.

Table 13. 1972 and 1973 dry matter yields (g/m^2) Echinochloa crusgalli and Setaria lutescens when alone, or together, with and without alfalfa.

Treatment[1]	Without Alfalfa		With Alfalfa	
	1972	1973	1972	1973
E0 S1	671	133	28	40
E0 S2	823	108	190	34
E1 S0	645	138	36	20
E1 S1	776	96	67	53
E1 S2	863	125	213	44
E2 S0	828	66	200	51
E2 S1	855	131	165	50
E2 S2	822	119	241	34
Mean	785	115	142	41
LSD.05	197	39	69	NS

[1]Please refer to Table 6.

Dry Matter Yields, Alfalfa

Neither *Echinochloa* nor *Setaria* had significant effect on alfalfa dry matter yield during the 1973 season (Table 14). There were no differences in yield by cutting or for the seasons total.

Alfalfa yields over the two seasons are summarized in Table 15. While high density *Setaria* had a depressing effect on alfalfa yields during 1972 this effect did not carry over into the second season. There are no significant differences between treatments for the 1973 season nor for the two season total of alfalfa yields.

The perennial alfalfa plants became well established during the 1972 season and started growth early in the spring of 1973. This early growth offered competition to seed and seedlings of the weed species. Dry matter yields and stand densities of weeds decreased while alfalfa yield was not affected by weed treatments.

Seed Head Yield, *Echinochloa* and *Setaria*

In 1972 head count data were taken from only one cutting (Table 16). The total head production for 1972 would have been higher had additional counts been made. 1973 head counts were from three regular season harvests and one post season clipping.

The original treatments in main plots without alfalfa were mixed by floating seed. No valid conclusions can be reached concerning density treatments. However, looking at the over-all main

Table 14. 1973 dry matter yields of alfalfa (g/m^2) Alfalfa yields at three densities of Echinochloa crusgalli or Setaria lutescens

Treatment[1]	Cutting 1	2	3	4	5	6	Total
E0[2]	278	349	233	193	216	106	1371
E1	293	331	241	186	209	98	1358
E2	283	351	237	197	214	115	1397
Mean	285	337	237	192	213	106	1375
LSD.05	No significant differences by cutting or total						
S0[3]	283	329	231	194	202	110	1349
S1	282	355	246	194	218	96	1390
S2	288	348	234	189	218	112	1390
Mean	284	344	237	192	212	106	1376
LSD.05	No significant differences by cutting or total						

[1]E = Echinochloa crusgalli
S = Setaria lutescens
0, 1, 2 refer to seeding rates of 0, 10, 150 seeds/929 cm^2

[2]By Echinochloa Density

[3]By Setaria Density

Table 15. Dry matter yields of alfalfa (g/m^2) Alfalfa grown alone, with *Echinochloa crusgalli* and/or with *Setaria lutescens*.

Treatment[1]	Total Alfalfa Yield by Treatment 1972	1973	Total
E0 S0	925	1377	2302
E0 S1	1043	1380	2423
E0 S2	872	1368	2240
E1 S0	848	1361	2209
E1 S1	1001	1400	2401
E1 S2	718	1312	2030
E2 S0	920	1310	2330
E2 S1	805	1390	2195
E2 S2	803	1489	2292
Mean Yield	882	1377	2258

[1]E = *Echinochloa crusgalli*
S = *Setaria lutescens*
0, 1, 2 refer to seeding rates of 0, 10, 150 seeds /929 cm^2

Table 16. Seed head yields (heads/m^2) Echinochloa crusgalli and Setaria lutescens when alone, or together, with and without alfalfa.

Treatment[1]	Echinochloa		Setaria	
	1972	1973	1972	1973
Without Alfalfa				
E0 S1	15	26	1077	1641
E0 S2	72	30	1339	1419
E1 S0	873	22	2	952
E1 S1	246	24	1063	1051
E1 S2	34	14	1483	1640
E2 S0	1008	49	-	73
E2 S1	850	18	328	1615
E2 S2	230	7	1165	1148
Mean	390	24	807	1192
LSD.05	328	NS	286	430
With Alfalfa				
E0 S1	-	14	70	604
E0 S2	1	6	332	572
E1 S0	11	52	-	83
E1 S1	6	15	171	686
E1 S2	2	6	339	734
E2 S0	59	127	-	43
E2 S1	34	29	83	641
E2 S2	20	13	273	525
Mean	17	33	159	486
LSD.05	36	53	137	341

[1]Please refer to Table 6.

plot, Setaria seed head production increased 72 percent (over 1972) while Echinochloa seed head production decreased 94 percent (Table 16). Echinochloa produced very few seed heads even in the hand weeded treatment.

Looking at the mean of all treatments in the presence of alfalfa, Setaria increased seed head numbers by 300 percent over 1972. Echinochloa also increased, by 190 percent, but the total numbers were very low. Setaria produced an average of 15 times more seed heads with alfalfa than did Echinochloa for 1973.

Part of the increased seed head production by Setaria is due to the larger number of cuttings that head counts were made. Echinochloa on the other hand had strong decreases in production, probably due to extreme high density competition, nutrient deficiency and clipping in the main plots without alfalfa. With alfalfa, Echinochloa yielded approximately the same number of heads as in 1973.

Seed Yield, Echinochloa and Setaria

No valid conclusions can be reached on density treatments in the main plot "without alfalfa" because of the seed mixing by irrigation water in 1972 (Table 17). However, looking at the plots over-all, Echinochloa versus Setaria, it is evident that Setaria dominated. Total Setaria seed production was 80 percent greater in 1973 than in 1972. Echinochloa produced no mature seeds in the material

Table 17. Seed yields (g/m^2) Echinochloa crusgalli and Setaria lutescens when alone, or together, with and without alfalfa.

Treatment[1]	Echinochloa		Setaria	
	1972	1973	1972	1973
Without Alfalfa				
E0 S1	2	-	42	80
E0 S2	12	-	52	71
E1 S0	140	-	-	47
E1 S1	39	-	41	53
E1 S2	5	-	58	81
E2 S0	161	-	-	3
E2 S1	136	-	13	81
E2 S2	37	-	45	59
With Alfalfa				
E0 S1	-	-	3	28
E0 S2	.01	-	13	26
E1 S0	.14	-	-	4
E1 S1	.08	-	7	32
E1 S2	.03	-	13	34
E2 S0	.77	-	-	2
E2 S1	.44	-	3	29
E2 S2	.31	-	11	24

[1]Please refer to Table 15.

harvested in this portion of the test during 1973 (Table 16).

Seed production by Setaria with alfalfa was 300 percent greater than in the previous year. Echinochloa produced no mature seed during 1973 when grown with alfalfa.

Seed production results were rather startling. Setaria was able to mature seed between clippings and in the post-harvest season. Echinochloa was unable to mature seed in the 30-day interval between harvests and the plants ceased to produce seed heads after early October. It is recognized that Echinochloa can and will mature seed in an alfalfa field, but mature seeds were not found in the harvested material of this experiment. In main plots "without alfalfa" the extreme plant densities ($2300/m^2$) and nutrient deficiencies had a much more severe effect on Echinochloa than on Setaria. Many of the tiny Setaria plants were able to send up a single, small seed head; but Echinochloa did not produce many heads above clipping height, and those that did appear had no mature seed. With alfalfa the prostrate Setaria was able to avoid severe damage from clipping while erect Echinochloa has most of its foliage and immature panicles removed at each clipping. In addition, Setaria continues to produce seed into the late fall while Echinochloa dies.

Post-Harvest Seed Yield, Echinochloa and Setaria

Fifty-one percent of the seasonal seed production of Setaria lutescens came in the post-alfalfa harvest season during 1973 (Table 18). The collection date was October 29, 1973. Clippings were taken from all alfalfa plots, seed heads counted and heads weighed for seed production estimates.

One of the largest reproductive advantages of Setaria is its late season growth and seed production (Table 18). Echinochloa does not produce seed this late in the season, having normally concluded its growth by late September. Setaria continues to grow slowly and produce seed until the first frost which can be mid-November in Yolo County. This late season growth is unmolested by clipping.

Table 18. Seed yields (g/m^2) Echinochloa crusgalli and Setaria lutescens with alfalfa. Late season yields--October 29, 1973

Treatment[1]	Seed Yield		Percent of Season Total
	Echinochloa	Setaria	Setaria
E0 S1	-	14.7	53
E0 S2	-	14.8	56
E1 S0	-	2.9	75
E1 S1	-	14.2	45
E1 S2	-	16.8	50
E2 S0	-	1.5	77
E2 S1	-	14.3	48
E2 S2	-	12.6	51

[1]Please refer to Table 15.

Echinochloa inflorescences were present at harvest but all caryopses were blank.

Stand Density, Alfalfa

There was a small but significant decrease in alfalfa stand due to high density Setaria treatment (Table 19). There was a slight decrease with Echinochloa, but the difference was not statistically significant.

Figure 3 displays in histogram form the alfalfa stand densities due to treatment. A definite trend exists of decreasing alfalfa stand with increase in Setaria density.

Summary, Davis Competition Studies

As a portion of this overall study, Echinochloa and Setaria were grown together at varying densities. From this work it is evident that Echinochloa and Setaria are very adaptable to a range of plant densities (10 to 200/m^2) as shown by vegetative and seed yields during the first year of testing. Both species are capable of utilizing open areas or free space through increased growth and reproduction by individuals. The two species have competitive effects on each other as demonstrated by reductions in seed yield in mixed plantings. Both Echinochloa and Setaria are capable of reproducing under frequent clipping as shown by seed production during the first season. However, Echinochloa and Setaria do not have the same ability to grow and reproduce under situations of extreme plant density (2,000/m^2), and low nutrient availability as shown by comparative

Table 19. 1974 alfalfa stand density (plants/929 cm^2) Alfalfa density with Echinochloa crusgalli or Setaria lutescens or both.

By Weed Treatment

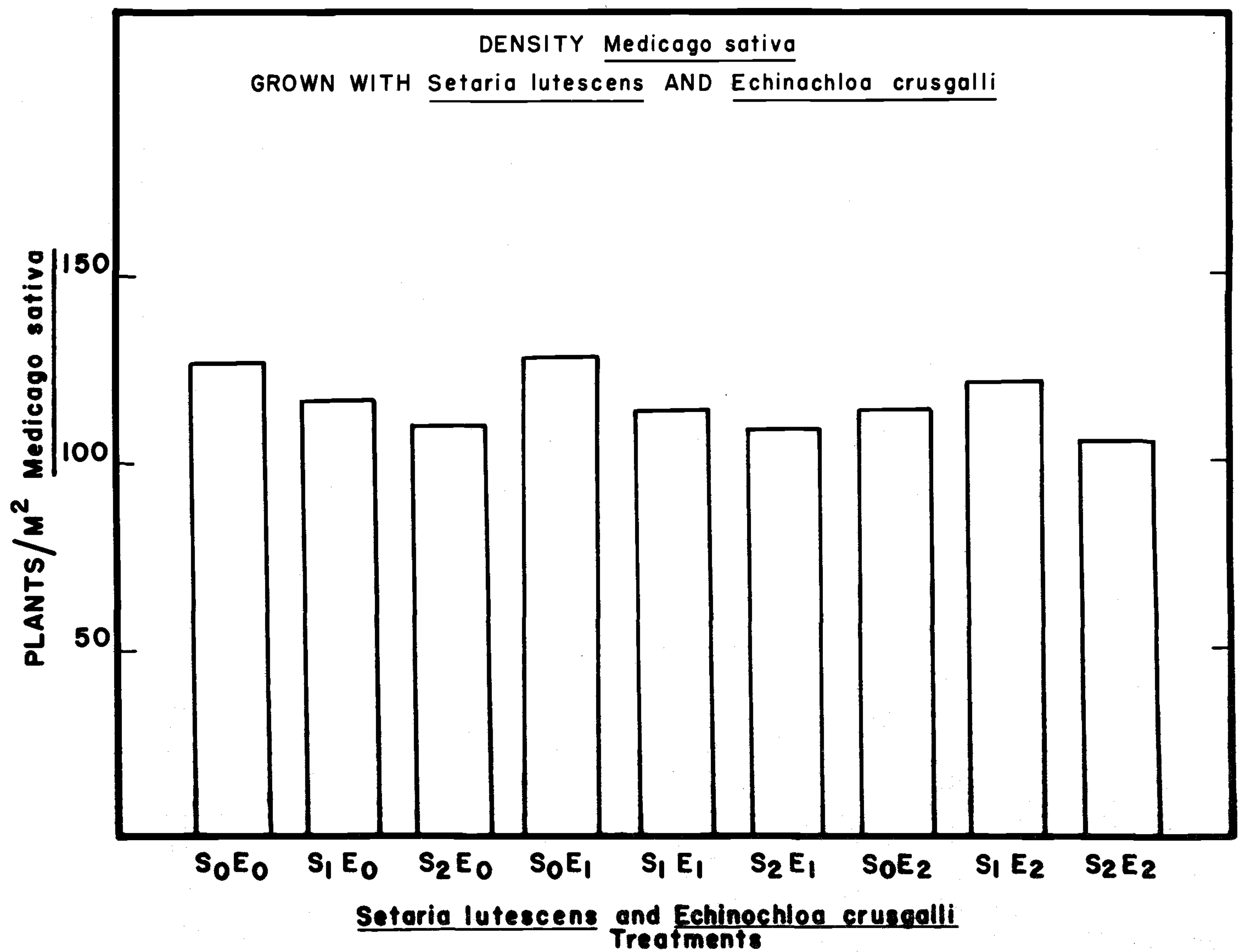
Setaria[1] Density	Echinochloa Density E0	E1	E2
S0	11.8	11.9	10.6
S1	10.9	10.6	11.3
S2	10.2	10.1	9.7

By Echinochloa Density and By Setaria Density

Echinochloa Density	Alfalfa Density	Setaria Density	Alfalfa Density
E0	11.0	S0	11.4
E1	10.9	S1	10.9
E2	10.5	S2	10.0
LSD.05	.93		

[1] S = Setaria lutescens
E = Echinochloa crusgalli
0, 1, 2 refers to seeding rate of 0, 10, 150 seeds/929 cm^2

Figure 3. Alfalfa (Medicago sativa) plant density according to weed treatment at the conclusion of the Davis Competition Study. S represents Setaria lutescens, E represents Echinochloa crusgalli, 0, 1, 2 represent Echinochloa and Setaria seeding rates of 0, 10 and 150 seeds/929 cm^2.


DENSITY Medicago sativa
GROWN WITH Setaria lutescens AND Echinochloa crusgalli
PLANTS/M2 Medicago sativa
150
100
50
S0E0
S1E0
S2E0
S0E1
S1E1
S2E1
S0E2
S1E2
S2E2
Setaria lutescens and Echinochloa crusgalli
Treatments

seed yields in the second season. Setaria was able to reproduce at a high rate while Echinochloa was not able to produce mature seed under the very difficult conditions in the second season of the experiment.

Alfalfa has a growth depressing effect on both weed species. Echinochloa and Setaria are capable of growth and reproduction in seedling alfalfa as indicated by first-year seed yields. A dense stand of mature alfalfa dominated but did not eliminate the weedy grass species during the second season. Setaria demonstrated greater ability to establish seedlings in mature alfalfa than Echinochloa and Setaria produced a relatively high seed yield in mature alfalfa. Echinochloa was not able to reproduce as evidenced by the lack of seed yield in the second season with mature alfalfa.

Alfalfa yields were decreased slightly due to weed competition in the first year, but second-year alfalfa was not affected by Echinochloa or Setaria. Alfalfa stand was reduced by 11 percent in high density Setaria treatments at the end of the first year; the stand reduction increased slightly, to 12%, in the second year. Alfalfa stand had a normal mortality over the period 1972 to 1974. The initial stand of 35 plants/929 cm^2 was reduced to 25/929 cm^2 by the beginning of 1973 and to 12 plants/929 cm^2 by the spring of 1974. The original stand was of a higher density than is normal for first-year alfalfa in the field. Growers consider 25 plants/929 cm^2 an excellent first-year stand and 12 plants/929 cm^2 an adequate third-year plant density.

Windrow Studies

Close observation of grower fields in late 1972 indicated that cultural practices must be giving grassy weeds advantage over alfalfa in commercial fields. Rows of *Setaria* seed heads appeared to be running parallel to irrigation borders. This row pattern was not evident in experimental plots. Inspection of several fields indicated the row pattern of seed heads may be correlated with the method of harvest. It was determined to establish a field survey the following season to learn which cultural practices might be assisting in field establishment of *Setaria*.

Purpose of the Studies

Field studies entailed surveys of plant populations within irrigation strip checks of established alfalfa fields. Alfalfa stands with a history of sparse populations of *Setaria lutescens* and *Echinochloa crusgalli* were chosen for the investigation.

The purpose was to determine location of initial invasions of alfalfa stands by *Echinochloa* and *Setaria* and the relationship of these invasions to cultural operations used in production of alfalfa forage.

The ultimate objective was to discover which cultural operations might provide favorable environments for establishment of summer grasses and to determine the nature of these favorable environments.

Methods

Two alfalfa fields located in Yolo County were chosen for the study. Both fields were operated by a grower using the normal forage production equipment and methods for the Yolo County area. The fields had previous histories of relatively low *Echinochloa* and *Setaria* populations. Field I was a second-year stand of commercial, non-dormant alfalfa. Field II, also a second-year stand, but of a semi-dormant Lahontan variety. Five irrigation strip checks (16 meters wide) were chosen at random from each field. At the time of first harvest permanent marker cans were driven into the soil beneath each windrow. Each strip contained four windrows, times five checks gave a total of twenty windrows for each field. At each succeeding harvest the fields were inspected for weed seedlings and the location of windrows mapped in relation to the permanent marker cans. When summer grasses (*Echinochloa* and *Setaria*) became well established, continuous transect plant counts were taken across each check.

Transects of Alfalfa Strip Checks

A histogram of *Echinochloa* and *Setaria* populations in field number II is depicted in Figure 4. Mixed populations of Echinochloa and Setaria existed within the strip checks. Overall density of the two species was relatively low in this field, ranging from 0 to 52 plants/m^2. The peak of Setaria populations corresponded with placement of early season windrows as shown by the histogram. Echinochloa plant density also corresponds closely to windrow placement. In this field transects showed that peak Echinochloa and Setaria populations did not occur at precisely the same location on the transect.

The locations of a mixed population of alfalfa, Echinochloa and Setaria in relation to windrow placement are illustrated in Figure 5. Echinochloa and Setaria populations range from 1 to 140 plants per m^2. Setaria has the higher density with peaks of 140 plants/m^2 compared to Echinochloa peaking at 80 plants/m^2. Alfalfa density is relatively uniform across the strip check with the exception of slight decreases beneath outer windrow placements. In the field the density of Echinochloa and Setaria populations correspond closely with placement of forage windrows by the swathing machine.

Summary of Windrow Studies

The results of plant density counts across irrigation strip checks of these two alfalfa fields indicate that high Echinochloa and Setaria plant densities corresponded closely to the placement of alfalfa hay windrows. Careful observation of the alfalfa strip checks

Figure 4. A transect of *Echinochloa crusgalli* and *Setaria lutescens* plant densities is illustrated in this figure. Plant counts are shown as continuous (.25 m^2 quadrat) transects across the 16 meter alfalfa strip check. The placement of four alfalfa forage windrows is indicated beneath each histogram.

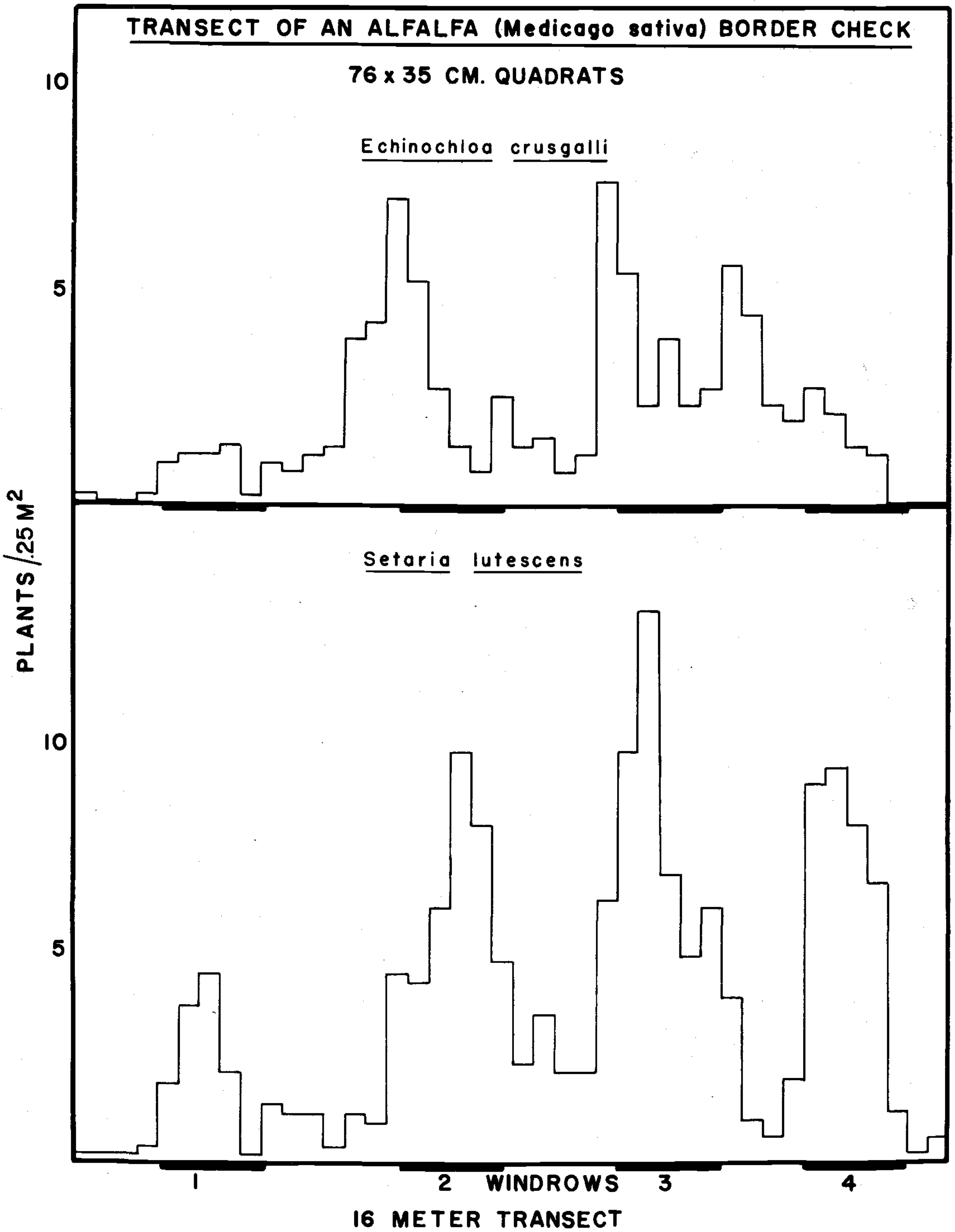
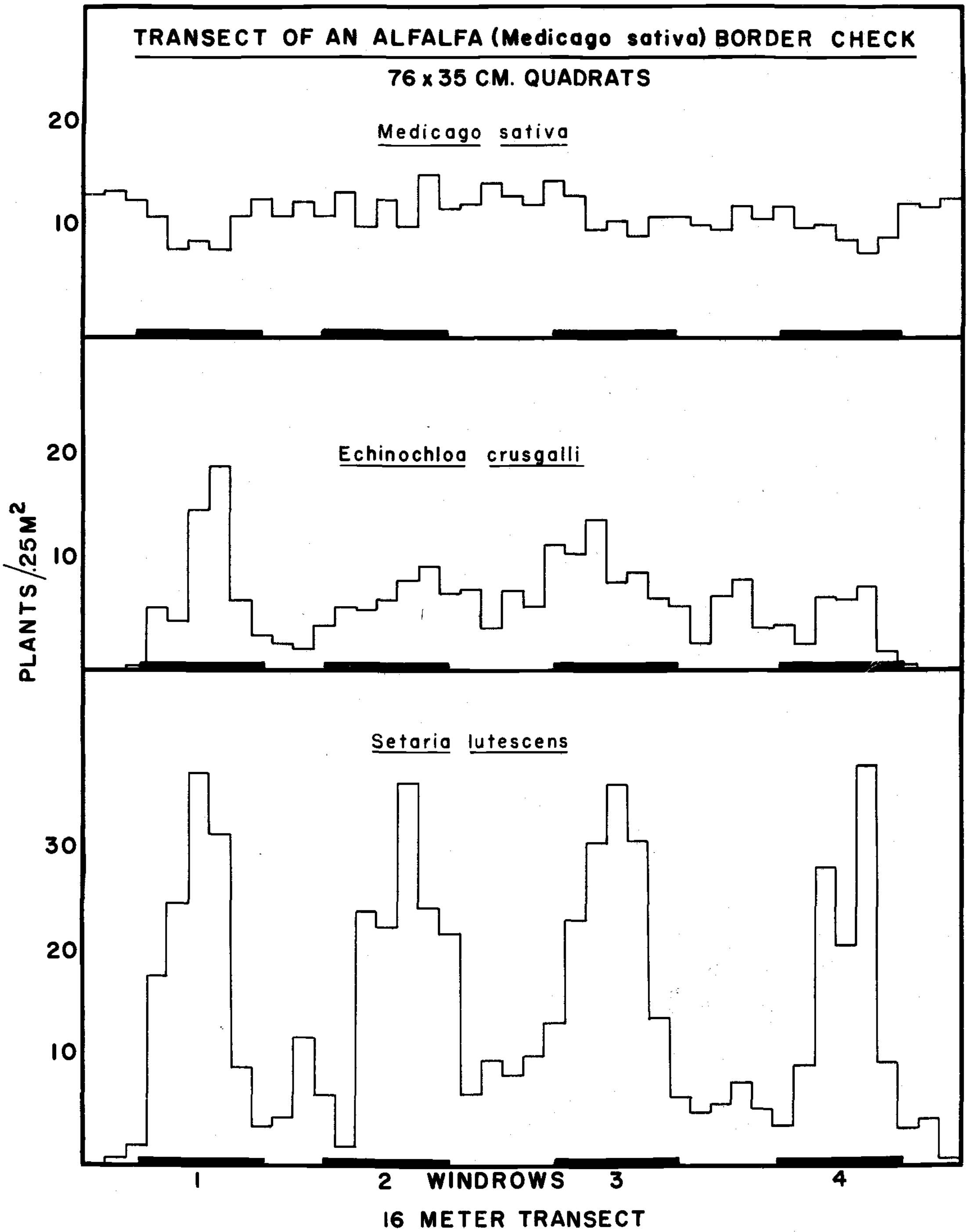

TRANSECT OF AN ALFALFA (Medicago sativa) BORDER CHECK
76 x 35 CM. QUADRATS
Echinochloa crusgalli
Setaria lutescens
PLANTS /.25 M²
10
5
10
5
1
2
WINDROWS
3
4
16 METER TRANSECT

Figure 5. A transect of Echinochloa crusgalli, Setaria lutescens and Medicago sativa plant densities is illustrated in this figure. Plant counts are shown as continuous (.25 m^2 quadrat) transects across the 16 meter alfalfa strip check. The placement of four alfalfa forage windrows is indicated beneath each histogram.


TRANSECT OF AN ALFALFA (Medicago sativa) BORDER CHECK
76 x 35 CM. QUADRATS
Medicago sativa
Echinochloa crusgalli
Setaria lutescens
PLANTS/.25 M2
20
10
30
1
2
3
4
WINDROWS
16 METER TRANSECT

throughout the summer indicated several explanations for this occurrence.

Prior to first harvest, foliage feeding insects were present in alfalfa. The swathing machine, cutting a 3.6 meter swath and concentrating the vegetative matter into a .9 meter windrow, also concentrated insects. Insect larvae remained beneath the windrow for several days feeding on alfalfa regrowth. In addition, the damp, cool microenvironment beneath the green alfalfa windrow was ideal for increasing incidence of alfalfa foliage infecting fungi. As a consequence of alfalfa regrowth destruction, grass seedlings had very little competition from alfalfa when the windrow was removed by baling. After hay was baled the fields were flood irrigated. Additional grass seedlings emerged in defoliated strips left by insects and plant pathogens. Daytime temperatures had risen above 32°C (90°F) by the second harvest. When the 61 cm tall alfalfa was mowed, the soil surface not covered by windrows, baked and cracked in the hot sun. Grass seedlings desiccated and died. Under the windrow, conditions were cool, moist and generally favorable for survival of seedlings. And when the windrow was removed a thin layer of shattered alfalfa leaves and debris remained as insulation from the hot sun. During the five to eight days windrows were in place the remaining alfalfa regrowth became etiolated and weakened from the intense shade of the windrow.

A combination of the above factors, some favorable to grasses, others damaging to alfalfa provided a tremendous advantage for *Setaria* and *Echinochloa* enabling them to become rapidly established in the field.

Overall Summary and Discussion

The initial purpose of the competition studies was to collect information on morphological, physiological and cultural factors that might lead to success of *Setaria lutescens* and/or *Echinochloa crus-galli* as invaders of California alfalfa. The investigations have, perhaps, answered some questions but have opened a great many others.

It was evident from experimental results that both *Echinochloa* and *Setaria* had great plasticity as far as growth and reproductive capacity of the individual was concerned. Evidence gathered from competition between *Echinochloa* and *Setaria* indicate that *Setaria* would dominate under conditions of this experiment. The question of why *Echinochloa* failed to reproduce in a high density mixed stand with *Setaria* was not answered. It is speculated that a combination of density, lack of nutrients and frequent clipping were more disadvantageous to *Echinochloa* than to *Setaria*. *Setaria*'s chief advantage would seem to be ability to reproduce under extreme adversity. The work of Gregg (1971) with *Setaria lutescens* in sand culture confirms its ability to survive at extreme densities. He worked with plant counts of from $100/m^2$ to $10,000/m^2$. Gregg found that at the lower density, Setaria plants produced 24 grams of dry weight and 100 percent of the plants flowered. At a density of $10,000/m^2$ there was 84 percent mortality and the remaining plants were reduced to a dry weight of .62 grams per plant, but 65 percent of the living plants (1,040) were flowering at time of harvest. Gregg also measured seed production from relatively sparse Setaria lutescens stands and recovered 35,000 $seeds/m^2$.

Clipping has been found to affect growth and reproduction of both Echinochloa and Setaria. Santelmann et al. (1963) showed the ability of Setaria lutescens to produce seed heads only three weeks after clipping of plants in full bloom. Kacperska-Palacz et al. (1963) noted that Echinochloa responded to clipping shoot tips by increased tillering, and Roche and Muzik (1964) demonstrated that some biotypes of Echinochloa would produce seed heads even when clipped to a height of one inch. These studies plus the present experiments seem to indicate that clipping alone was not the main reason for Echinochloa's inability to produce seed. Rather there is a combination of factors responsible.

Alfalfa was an excellent competitor and did limit grass seedling establishment and vegetative growth. Once Echinochloa and Setaria seedlings were established they did grow and reproduce in a first-year alfalfa stand. The weedy grasses exerted a depressing effect on alfalfa vegetative yield during the first year, and Setaria was shown to reduce alfalfa stand when present at high densities. Alfalfa in turn decreased Setaria vegetative and seed yield when compared to the control (without alfalfa). Echinochloa yield was greatly reduced by competition from alfalfa and Setaria, and seedling establishment in second-year alfalfa was a serious problem for Echinochloa. It has been shown that Setaria and Echinochloa seed will germinate and emerge under a wide range of environmental conditions. Stoller and Wax (1973) investigated seasonal emergence of field weeds and found that Setaria lutescens would germinate and establish rapidly during a several month spring and summer period, whenever moisture and temperature conditions were favorable. Vengris et al. (1966) showed Echinochloa crusgalli had similar capabilities. The ability to germinate and establish rapidly is very important, especially in California alfalfa fields where the right combination of temperature, moisture and light may be available for only short periods following harvest. It is speculated that ground cover or shade by alfalfa vegetation may affect germination and seedling growth of Echinochloa and Setaria.

Seeds of Echinochloa and Setaria have been studied, relative to light requirements for germination, by several workers. Goncharov and Khomko (1972) investigated germination of twenty-two weed species in the absence of light and found Setaria lutescens was one of four germinating in the dark. Taylorson (1970) found that soil storage increased the sensitivity of Echinochloa crusgalli to light but that Setaria lutescens seed did not appear to require light for germination. In a related study on light filtration by foliar canopies, Taylorson and Borthwick (1969) found that plant leaves intercepted much red light and indicated this type of light filtration may affect germination of light sensitive seeds. The idea of potential germination differences between Setaria and Echinochloa due to foliar shading of the soil surface is an interesting speculation that would be worth further investigation.

Shade may also play a part in reduction of yields and reproduction of the two grass species after they are established plants. Santelmann et al. (1963) demonstrated that 60 percent and 90 percent shade consistently reduced dry weight, and tillering in Setaria lutescens by two-thirds or more. Dickerson et al. (1966) noted that 70 to 75 percent shade consistently reduced weight, tiller and panicle production of Echinochloa crusgalli. Results of field studies support speculation that shade had influence on weed species. A portion of the windrow effect favorable to grasses is destruction of alfalfa regrowth leaving the soil surface open to light penetration. Other effects of windrowing have been mentioned in transect studies. It is apparent that this cultural practice, which has been instituted within the past 20 years, aids the two grass species in germination, establishment, growth and reproduction. For while Setaria and Echinochloa have been shown capable of invading alfalfa, both weeds need help from man to overcome dense stands of the perennial plant.

In addition to the windrow effect, there are other cultural practices helpful to weeds in alfalfa. Improper leveling of fields or over irrigation often destroys alfalfa stands in localized areas of the field. Echinochloa is considered an invader of poor drainage locations in the field. Wiese and Vandiver (1970) investigated the competitive ability of ten plant species under wet, medium and dry soil conditions. They found Echinochloa crusgalli to grow well and be a good competitor under wet soil conditions and do poorly under dry soil conditions. Dickerson et al. (1966) noted that Echinochloa growth was significantly reduced when soil was maintained at saturation, but there was no difference in growth of the plant between 35 percent and 65 percent available moisture. Vengris (1966) subjected Echinochloa crusgalli to wet and dry treatments and found the plants grew and developed best under wet conditions. Dry soil conditions in particular depressed Echinochloa height, yield and panicles per tiller. These investigations support the field observation that Echinochloa crusgalli is more adapted to wet areas. In our competition tests, soil moisture was always adequate but would not be considered wet. The lack of wet areas may have been a disadvantage to Echinochloa and an added advantage to Setaria in their struggle for dominance.

Conclusions

Setaria lutescens emerged as the dominant species when Echinochloa and Setaria were grown together under conditions of this investigation. The factors involved in Setaria's success were, ability to grow and reproduce under high density plant populations, insufficient plant nutrients and frequent clipping.

Setaria and Echinochloa will grow and reproduce in competition with seedling alfalfa. Weed growth and reproduction is reduced by alfalfa competition as compared to weed growth without alfalfa.

Setaria is capable of growth and reproduction in established alfalfa stands. Setaria produced in excess of 10,000 seeds/m^2 in second-year alfalfa. Echinochloa density and growth were severely limited by dense, second-year alfalfa. Echinochloa established 85 percent fewer seedlings than Setaria and failed to reproduce by seed in second-year alfalfa under conditions of this experiment.

It is speculated that competition for light between established alfalfa and grass seedlings is partially responsible for decreases in weed growth and failure of Echinochloa to reproduce.

Vigorously growing, dense stands of alfalfa overcame first-year invasions by Setaria and Echinochloa and demonstrated no decrease in second-year forage yields. Alfalfa stand was decreased 12 percent by high density populations of Setaria lutescens over a two-year period. The cause of alfalfa stand decline is not known.

It is concluded that Echinochloa will not become dominant to alfalfa when alfalfa is maintained at high population density and in a vigorously growing condition.

Setaria will grow and reproduce in a dense, vigorously growing alfalfa stand but cultural factors favorable to Setaria and damaging to alfalfa may be responsible for the rapid success of Setaria in the field.

Field studies by transect showed that Setaria and Echinochloa densities were greatest in areas covered by windrows during the forage curing interval. Factors favoring weedy grasses in the windrow area were, seedling and soil protection that prevented drying and desiccation and concentration of mature weed seed in the windrow area. Windrow factors damaging to alfalfa were, concentration of foliage feeding insects, creation of favorable environments for foliar pathogens of alfalfa, and etiolation of alfalfa regrowth.

The factors believed to contribute to success of Setaria as an invader of alfalfa are its ability to grow and reproduce in dense alfalfa stands and to take advantage of the detrimental effect of forage windrows on alfalfa regrowth following harvest.

SETARIA LUTESCENS BIOTYPE COMPETITION

Purpose of the Studies

Previous investigations (biotype comparisons and interspecies competition) have shown differences exist between biotypes from Connecticut, Iowa, Massachusetts, Pennsylvania and California and that the California biotype is adapted to alfalfa culture. The question arises as to how biotypes from other regions will perform under frequent clipping in competition with alfalfa in California? The following experiments were developed to answer this question.

Setaria lutescens biotypes (Connecticut, Pennsylvania, California) were chosen for a comparative study of their ability to grow and reproduce in an environment simulating that of alfalfa cultivated for forage in California.

Three experiments were used in these comparisons. The first two tests were conducted concurrently.

I. Each biotype planted individually at two plant densities.

II. Each biotype planted individually at two plant densities with alfalfa (*Medicago sativa*).

Experiments I and II were subjected to frequent clipping on an alfalfa hay schedule throughout the growing season.

In a third test (Experiment III), the three biotypes plus *Echinochloa crusgalli* were planted in greenhouse pots. The potted plants were then buried in an alfalfa stand and subjected to an alfalfa harvest schedule.

The purpose of these experiments was to determine if biotypes of Setaria lutescens from other areas react similarly to the California biotype when grown under a simulated California alfalfa cultural environment.

The objective was to reject or verify a hypothesis that the California biotype of Setaria lutescens is adapted to alfalfa culture as practiced in the irrigated valleys of California.

Biotype Competition Studies I and II

Methods

A site (5m x 7m) with no previous history of Setaria lutescens was selected for the study. The soil type was Yolo silt loam, irrigation by flooding. A randomized complete block design with factorial arrangement of treatments was chosen to meet objectives of the test. Experiments I and II were situated side by side with similar dimensions. Individual plot size was $.67m^2$ (.67m x 1.0m).

Treatments

Experiment I (Without Alfalfa)			Experiment II (With Alfalfa)		
Treat. No.	Biotype	Plant Density Per m^2	Treat. No.	Biotype	Plant Density Per m^2
1.	California	9	1.	California	9
2.	California	45	2.	California	45
3.	Connecticut	9	3.	Connecticut	9
4.	Connecticut	45	4.	Connecticut	45
5.	Pennsylvania	9	5.	Pennsylvania	9
6.	Pennsylvania	45	6.	Pennsylvania	45

Alfalfa (var. Lahontan) and Setaria biotypes were planted in alternate rows spaced five centimeters apart. The seeding rate for Setaria was 150 and 1500 seeds/m^2 and for alfalfa 16.8 Kg/Ha (15 lb/acre). Planting was completed on October 29, 1972, and rainfall occurred on October 30. Alfalfa seedlings emerged in late November. Setaria seedlings emerged from mid to late March, 1973. Setaria lutescens biotypes were thinned to stand of 9 plants/m^2 and 45 plants/m^2. Beginning alfalfa density was 270 plants/m^2.

The experiments were irrigated and harvested on an alfalfa hay schedule throughout the season. Clipping was accomplished with an electric hedgetrimmer set to cut at a 7.6 cm height. Harvested green material was hand separated, dried and weighed. Head counts were made from each sample. Subsamples of 100 heads from each

Table 20. Dry matter yield Setaria lutescens biotypes with and without alfalfa.

Density	Biotype Calif.	Conn..	Penna.	Density Mean
EXPERIMENT I - Total dry matter yield Setaria lutescens biotypes - Without alfalfa (gm/m^2)				
$9/m^2$	790	176	437	468
$45/m^2$	1527	537	753	939
Variety mean	1158	357	595	
LSD.05 Variety = 197			LSD.05 Density = 161	
EXPERIMENT II - Total dry matter yield Setaria lutescens biotypes - With alfalfa (gm/m^2)				
$9/m^2$	200	36	68	101
$45/m^2$	801	59	261	374
Variety mean	501	48	165	
LSD.05 Variety = 78			LSD.05 Density = 64	

biotype were weighed to estimate seed yield. Stand counts of alfalfa were made at the beginning and end of the experiment.

Experiment I was harvested five times starting on June 9.

Experiment II was harvested seven times starting on April 19.

Dry Matter Yields, Biotypes

When the three biotypes were grown without alfalfa but clipped regularly, California produced three times more vegetative yield than Connecticut and twice that of Pennsylvania. The high density ($45/m^2$) plantings yielded twice as much dry matter as the low density treatments ($9/m^2$) but had five times as many plants (Table 20).

Grown with alfalfa the California biotype produced ten times more vegetative yield than Connecticut and three times that of Pennsylvania. The high density treatment yielded three and a half times more dry matter than the low density treatments with five times as many plants (Table 20).

When yield totals of the two experiments are compared, all three biotypes suffered reduction in dry matter production. California *Setaria lutescens* was reduced by 57% in yield, Connecticut by 87% and Pennsylvania by 72%, when grown with alfalfa as compared to growing alone.

Dry matter yield of *Setaria lutescens* biotypes without alfalfa is illustrated in Figure 6a. Data presented is from the $45/m^2$ density treatment, by cutting, for the season. Connecticut and Pennsylvania show early season growth and maturity as compared to California. They not only yielded greater amounts of dry matter in cuttings three and four, but they also reached near maximum production by cutting five. California dry matter production continued through the seventh cutting.

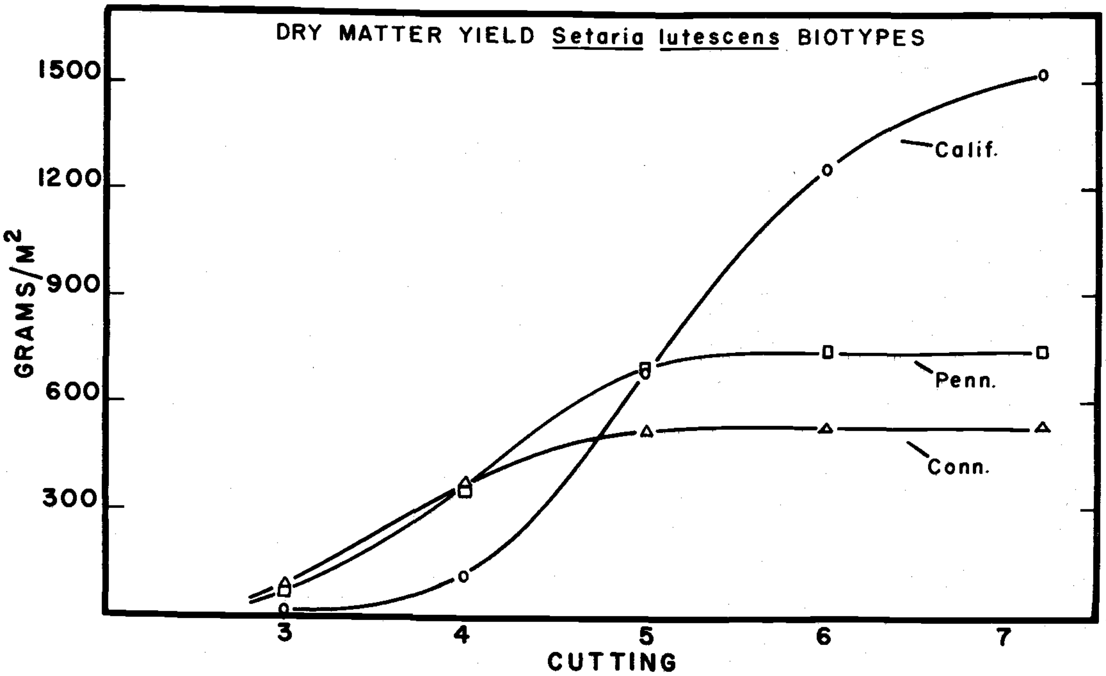
Pennsylvania and Connecticut reach near maximum yield by the fourth harvest and make little growth thereafter. California reaches its near maximum at sixth harvest (Figure 6b with alfalfa).

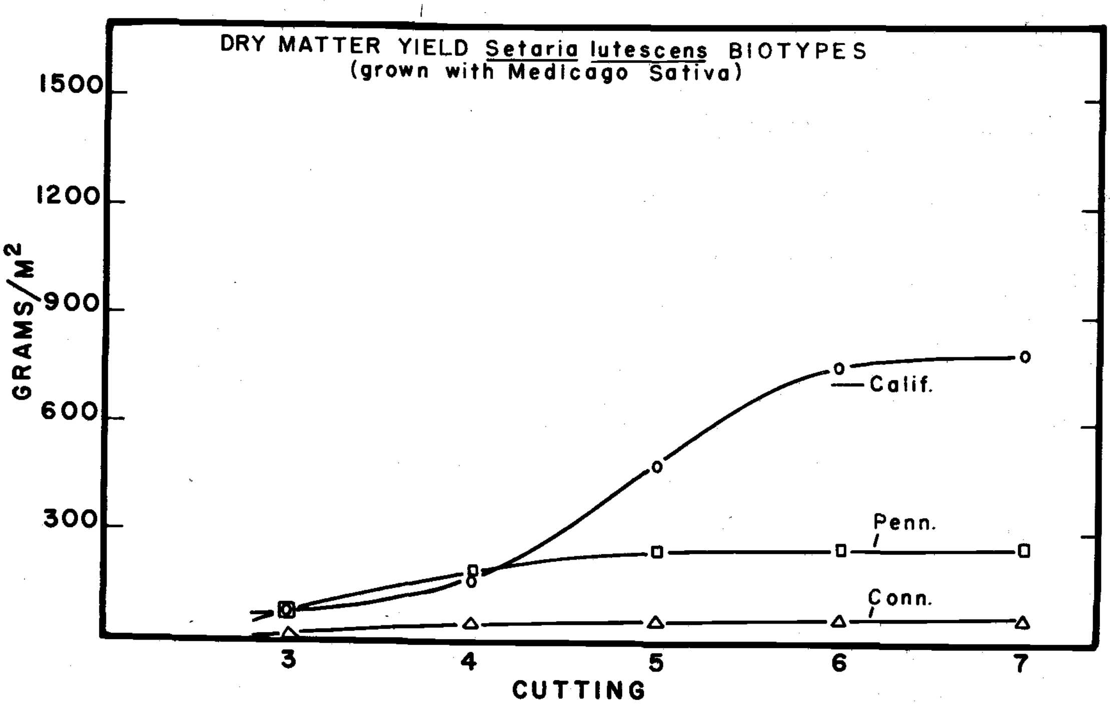
When Experiments I and II are compared, it can be seen that all three biotypes make considerably less vegetative growth when in competition with alfalfa.

An explanation of the higher early yield of the Connecticut and Pennsylvania biotypes is found in their erect growth which places much of the vegetative portion of the plants above the 7.6 cm cutter bar. California's prostrate habit allows most of its early vegetation to remain unharvested and undamaged. It is very likely that the early cessation of vegetative growth by Connecticut and Pennsylvania is partially due to clipping damage. Alfalfa competition had more adverse effect on the two out of state biotypes than on California. A dense stand of alfalfa is a tough competitor for weeds as was seen in the earlier experiment with Echinochloa and Setaria. When weeds are growing alone at low densities, they tend to attain a greater size

Figure 6 a. Cumulative dry matter yields of Setaria lutescens biotypes without alfalfa. Vegetative yield of Connecticut, Pennsylvania and California Setaria lutescens biotypes by cutting, for the 1973 season. Yield data from $45/m^2$ density treatment.

b. Cumulative dry matter yields Setaria lutescens biotypes with alfalfa. Vegetative yield of Connecticut, Pennsylvania and California Setaria lutescens biotypes by cutting, for the 1973 season. Yield data from $45/m^2$ density treatment.


DRY MATTER YIELD Setaria lutescens BIOTYPES
1500
1200
900
600
300
GRAMS/M2
Calif.
Penn.
Conn.
3
4
5
6
7
CUTTING


DRY MATTER YIELD Setaria lutescens BIOTYPES
(grown with Medicago Sativa)
1500
1200
900
600
300
GRAMS/M2
Calif.
Penn.
Conn.
3
4
5
6
7
CUTTING

by filling up the free space. In alfalfa at high density there is no free space.

Dry Matter Yields, Alfalfa

The upper half of Table 21 contains yield data from cuttings 1 and 2. This is baseline information in that weeds had no effect on alfalfa prior to these two harvests. The significant yield difference due to density must be attributed to chance since treatments (weeds) were not exerting an effect at this early date. There are no yield differences due to biotype at the first two harvests.

The lower half of Table 21 shows dry matter yields of alfalfa for the balance of the season (cuttings 3 through 7). The California biotype depressed yield by 37% when compared to Connecticut and Pennsylvania. The greatest portion of the yield decrease is due to the $45/m^2$ California biotype treatment. This treatment reduced alfalfa yield by 42% compared to the mean of all other treatments. The yield difference between the $45/m^2$ California biotype treatment versus all others is significant at the one percent level of probability.

Alfalfa yields for the first two cuttings were similar for all biotypes (Figure 7). The overall yield depression shown at cutting three was due to a shortened harvest interval. The California biotype began to depress alfalfa yields at the third cutting and continued this pattern throughout the season. When forage yield from all seven

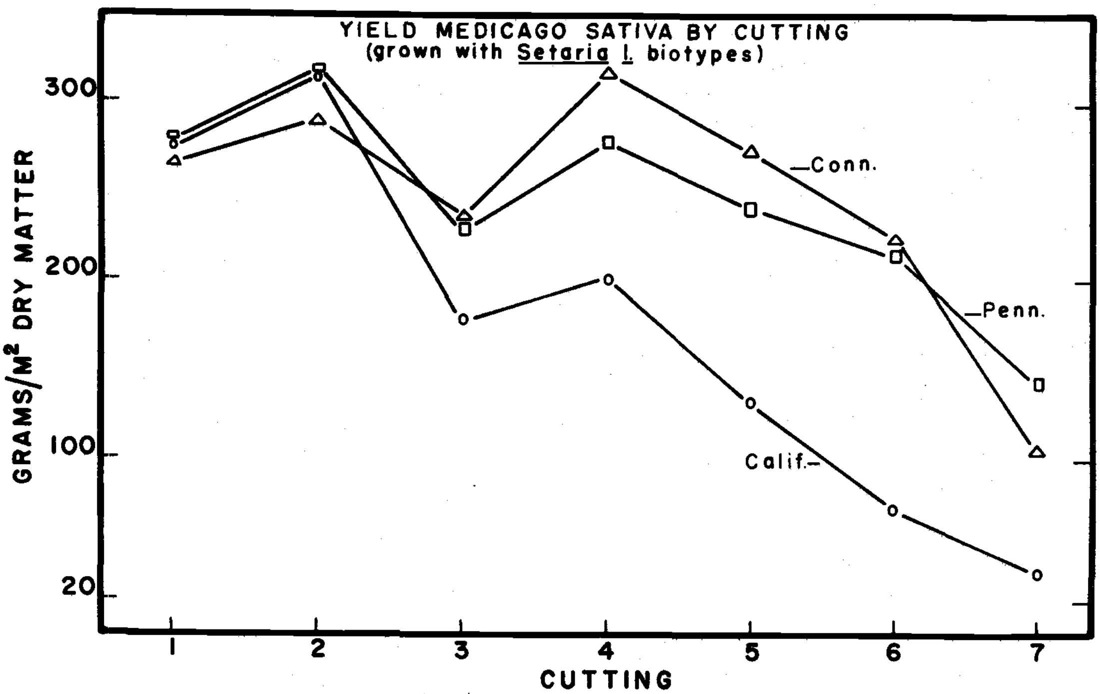
Table 21. Dry matter yields of alfalfa (g/m^2) Alfalfa grown with *Setaria lutescens* biotypes at two densities.

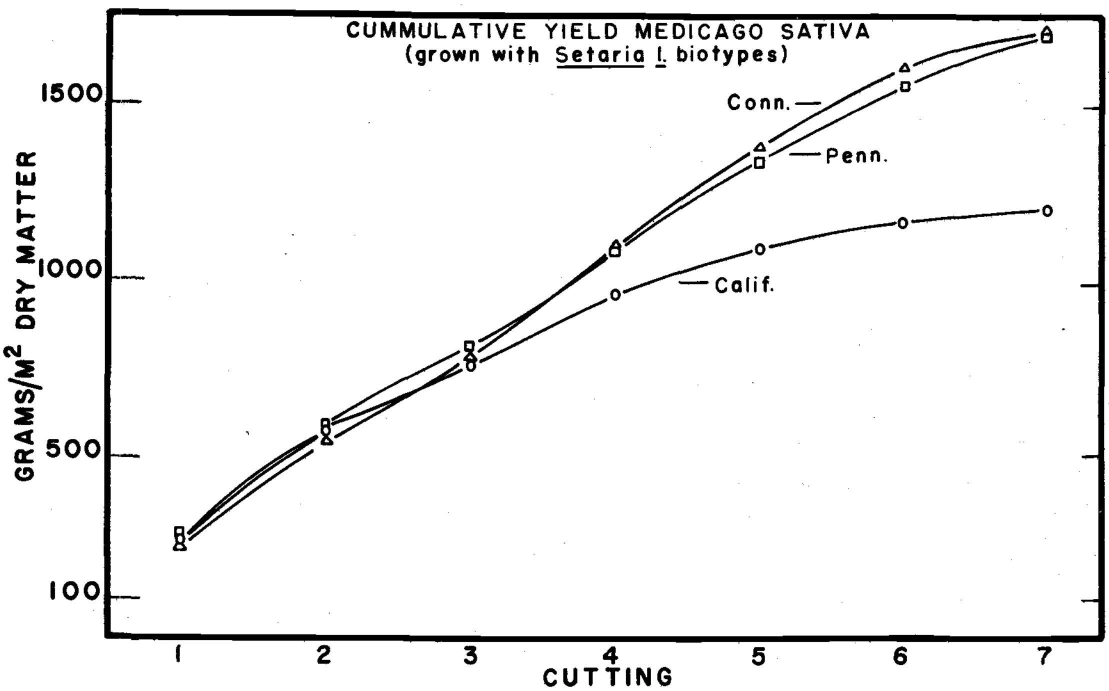
Setaria Density	Biotype Calif.	Conn.	Penna.	Density Mean
Alfalfa yield cuttings 1 and 2				
9/m^2	534	461	467	487
45/m^2	590	555	595	580
Variety mean	562	508	531	
LSD.05 Variety = NS			LSD.05 Density = 92.5	
Alfalfa yield cuttings 3 - 7				
9/m^2	995	1052	1015	1020
45/m^2	618	1154	1102	958
Variety mean	806	1103	1059	
LSD.05 Variety = 176			LSD.05 Density = NS	

Calif. 45/m^2 vs all others - LSD.05 = 248, LSD.01 = 354

Figure 7 a. Yield of Medicago sativa (alfalfa) by cutting during the 1973 season. Vegetative yield of alfalfa grown with Setaria lutescens biotypes from Connecticut, Pennsylvania and California. Yield data from $45/m^2$ density treatment.

b. Cumulative yield of Medicago sativa (alfalfa) by cutting during the 1973 season. Vegetative yield of alfalfa grown with Setaria lutescens biotypes from Connecticut, Pennsylvania and California. Yield data from $45/m^2$ density treatment.


YIELD MEDICAGO SATIVA BY CUTTING
(grown with Setaria l. biotypes)
GRAMS/M² DRY MATTER
300
200
100
20
Conn.
Penn.
Calif.
1
2
3
4
5
6
7
CUTTING


CUMMULATIVE YIELD MEDICAGO SATIVA
(grown with Setaria l. biotypes)
GRAMS/M² DRY MATTER
1500
1000
500
100
Conn.
Penn.
Calif.
1
2
3
4
5
6
7
CUTTING

cuttings is considered, the $45/m^2$ density California biotype depressed alfalfa yields 35%.

Cuttings one and two were kept separate in the tables because weeds had no effect on these yields. Cuttings 1 and 2 show that the alfalfa in the $45/m^2$ California biotype plots was yielding normally at the end of two cuttings. California biotypes became well established by the third harvest and when alfalfa was cut to 7.6 cm, the Setaria plants overtopped alfalfa regrowth and retarded its development. Because of its prostrate habit, the California biotype is not seriously damaged by clipping. The Connecticut and Pennsylvania biotypes maintained their erect habit and did not affect alfalfa growth or yield.

Seed Head Yields, Biotypes

Connecticut and Pennsylvania biotypes yielded similar numbers of seed heads under frequent clipping and in the absence of alfalfa (Table 21). California yielded 63% more heads than the mean yield of Connecticut and Pennsylvania. Higher plant densities increased seed head numbers but not in direct proportion to the increased numbers of plants.

In the presence of alfalfa all biotypes produced fewer seed heads/m^2 (Table 22). Connecticut yielded 86% less, Pennsylvania 79% less and California 59% fewer heads with alfalfa as compared to the same biotypes without alfalfa. Plant density played a larger part

Table 22. Seed head yields (heads/m^2) Setaria lutescens biotypes at two densities with or without alfalfa.

Density	Biotype			Density Mean
	Calif.	Conn.	Penna.	
EXPERIMENT I - Total seed head yield, Setaria lutescens biotypes - Without alfalfa				
9/m^2	2944	811	1038	1597
45/m^2	6713	2777	2367	3952
Variety mean	4828	1794	1702	
LSD.05 Variety = 672			LSD.05 Density = 548	
EXPERIMENT II - Total seed head yield, Setaria lutescens biotypes - With alfalfa				
9/m^2	1090	143	157	462
45/m^2	4640	366	555	1854
Variety mean	2865	254	356	
LSD.05 Variety = 292			LSD.05 Density = 238	

in number of seed heads produced by the biotypes when in competition with alfalfa.

It is evident from data in these tables that the California biotype yields greater numbers of seed heads under frequent clipping than either Pennsylvania or Connecticut biotypes. This is true either with or without alfalfa. California yielded 27% greater numbers of heads than Pennsylvania and Connecticut combined in absence of alfalfa and 78% more heads than the combination of Pennsylvania and Connecticut in the presence of alfalfa. Again, the California biotype's prostrate growth habit ensures less damage to the plant from clipping while the erect Pennsylvania and Connecticut are seriously damaged by clipping and recover slowly after harvest.

Seed Yield, Biotypes

Information in Table 23 was developed by multiplying seed head counts times seed weight of 100 head samples.

In the absence of alfalfa, the California biotype yielded 71% more seed than Pennsylvania and 84% more than Connecticut. Connecticut produced 46% less seed than Pennsylvania.

California yielded 93% more seed than Pennsylvania and 98% more than Connecticut when in competition with alfalfa. Comparing the two experiments, the mature seed production was drastically reduced for all biotypes in presence of alfalfa.

Table 23. Seed yields (g/m^2) Setaria lutescens biotypes at two densities with or without alfalfa.

Density	Biotype Calif.	Conn.	Penna.	Density Mean
EXPERIMENT I - Total seed yield, Setaria lutescens biotypes - Without alfalfa				
9/m^2	505	50	134	230
45/m^2	1058	187	313	519
Variety mean	782	119	223	
LSD.05 Variety = 99			LSD.05 Density = 81	
EXPERIMENT II - Total seed yield, Setaria lutescens biotypes - With alfalfa				
9/m^2	85	2	6	31
45/m^2	375	5	24	134
Variety mean	230	4	15	
LSD.05 Variety = 20			LSD.05 Density = 16	

Although total seed yield is decreased for all biotypes when they are growing with alfalfa, the relationship between biotypes remains the same (Figure 8). Seed production of Pennsylvania and Connecticut biotypes peaks at the fifth cutting while California continues to produce well through the seventh cutting. California's relative advantage in seed yield increases considerably over Connecticut and Pennsylvania when all are grown in competition with alfalfa.

After noting the seed production of Connecticut and Pennsylvania under frequent clipping, one might wonder if they actually have potential to produce large amounts of seed when not damaged by harvest. Uniform environment experiments provided an estimate of seed yield in absence of clipping (Table 24).

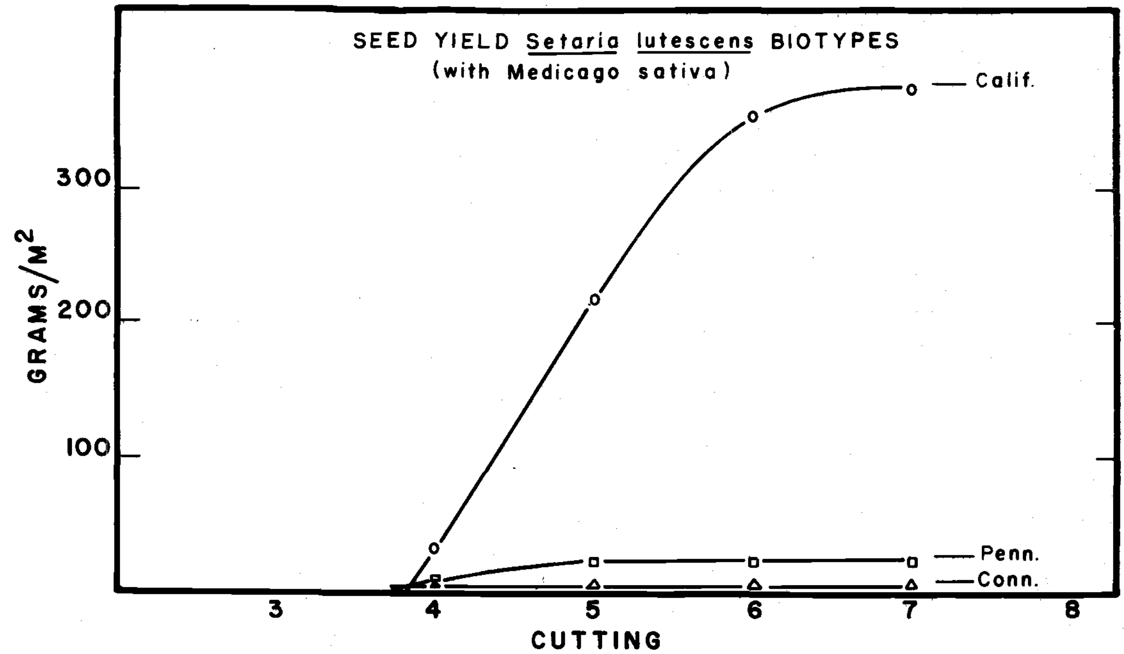
Table 24. Seed production estimates per plant. Unclipped Setaria lutescens biotypes from 1973 uniform environment study (Table 3).

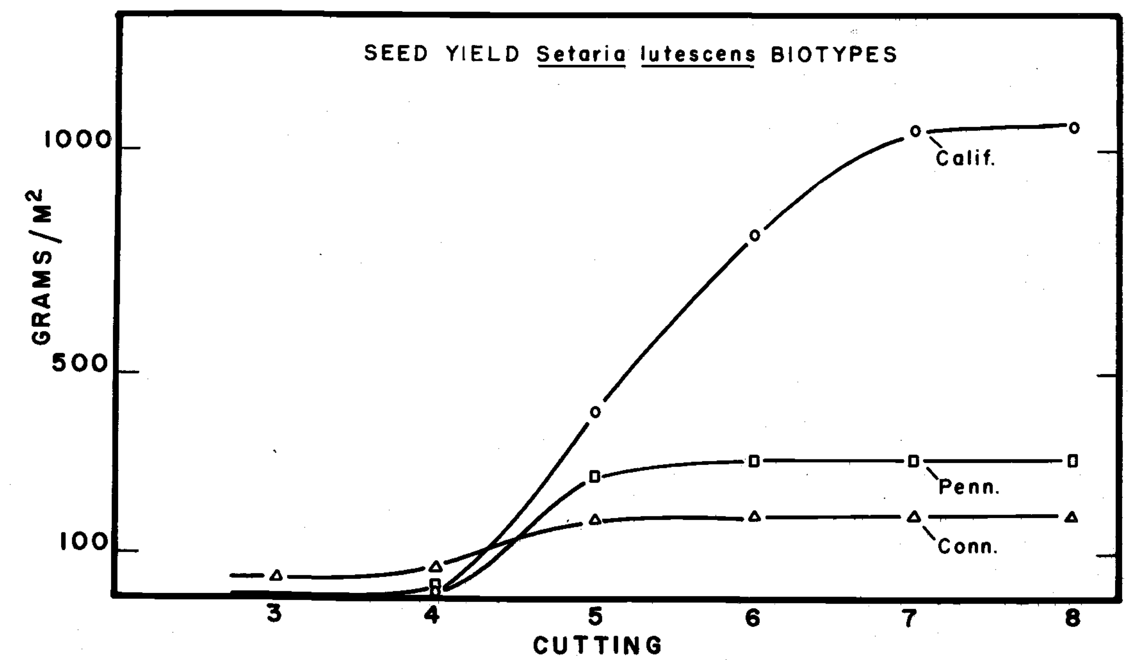
Biotypes	Mean No. Seed Heads	Mean Weight Per Head · gms.	Grams Seed Per Plant
California	276	.176	48.6
Connecticut	70	.272	19.1
Pennsylvania	166	.262	43.9

Yields of seed per plant indicate that Connecticut has a potential of producing only one-third as much as the California biotype

Figure 8 a. Seed yield of Setaria lutescens biotypes. Cumulative yield of Connecticut, Pennsylvania and California biotypes by cutting when grown with Medicago sativa (alfalfa). Yield data from $45/m^2$ density treatment.

b. Seed yield of Setaria lutescens biotypes. Cumulative yield of Connecticut, Pennsylvania and California biotypes by cutting when grown alone. Yield data from $45/m^2$ density treatment.


SEED YIELD Setaria lutescens BIOTYPES
(with Medicago sativa)
Calif.
Penn.
Conn.
GRAMS/M²
300
200
100
3
4
5
6
7
8
CUTTING


SEED YIELD Setaria lutescens BIOTYPES
Calif.
Penn.
Conn.
GRAMS/M²
1000
500
100
3
4
5
6
7
8
CUTTING

when both are unclipped (Table 24). Pennsylvania's estimated seed production is only eleven percent less than California.

Information from the low density ($9/m^2$) biotype treatments of the Woodland biotype competition is expressed in Table 25. This information indicates that on a per plant basis the California biotype produced 3.75 times more seed than Pennsylvania and 10 times more than Connecticut.

Table 25. Seed production per plant. Clipped Setaria lutescens biotypes from Woodland biotype competition study (Table 22 and 23).

Biotype	Mean No. Seed Heads	Grams Seed Per Plant
California	327	56.0
Connecticut	90	5.6
Pennsylvania	115	14.9

It must be remembered that values from the uniform environment are estimates while data from the Woodland Competition test is actual seed yield information. Then *if* information in the two tables can be fairly compared, it would seem to indicate that clipping stimulates slightly more seed head production by Connecticut and California and slightly fewer seed heads from Pennsylvania. It would also appear that clipping is much more damaging to the reproductive capacities of Connecticut and Pennsylvania than to California biotype. Under frequent clipping the seed heads of Pennsylvania and Connecticut are smaller and many are immature at harvest time. Without clipping seed can mature normally.

Stand Density, Alfalfa

The high density ($45/m^2$) California biotype treatment caused a 48% reduction in alfalfa plant density in this experiment (Table 26). No stand reductions were encountered in other treatments. (Fig. 9)

Table 26. Alfalfa stand density (plants/m^2) Alfalfa grown with *Setaria lutescens* biotypes at two densities.

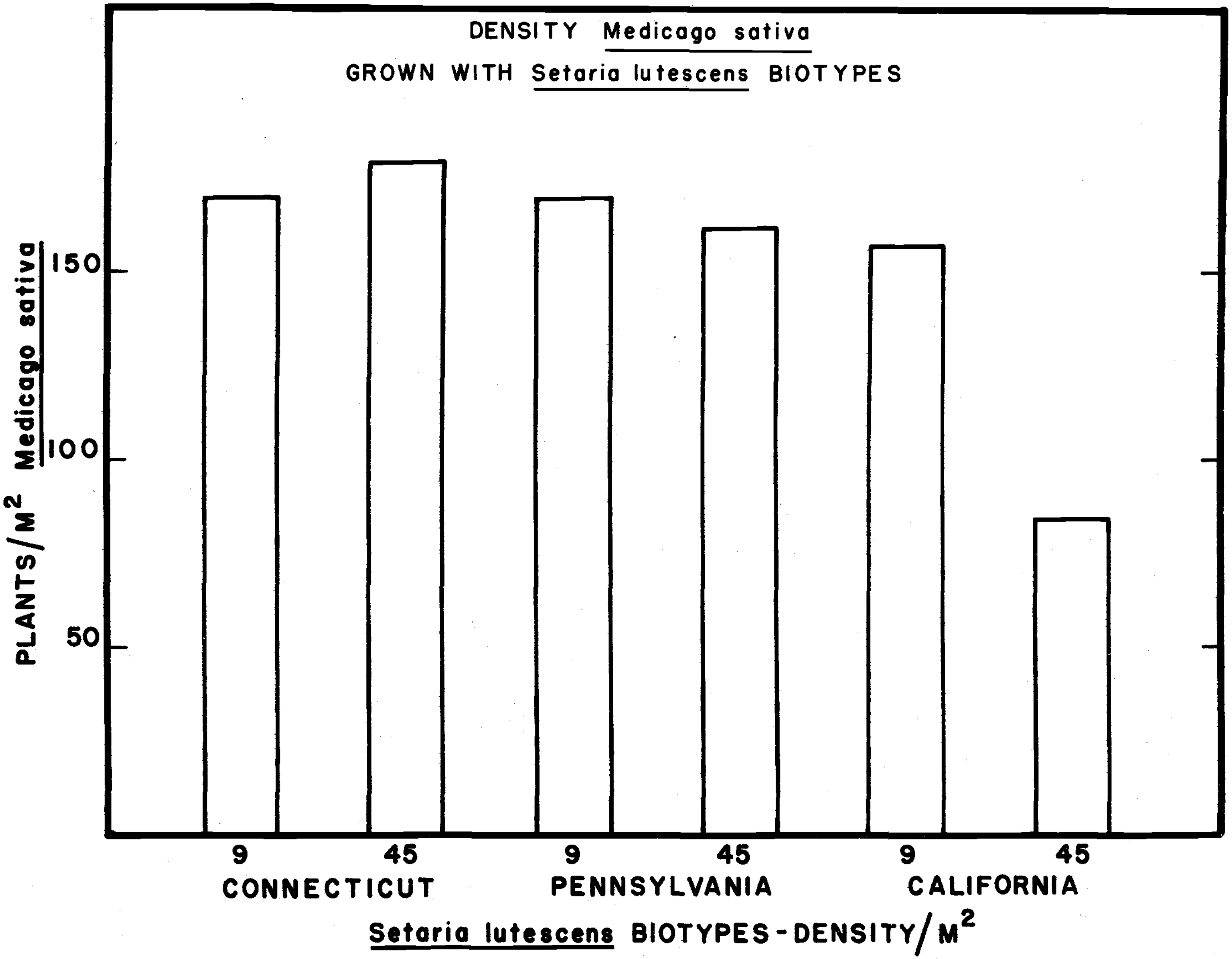
Density	Biotype Calif.	Biotype Conn.	Biotype Penna.	Density Mean
$9/m^2$	160	164	167	164
$45/m^2$	86	172	166	141
Variety mean	123	168	167	

LSD.05 variety = 14 LSD.05 Density = 12

LSD.01 - California ($45/m^2$) vs All Others = 19

While no definite answer can be given for stand reduction under the high plant density California biotype treatment, it is speculated that a portion of the yield reduction and perhaps stand loss, suffered

Figure 9. Plant density of Medicago sativa (alfalfa) when grown with Connecticut, Pennsylvania and California Setaria lutescens biotypes at two densities. Alfalfa densities expressed in plants/m^2 at the end of the 1973 season.


DENSITY Medicago sativa
GROWN WITH Setaria lutescens BIOTYPES
PLANTS/M2 Medicago sativa
150
100
50
9
45
9
45
9
45
CONNECTICUT
PENNSYLVANIA
CALIFORNIA
Setaria lutescens BIOTYPES - DENSITY/M2

by alfalfa was due to the aggressive, prostrate growth habit of this biotype. The California *Setaria lutescens* tended to overtop and shade alfalfa regrowth for several days following each harvest. Alfalfa regrowth was observed to be less vigorous and to lack maturity at harvest time. Shading of regrowth may have weakened alfalfa plants over the course of the summer.

Summary and Discussion

The Pennsylvania and Connecticut biotypes were early maturing with a shorter season of growth and production than the California biotype. Although Pennsylvania and Connecticut produced numerous seed heads the seed was frequently not mature at harvest time. California biotype seed heads were usually shattering at harvest. The Connecticut and Pennsylvania entries suffered greatly from competition with alfalfa, producing fewer seed heads and less mature seed than when they were grown alone. California biotype seed head numbers and seed yields were also reduced when growing with alfalfa, but this biotype still retained a high reproductive capacity as shown by seed yields. Plants of all three biotypes grew larger and produced more dry matter and seed when grown at low densities.

The dry matter yield and stand density of alfalfa was reduced substantially by the high density ($45/m^2$) California biotype treatment.

It appears from comparing data on dry matter and seed yield that the Pennsylvania and Connecticut *Setaria lutescens* biotypes are not well adapted to an alfalfa culture environment as carried out in this test. The California biotype does seem well adapted to alfalfa production conditions. Depression of alfalfa yield and stand by the high density California biotype treatment confirms field observation and grower experience that this weedy grass is capable of offering severe competition to alfalfa as grown under the cultural management of California's Central Valley.

A question raised by these experiments is: What type of competition does alfalfa provide for *Setaria lutescens* and *Echinochloa*? Does alfalfa compete for moisture, nutrients, light or perhaps it has some alleopathic effect on weeds? Does competition provided by alfalfa have most effect on seedling weeds or the more mature *Echinochloa* and *Setaria individuals*? The third experiment in this competition series was designed to shed some light on these questions.

Biotype Competition Study III
(Connecticut, Pennsylvania, California biotypes plus *Echinochloa crusgalli*)

Comparisons of three *Setaria lutescens* biotypes and *Echinochloa crusgalli* under frequent clipping, following a competition free start and without competition for moisture and nutrients.

Methods

Seed of Setaria lutescens biotypes (Connecticut, Pennsylvania and California) and Echinochloa crusgalli was planted in two-quart (15 cm x 15 cm) plastic pots in June of 1973. Pots were hand watered until seedlings were well established. The pots were then buried to the level of the soil surface in an established stand of non-dormant alfalfa. The alfalfa was clipped to 7.6 cm. height at the time pots were placed in the soil. The experimental design was a completely randomized plot with four treatments and ten replications for a total of forty plants. Four harvests were made during the growing season with head counts, dry matter and seed weights tabulated.

Dry Matter, Seed Head, and Seed Yields, Biotypes

Echinochloa crusgalli produced the largest dry matter yield per plant followed by the California, Pennsylvania and Connecticut biotypes of Setaria lutescens (Table 27). The California biotype produced 2.5 times more seed heads than Echinochloa, 7 times Connecticut and 11 times more seed heads than the Pennsylvania biotype. The California entry was the only one producing seed at the November 11 harvest. Seven of the Connecticut and five of the Pennsylvania biotypes died following the August 6 harvest.

This was a late season planting; it would be considered near the end of field germination and emergence period for Setaria lutescens

Table 27. Dry matter, seed head and seed yields per plant. *Setaria lutescens* biotypes and *Echinochloa crusgalli*. (Yields expressed on a per plant basis.)

	Harvest Date				Total
	7-28	8-25	10-6	11-10	
Dry Matter Yield Grams per Plant					
California	.70	2.59	3.44	3.40	10.13
Connecticut	.45	1.67	.09	.00	2.21
Pennsylvania	.60	5.15	.25	.00	6.00
E. crusgalli	.75	12.54	5.83	.34	19.45
				LSD.01 =	5.14
Seed Heads Per Plant					
California	-	2.7	20.8	28.4	51.9
Connecticut	-	5.3	2.1	.0	7.4
Pennsylvania	-	2.0	2.6	.0	4.6
E. crusgalli	-	1.3	13.4	4.8	19.5
Seed Yield Grams per Plant					
California	-	.00	1.35	.77	2.12
Connecticut	-	.02	.02	.00	.04
Pennsylvania	-	.00	.12	.00	.12
E. crusgalli	-	.00	1.54	.00	1.54
				LSD.01 =	.69

and Echinochloa crusgalli. Mean emergence was June 18. The test did provide some interesting information. Echinochloa crusgalli did produce abundant mature seed when given a competition free start. Echinochloa seedlings were not influenced by competition for water, nutrients or light. Shading of the well established plants (after pots were in the soil) by alfalfa did not prevent them from maturing seed.

With the late season start all plants entered had fewer than normal number of tillers and tended to initiate reproductive growth within a short time after emergence. As a result of late start and early flower initiation, the second clipping removed immature heads and most foliage on all but the prostrate California biotype. Echinochloa survived the shock but produced no more seed. Several of the Connecticut and Pennsylvania plants did not survive the drastic defoliation resulting from clipping to 7.6 cm shortly after heading. The late season seed production capability of the California biotype was demonstrated again.

Overall Summary and Discussion, Biotype Competition

Setaria lutescens is a weed of widespread economic importance in the Northeast and Midwest. Santelman et al. (1963) state that

> Probably the most common weedy foxtail on the East coast is yellow foxtail. It starts growth in the spring and is often a serious problem in spring-seeded stands of alfalfa and other forage legumes as well as in grain crops. Wheat yield reduction of 16%, oat yield reductions of 11% and

> soybean reductions of 15% as a result of yellow foxtail have been reported.

Peters and Yokum (1961) describe yellow foxtail (*Setaria lutescens*) as one of the most prevalent annual grasses in the eastern United States. According to Peters and Yokum, *Setaria lutescens* is most frequently associated with annual crops or with the first-year growth in perennial crops such as forages where the soil has been recently disturbed. These workers indicate that *Setaria lutescens* can be a problem in first-year forage seedings but do not describe the species as a problem once a perennial crop is established. Workers from other states have shown *Setaria lutescens* an economic weed in field crops. Feltner *et al.* (1960) found that *Setaria lutescens* could reduce milo yields up to 50% in Kansas. Staniforth of Iowa (1956, 1958, 1965) investigated competitive effect of *Setaria lutescens* on soybeans and found yield reductions of 2% to 19%. Nieto and Staniforth (1961) found 10% to 28% reductions in corn yield with high populations of *Setaria lutescens*. All of these workers indicate *Setaria lutescens* is normally a weed problem in annual crops or the first year of perennial crops. Conversely, in California *Setaria lutescens* is not considered a serious weed of annual crops. It is, however, an extremely serious weed in both seedling and established stands of alfalfa. Once the weed infests an alfalfa field it grows progressively worse until the stand is destroyed. The difference in habits of *Setaria lutescens* in these widely separated regions could be due to plastic adaptability of the species; however, this comparative testing of Connecticut, Pennsylvania and California biotypes under California alfalfa cultural conditions indicate the difference to be more than plastic adaptability.

The difference between erect and prostrate growth habits is certainly a benefit to the California biotype in competition with alfalfa. How much of an advantage can be estimated from the comparative dry matter and seed yields of the three biotypes with alfalfa.

Reduction of alfalfa yield and alfalfa plant density associated with the California biotype at Davis and Woodland raises interesting questions. While it was observed that Setaria lutescens overtopped alfalfa regrowth for several days after harvest it seems unlikely that shading alone can be the cause of stand reduction.

Several workers have studied alleopathy with the Setaria species. Bell and Koeppe (1972) conducted intensive investigations with Setaria faberii and have shown an unidentified toxic substance that reduced dry matter production of corn by 35%. Schreiber and Williams (1967) demonstrated reduction of root growth of corn in soils containing root residues of Setaria faberii, Setaria glauca (lutescens) and Digitaria sanguinalis. Yokum et al. (1961) conducted extensive and intensive investigations on the inhibitory substance produced by yellow foxtail (Setaria lutescens). They state:

> Aqueous extracts of yellow foxtail were found to be inhibitory to the germination and growth of seeds of several crop plants. The germination and growth inhibitor produced by yellow foxtail was found to be present in equal amounts in both tops and roots of the foxtail plant and in both dried and green material.

These researchers characterized the material through extensive chemical experimentation and indicated that it was associated with organic sugars. The considerable work on inhibitory substances leads to speculation that some of the yield depression and stand loss in alfalfa associated with Setaria lutescens may be of an alleopathic nature.

Whatever the cause of alfalfa yield and stand losses, they were most severe with the California biotype of Setaria lutescens, in fact the Connecticut and Pennsylvania biotypes seemed to have no repressive effect on alfalfa.

The comparative results with Echinochloa crusgalli and Setaria lutescens grown in greenhouse pots within an alfalfa stand also opens some interesting questions. In this test Echinochloa crusgalli seedlings were established free of competition for light. This leads to speculation that it may be the shade effect of alfalfa canopy on Echinochloa crusgalli seed germination and seedling growth that prevents this grass from being a more serious pest in established alfalfa.

SETARIA LUTESCENS BIOTYPE SEED GERMINATION

Throughout the progress of biotype comparison and competition tests it was observed that the California biotype seed had higher germination percentages and more rapid seedling emergence than biotypes from Connecticut, Pennsylvania, Iowa or Massachusetts. This led to speculation that seed of the various biotypes may have different physiological requirements for germination and growth. Many workers have investigated germination and dormancy of *Setaria lutescens* but have not all reached the same conclusions. Could it be possible that some of the variation in results may have been due to ecotypic differences in the *Setaria lutescens* parent plants? To test this speculation a series of germination experiments were carried out in cooperation with Dr. Robert Norris, Assistant Professor of Botany, University of California, Davis.

Purpose of the Study

The investigations included experiments of two types:

1. Seed collected in 1972 and 1973 (of the five biotypes) was tested for germination in an alternating cycle germinator.

2. Seeds of biotypes from Massachusetts, Pennsylvania, Connecticut and California were exposed to seven static temperatures in a gradient bar germinator.

The purpose of these experiments was to determine whether Setaria lutescens biotypes seed has different germination requirements and to determine optimum germination temperatures of California Setaria lutescens.

There were two objectives, one was to verify or reject a hypothesis that seed of the California biotype is physiologically adapted to a California environment in contrast with biotypes from other regions, the second was to learn more of germination requirements of the California biotype that might be helpful in field control.

Experiment I (1972 versus 1973 seed)

Methods

Seeds collected from biotype comparison tests in 1972 and 1973 were stored in paper containers at room temperature until December of 1973. Two hundred seeds of each biotype, plus Echinochloa crus-galli, were taken from seed lots of each year, making a total of twelve seed lots. Covered petri dishes with several layers of germination blotter in the bottom half were used as containers. Each 200 seed lot was divided into four replications of 50 seeds.

There were a total of 24 petri dishes for the experiment, each divided in the center and each containing two lots of 50 seeds of one biotype or species (ie. each petri dish contained 50 - 1972 seeds and 50 - 1973 seeds from one biotype). The petri dishes were placed in an alternating cycle germinator with a glass window admitting daylight. The germinator cycled 16 hours at $20^{o}C$ and 8 hours at $30^{o}C$. Containers were inspected daily, germinated seeds counted and removed and distilled water added as needed.

Variations Between Biotypes and Years

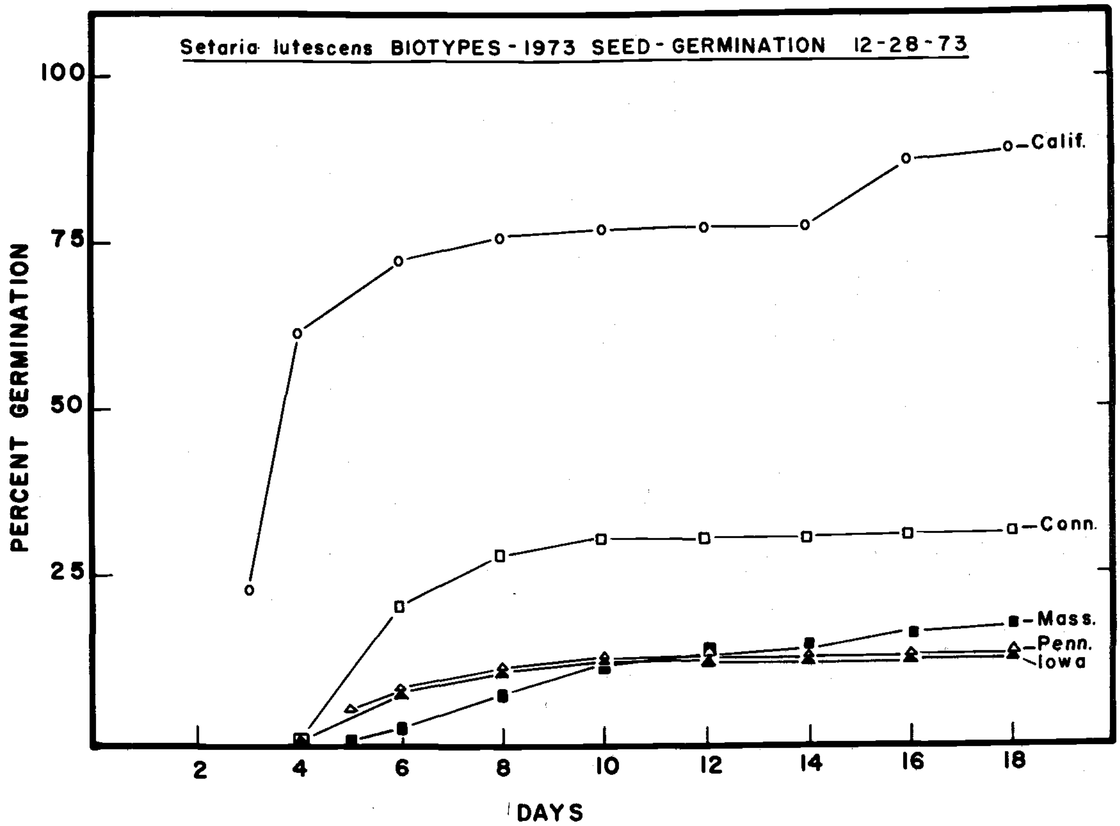
The germination percentage of 1972 seed was higher for every biotype than germination percentage of 1973 seed (Figure 10). California biotype had the highest germination percentage in each year. Seed of Massachusetts displayed the largest increase in germination percentage between years (20% for 1973 and 90% for 1972 seed). Overall germination percentage was low for Iowa, Connecticut and Pennsylvania seed, both years (below 30% for 1973 and below 55% for 1972 seed).

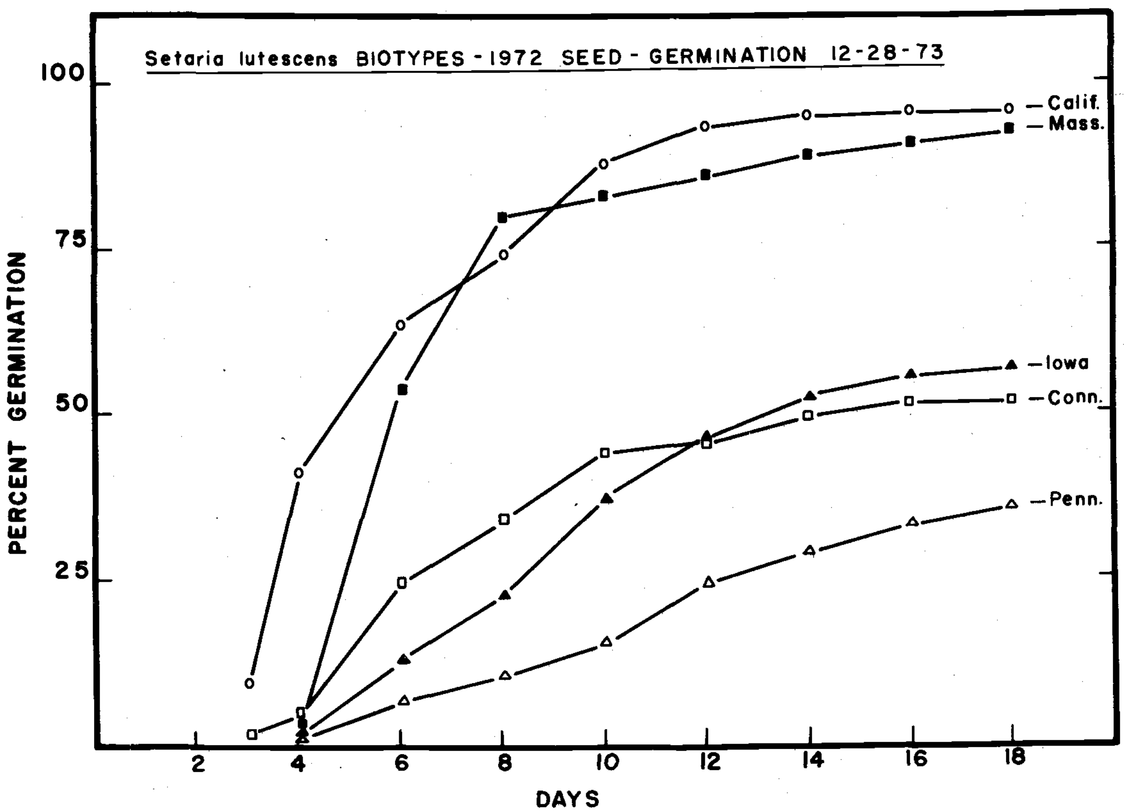
Differences between years might have been a seasonal effect rather than seed after-ripening; however, interaction between biotypes and years indicate that some of these differences are due to after-ripening in storage. Massachusetts seed appears to have a dormancy that can be broken by warm, dry storage for 18 months. Storage aided other biotypes to increase in germination percentages but by lesser amounts.

In preliminary 1971 tests (not reported), freshly harvested seed of the California biotype would not germinate until January, 1972,

Figure 10 a. Germination percentages (1973 seed) of _Setaria lutescens_ biotypes from Connecticut, Iowa, Massachusetts, Pennsylvania and California. Cumulative germination percentages over an eighteen-day period in an (20° - 30°C) alternating cycle germinator.

b. Germination percentages (1972 seed) of _Setaria lutescens_ biotypes from Connecticut, Iowa, Massachusetts, Pennsylvania and California. Cumulative germination percentages over an eighteen-day period in an (20° - 30°C) alternating cycle germinator.


Setaria lutescens BIOTYPES - 1973 SEED - GERMINATION 12-28-73
PERCENT GERMINATION
100
75
50
25
Calif.
Conn.
Mass.
Penn.
Iowa
2
4
6
8
10
12
14
16
18
DAYS


Setaria lutescens BIOTYPES - 1972 SEED - GERMINATION 12-28-73
PERCENT GERMINATION
100
75
50
25
Calif.
Mass.
Iowa
Conn.
Penn.
2
4
6
8
10
12
14
16
18
DAYS

indicating an after-ripening requirement. The 1973 seed used in these experiments had been in storage for four to five months before the test. After-ripening may have been completed during that period.

Experiments II and III
(1972 versus 1973 seed and stratification)

This investigation is divided in two parts. Part I was the December test repeated using 1972 and 1973 seed. Part II utilized 1973 seed, half of which had been subjected to stratification.

Methods

Part I was conducted identically to the December, 1973, germination test. Part II, one lot of 1200 seeds from the five biotypes plus *Echinochloa*, was continued in warm, dry storage from January until the start of the test on March 23, 1974. The second lot was placed in cold, moist storage for 62 days prior to the germination test (stored in petri dishes with wet blotters at 0 - 5°C). With the exception of cold storage all other methods were similar to those used in the December, 1973, test.

Variations Between Biotypes and Years

Seed in this experiment shows germination percentages very similar to the earlier test with 1972-1973 seed (Figures 11a and 12b). Germination of the biotypes ranges from 45% to 90%, with California having highest germination followed closely by Massachusetts. Connecticut, Iowa and Pennsylvania were grouped with germination near the 50% mark. As before, all biotypes showed greater germination of 1972 seed than of the 1973 seed lot. Massachusetts 1973 seed did increase in germination percentage between the December and March tests.

Results of the December and March tests with 1972-1973 seed are very similar. The exception is Massachusetts 1973 seed. In the December test its germination was 20% and in March germination increased to 50%.

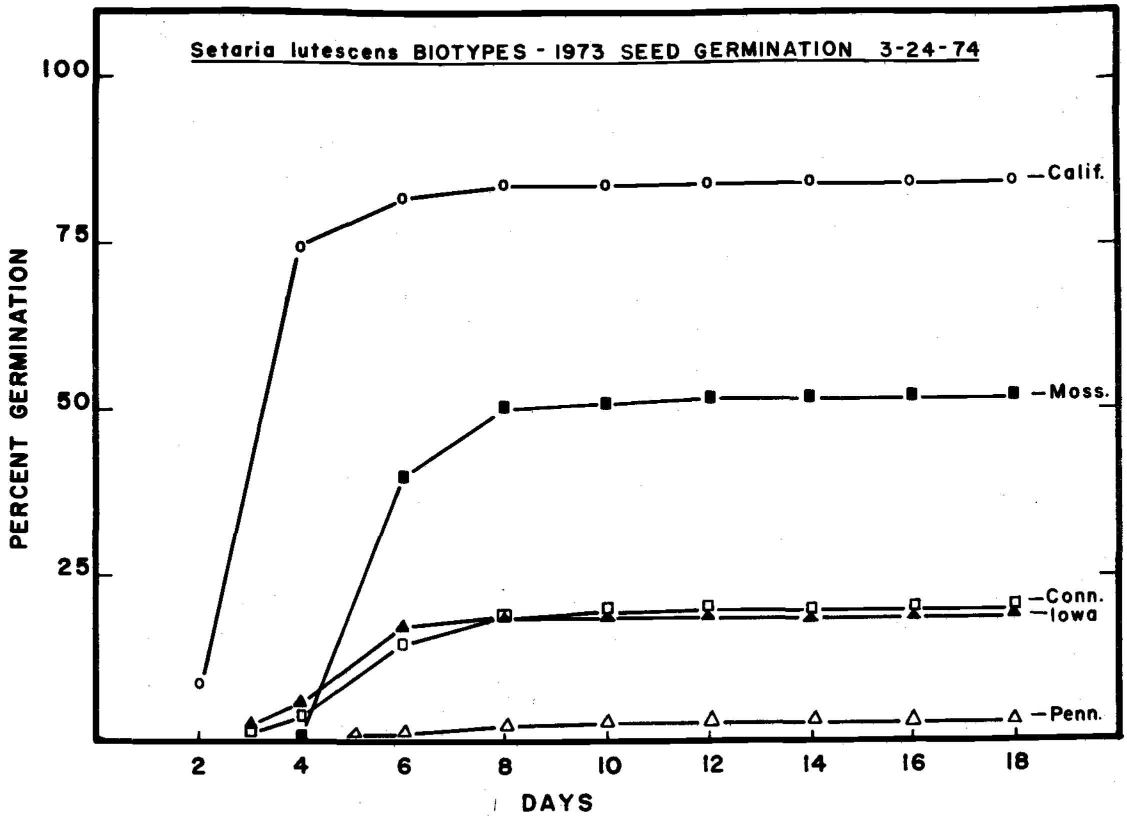
Stratification

Cold storage increased germination of all biotypes except California (Figures 11b and 12a). Increases in germination due to cold storage include: Connecticut from 34% to 59%, Iowa from 16% to 79%, Massachusetts from 56% to 80% and Pennsylvania from 12% to 28%. Cold storage decreased the germination percentage of the California biotype seed from 92% to 43%.

There are strong indications of physiological differences between biotypes as regards seed germination and seed dormancy. For example, the germination of California seed is cut in half by cold storage while other biotypes increased in germination percentage following stratification. Seed dormancy of Massachusetts and Iowa

Figure 11 a. Germination percentages (1973 seed) of Setaria lutescens biotypes from Connecticut, Iowa, Massachusetts, Pennsylvania and California. Cumulative seed germination percentages over an eighteen-day period in an (20^{o} - 30^{o}C) alternating cycle germinator.

b. Germination percentages of 1973 seed exposed to cold, moist storage (0^{o} - 5^{o}C) for 62 days prior to germination. Seed of Setaria lutescens biotypes from Connecticut, Iowa, Massachusetts, Pennsylvania and California. Cumulative germination over an eighteen-day period in an (20^{o} - 30^{o}C) alternating cycle germinator.


Setaria lutescens BIOTYPES - 1973 SEED GERMINATION 3-24-74
PERCENT GERMINATION
100
75
50
25
2
4
6
8
10
12
14
16
18
DAYS
Calif.
Moss.
Conn.
Iowa
Penn.

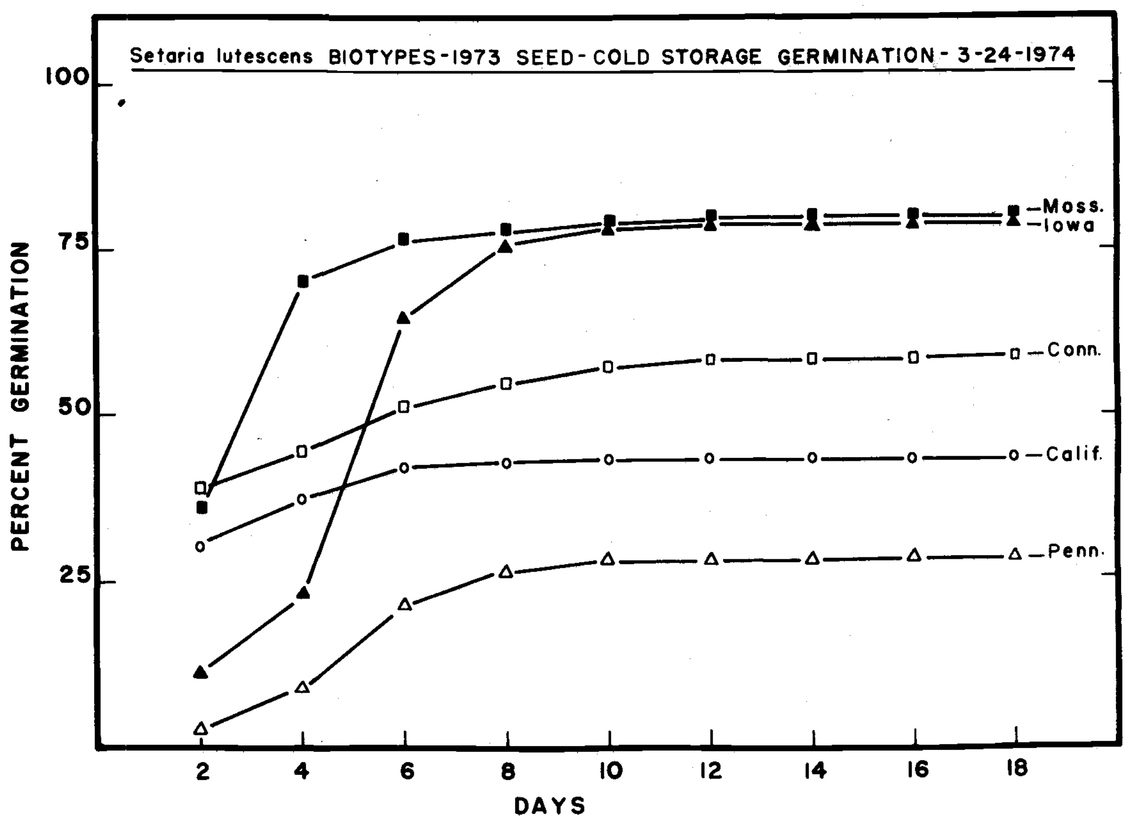
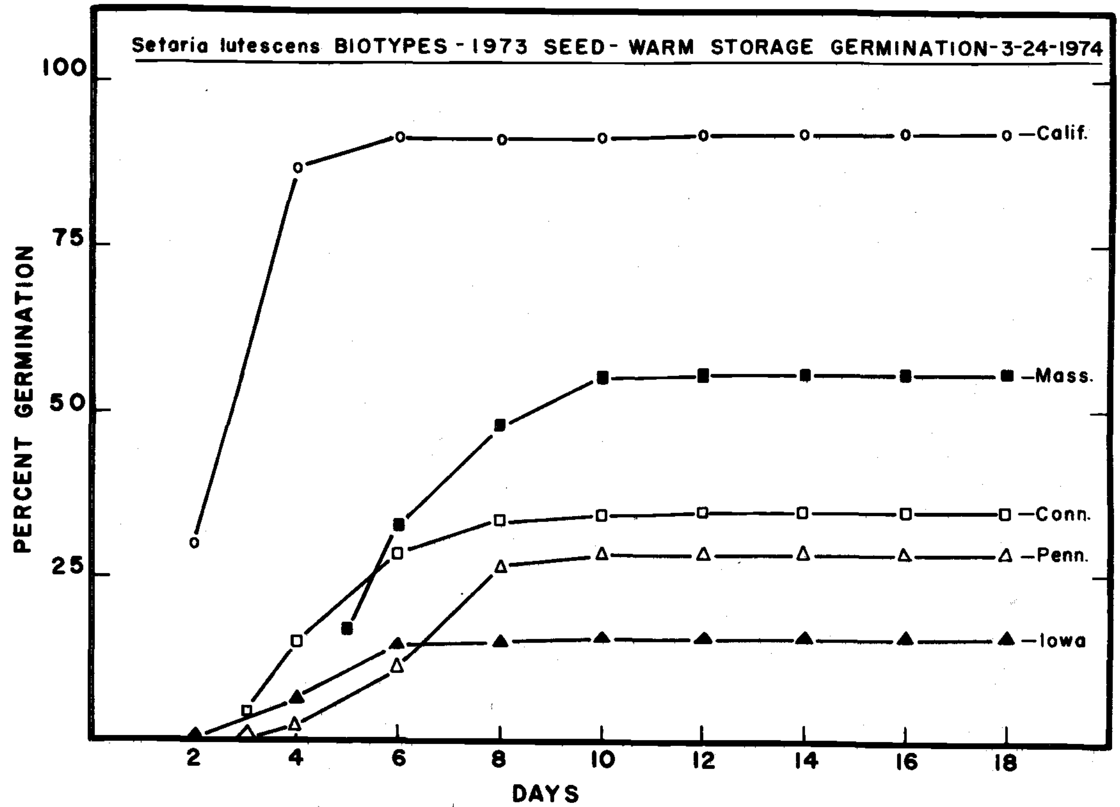
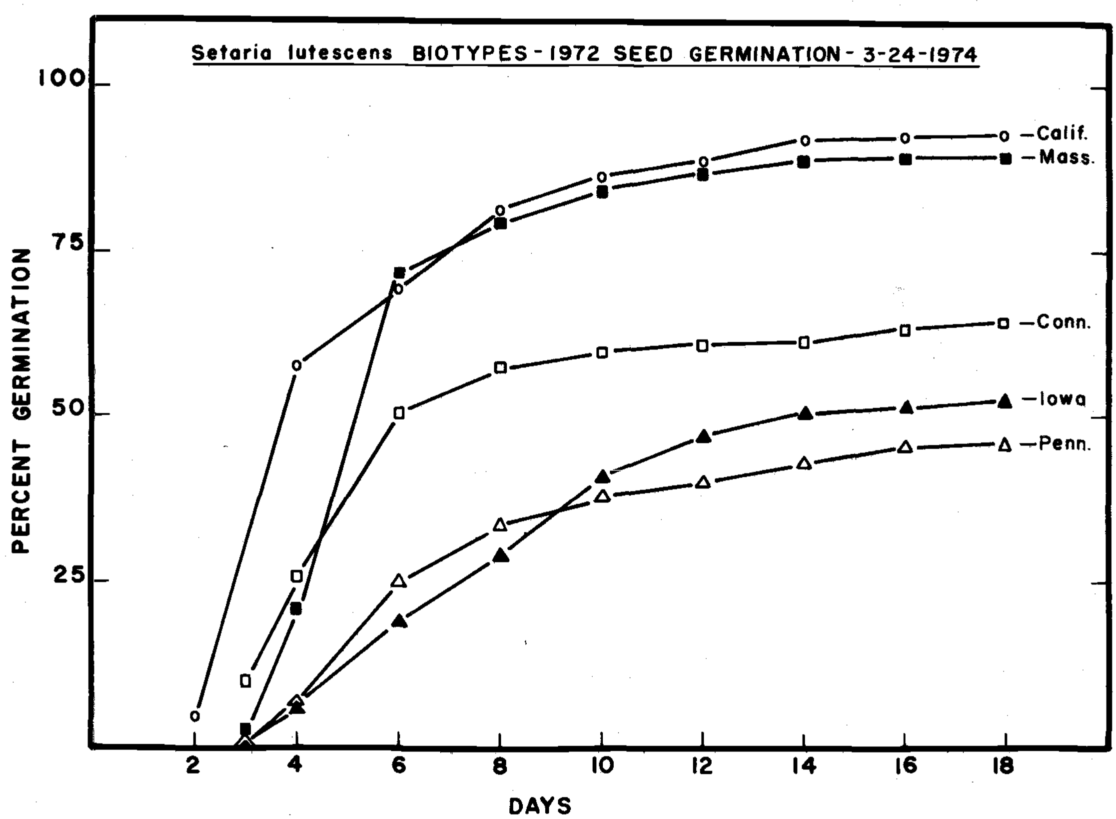

Setaria lutescens BIOTYPES-1973 SEED-COLD STORAGE GERMINATION-3-24-1974
PERCENT GERMINATION
100
75
50
25
2
4
6
8
10
12
14
16
18
DAYS
Moss.
Iowa
Conn.
Calif.
Penn.

Figure 12 a. Germination percentages (1973 seed) of Setaria lutescens biotypes from Connecticut, Iowa, Massachusetts, Pennsylvania and California. Cumulative seed germination percentages over an eighteen-day period in an (20^{o} - 30^{o}C) alternating cycle germinator.

b. Germination percentages (1972 seed) of Setaria lutescens biotypes from Connecticut, Iowa, Massachusetts, Pennsylvania and California. Cumulative seed germination percentages over an eighteen-day period in an (20^{o} - 30^{o}C) alternating cycle germinator.


Setaria lutescens BIOTYPES - 1973 SEED - WARM STORAGE GERMINATION - 3-24-1974
PERCENT GERMINATION
100
75
50
25
2
4
6
8
10
12
14
16
18
DAYS
—Calif.
—Mass.
—Conn.
—Penn.
—Iowa


Setaria lutescens BIOTYPES - 1972 SEED GERMINATION - 3-24-1974
PERCENT GERMINATION
100
75
50
25
2
4
6
8
10
12
14
16
18
DAYS
—Calif.
—Mass.
—Conn.
—Iowa
—Penn.

biotypes was almost entirely overcome by stratification, Connecticut and Pennsylvania germination increased somewhat after seed stratification, but these biotypes clearly have other requirements for breaking dormancy according to results of this test.

Temperature Gradient Bar Experiment

Methods

A temperature gradient bar was calibrated at 5°C intervals ranging from 10°C to 40°C. Petri dishes used as seed containers were filled with 7 mm of sterile sand overlain by two layers of filter paper. The sand layer served as a water reservoir. Seed of four biotypes collected in 1972 was used. Two biotypes were compared on each run of the gradient bar. Petri dishes divided in the center contained two lots of 50 seeds in each; however, each lot was of a different biotype. On the first temperature gradient bar run each petri dish contained 50 seeds of California biotype and 50 seeds of Massachusetts biotype. Each treatment was replicated two times for a total of 14 petri dishes containing 700 seeds per run. Petri dishes were inspected daily, seeds germinated were counted and removed. Seeds were kept under germination conditions on the gradient bar for 17 days.

Variations Between Biotypes

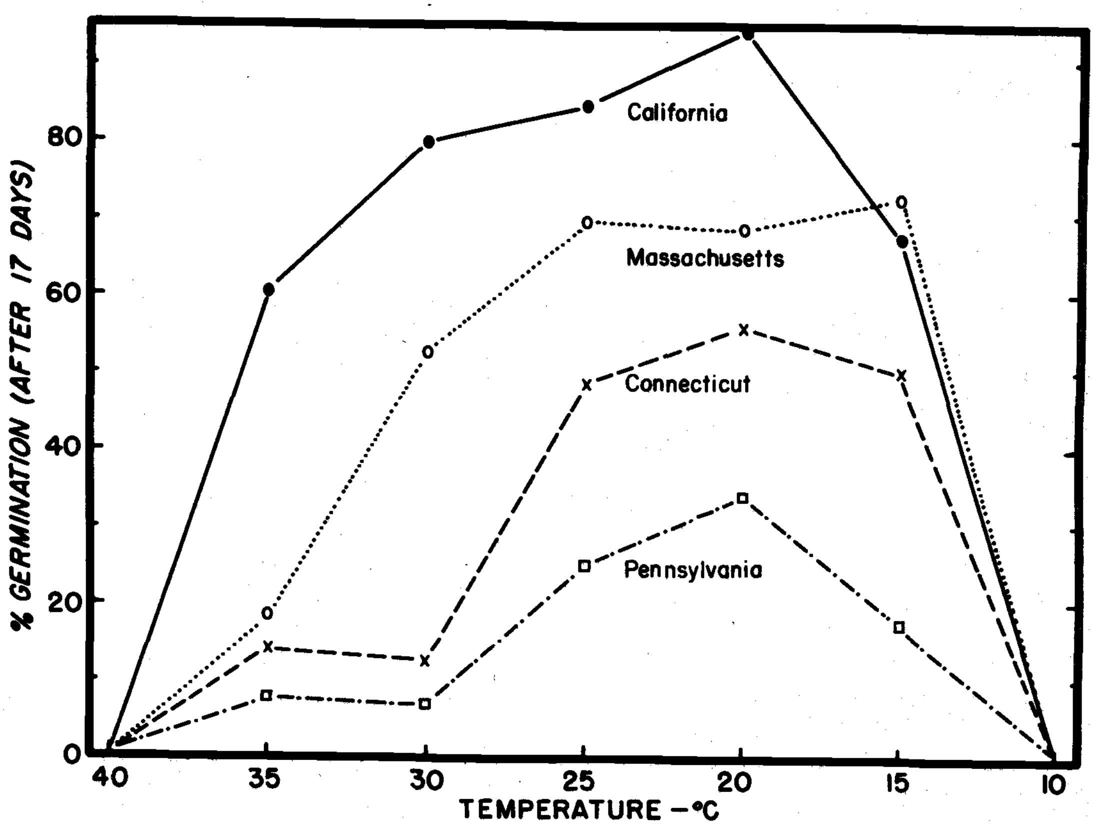
All biotypes have a similar range of germination temperatures (Figure 13a). Seed did not germinate at 10°C or 40°C. The highest percentage germination recorded for Pennsylvania was at 20°C, for Connecticut 20°C and California 20°C. Massachusetts had equal germination percentages at 15, 20 and 25°C. Pennsylvania had the lowest germination percentages at all temperatures followed by Connecticut and Massachusetts. California seed germination percentages were highest at all temperatures. The rapidity of seed germination of Massachusetts and California biotypes at various temperatures can be seen in Figure 13b. California germinates most rapidly at every temperature tested.

There are definite differences in the percentage germination of the biotypes at every temperature used, but the results are difficult to interpret. The germination percentages are in general agreement with those reached in the alternating cycle germinator.

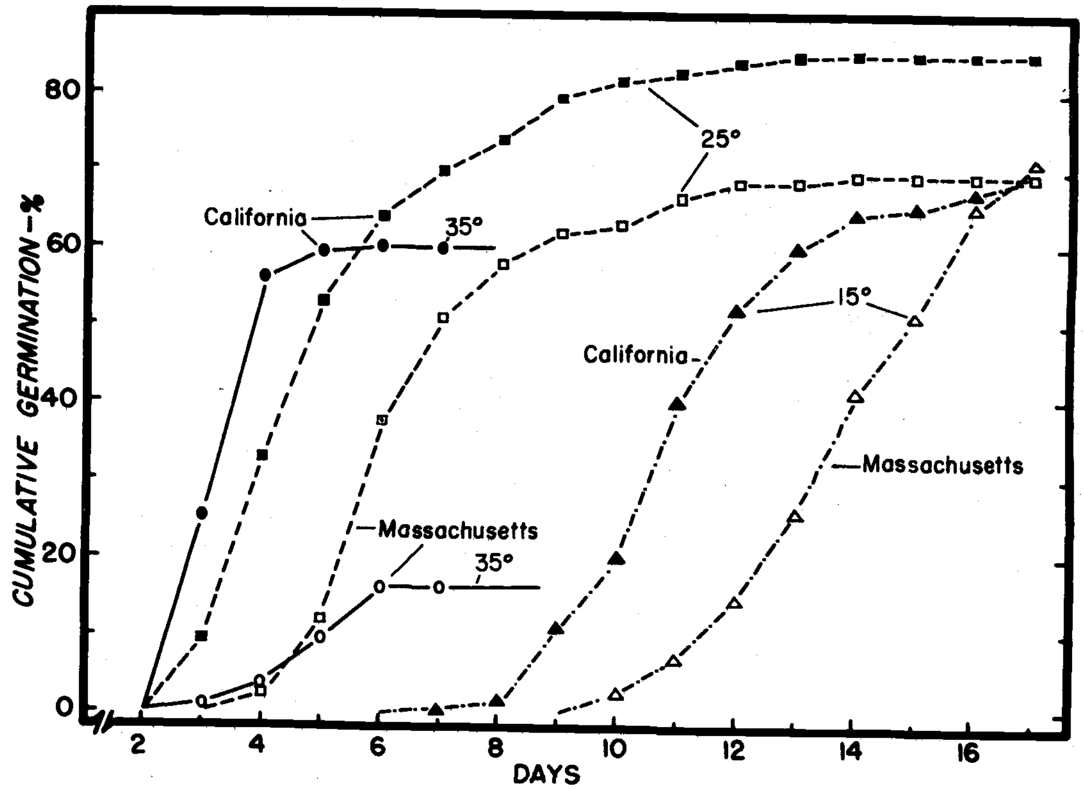
California biotype has a 60% or better germination percentage at a wider range of temperatures than all other biotypes. This biotype germinates readily at 35°C, the highest temperature at which germination occurred. The wide range exhibited by California could be interpreted as an adaptation to the mild winters and hot summers of the Central Valley. Connecticut and Pennsylvania clearly have a germination requirement that has not been met in these investigations.

Figure 13 a. Maximum seed germination percentages (1972 seed) of *Setaria lutescens* biotypes from Connecticut, Massachusetts, Pennsylvania and California. Maximum germination of seven seed lots exposed to seven different temperatures on a temperature gradient bar.

b. Germination percentages (1972 seed) of *Setaria lutescens* biotypes from Massachusetts and California. Cumulative seed germination percentages of three seed lots exposed to three different temperatures on a temperature gradient bar.



California
Massachusetts
Connecticut
Pennsylvania
% GERMINATION (AFTER 17 DAYS)
0
20
40
60
80
40
35
30
25
20
15
10
TEMPERATURE —°C



25°
California
35°
15°
California
Massachusetts
Massachusetts
35°
CUMULATIVE GERMINATION—%
0
20
40
60
80
2
4
6
8
10
12
14
16
DAYS

In the comparison of speed of germination between Massachusetts and California, it is evident that California seed germinates most rapidly at every temperature tested and has a higher percentage germination at high temperatures than does Massachusetts. This again could be speculated as adaptation to alfalfa cultural conditions in the hot Central Valley of California where rapid germination should be a valuable asset.

Summary and Discussion of Seed Germination

Most workers agree that *Setaria lutescens* seed must pass through an after-ripening period before germination will occur, even under favorable conditions. Following the after-ripening period much seed still exhibits dormancy when exposed to favorable germinating conditions. Rost (1973) studied the caryopsis coat in dormant and non-dormant *Setaria lutescens* seed. He defines the caryopsis coat as several cell layers from the parent plant that surround the developing embryo. He indicates that growth and maturation of the embryo and endosperm causes the crushing of these layers into a caryopsis coat that may contribute to dormancy of weed species. He speculates that in *Setaria lutescens* this coat may be impermeable to liquids and partially responsible for seed dormancy. Rost found the removal of the caryopsis coat increased seed germination. Biswas *et al.* (1969)

felt that dormancy may be due to the hull (lemma and palea) of Setaria lutescens. They found the hull to be high in cellulose and speculated this may provide mechanical resistance to growth of the embryo. They also found high lignin in the hull which may cause impermeability to liquids. In their studies, Biswas et al. were able to obtain 100 percent germination by hull removal. Tao et al. (1968) observed that germination of intact Setaria lutescens seed was normally less than 50 percent while the percentage germination approached 100 percent when the hull (glumes, palea and lemma) was removed. Based on oxygen consumption and imbibition of water by hulled versus unhulled seed, they speculated that dormancy is influenced considerably by the imperviousness of hulls to oxygen and water. Peters and Yokum (1961) indicate there is a post-harvest dormancy that must be met or the seed will not germinate, and after that time the inability of water to penetrate to the embryo is at least one factor in dormancy. They had success with scarification of Setaria lutescens seed to induce germination.

Nieto and Staniforth (1964) found two causes of dormancy in Setaria lutescens seed: One relating to the hull (lemma and palea), the other to the caryopsis (hulled seed). Freshly harvested seed had a high percentage of dormant caryopses that did not germinate when hulls were removed. Caryopsis dormancy was terminated by a combination of low temperature and high moisture, but seeds afterripened this way did not germinate appreciably until the hulls were removed. Isolated embryos grew normally on nutrient medium indicating that embryo dormancy was not a factor. They were unable to isolate the dormancy causing factor from dormant Setaria lutescens caryopses. Kollman and Staniforth (1970) found that seed from plants collected at Ames, Iowa, required stratification to overcome the primary or inherent dormancy. This confirms tests in the alternating germinator where 62 days of moist, cold storage increased germination of Iowa seed from 15% to 79%. However, the California tests also indicated that dry storage of Iowa seed for a year would substantially increase germination percentage. Vengris (1963) studying germination requirements in Massachusetts found the Massachusetts Setaria lutescens seed required only five days for 10% germination at 25°C and 11 days to reach the same germination percentage at 15°C. It is interesting to note that Massachusetts seed tested on the temperature gradient bar responded very similarly (Figure 13b).

It can be seen that there is not complete agreement between investigators on the nature of germination requirements for Setaria lutescens seed, and one may speculate whether this can be due to ecotypic differences. The California germination experiments show large differences between seed germination requirements of the five Setaria lutescens biotypes. Some appear to require after-ripening, some stratification and some have other requirements not met in these experiments, perhaps hull scarification. Perhaps imperme- ability of the hull is involved as suggested by several. California seed certainly seems to have the least rigid requirements for ger- mination of all the biotypes. This could be a reflection of environ- ment.

SUMMARY AND CONCLUSIONS
Ecotypic Adaptation of Setaria lutescens (Weigel) F. T. Hubbard, to Alfalfa Culture in California

Setaria lutescens plants grown from seed collected in Connecticut, Massachusetts, Iowa, Pennsylvania and California were compared in a California environment. The plants exhibited differences in color, height, leaf size, head numbers, growth habits and maturity. The most significant difference is in growth habit. The California biotype exhibits a prostrate growth habit that may be an adaptation to cultivated alfalfa (Medicago sativa) as grown in the central valleys of California. Biotypes from other regions have a generally erect growth habit although some culms may be decumbent.

There are differences in rate of maturity between the five biotypes. Connecticut is the earliest maturing, Iowa intermediate, Pennsylvania, Massachusetts and California are later maturing. Reproductive capacity as measured by seed production also differs between biotypes. The dormancy and germination requirements of seed from the five biotypes was compared. There are differences in seed germination percentage and seed germination requirements between biotypes. Dry storage for a year increased germination percentage of all biotypes with California and Massachusetts approaching 90% germination.

Stratification increased germination of seed of biotypes from

Iowa, Massachusetts, Connecticut and Pennsylvania. The germination percentage of Iowa seed increased from 16% to 79% following cold, moist storage while germination of the California biotype seed decreased from 92% to 43% following stratification. Optimum temperatures for germination were studied on a temperature gradient bar and although variations exist between biotypes optimum temperatures for all were found to range from $15^{o}C$ to $25^{o}C$.

Three biotypes were chosen for comparison of growth and reproductive capacity under simulated California alfalfa (Medicago sativa) forage producing practices. The California biotype produced the most vegetative matter of the three under frequent clipping. California yielded 71% more seed than Pennsylvania and 85% more than Connecticut when clipped on a monthly schedule. When the three biotypes were grown and harvested with alfalfa, the California biotype yielded the greatest amount of dry matter followed by Pennsylvania and Connecticut. California yielded 93% more seed than Pennsylvania and 98% more seed than Connecticut when grown with alfalfa and harvested under an alfalfa forage production schedule. The prostrate growth habit of the California biotype was observed to be advantageous when Setaria lutescens biotypes are subjected to frequent clipping at a 7.6 cm height.

First-year alfalfa yields were decreased by 35% and alfalfa stand reduced 48% when grown with a high density of California

Setaria lutescens plants. Setaria lutescens has been observed to retard alfalfa growth following harvest, but no other explanation is given for yield and stand reductions.

The growth and reproductive capacity of Echinochloa crusgalli and Setaria lutescens were compared when grown with and without alfalfa under simulated California alfalfa forage production practices. Echinochloa crusgalli and Setaria lutescens exhibited great plasticity regarding growth of individual plants at varying plant densities. When the two species were grown together at densities of 2300 plants/m^2, Setaria lutescens was able to produce mature seed, while Echinochloa crusgalli failed to reproduce. The overall growth and productivity of Echinochloa crusgalli and Setaria lutescens were drastically reduced when grown with alfalfa as compared to without alfalfa. Both species were able to grow and produce seed in the first year of an alfalfa stand. Echinochloa crusgalli plant density was reduced by second-year alfalfa and this species failed to produce mature seed when grown and harvested with second-year alfalfa. Setaria lutescens plant density was reduced slightly in second-year alfalfa, but this species produced an average of 10,000 seeds/m^2 when grown and harvested with second-year alfalfa. First-year alfalfa forage yields were reduced by high densities of Setaria lutescens. Alfalfa plant density was reduced during both first and second seasons when grown with high density Setaria lutescens.

Field studies of _Echinochloa crusgalli_ and _Setaria lutescens_ growing in commercially cultivated alfalfa for hay indicated that high density stands of the two species are related to the cultural practice of curing forage in windrows. Populations counts of the two species were made using continuous sampling transects across five irrigation strip checks in each of two fields.

The California biotype of _Setaria lutescens_ was observed to differ from _Setaria lutescens_ biotypes of other states in several morphological and physiological characteristics. At least one of these characteristics, prostrate growth habit, is assumed to be an adaptation to an agricultural crop.

The California biotype of _Setaria lutescens_ is adapted to growth with alfalfa cultivated for forage in California while _Setaria lutescens_ biotypes from Connecticut and Pennsylvania are not adapted to this type of environment. This conclusion is based on comparative dry matter and seed yields of the three biotypes grown under simulated California alfalfa forage production practices.

California _Setaria lutescens_ will invade a second-year stand of alfalfa cultivated for forage and will produce large quantities of seed. _Echinochloa_ will establish seedling plants under a similar situation but will not reproduce mature seed.

The commercial cultural practice of curing green alfalfa forage in windrows enables _Setaria lutescens_ to rapidly increase plant density in commercial fields. Windrow effects include destruction of alfalfa regrowth and creation of a favorable environment for establishment and growth of Setaria lutescens plants.

A very speculative conclusion concerning the success of Setaria lutescens in commercial alfalfa fields in California is: Setaria lutescens is adapted to alfalfa culture. It will invade alfalfa stand through seed transported by hay handling equipment; it will reproduce and maintain a low density population without further assistance from man. The practice of curing green alfalfa in windrows enables Setaria lutescens to increase rapidly until it is the dominant species in the alfalfa field.

Questions raised by the study include:

1. Is it possible that ecotypic variation within Setaria lutescens can account for differences in research results reported from investigations carried out in widely separated research facilities?

2. What is the real competitive effect of Setaria lutescens on alfalfa, is it competition for light, space, nutrients or alleopathy?

3. Are there differences between Echinochloa crusgalli and Setaria lutescens in seed germination under a foliar canopy of alfalfa?

4. Are there differences in the growth of Echinochloa crusgalli and Setaria lutescens seedlings under a foliar canopy of alfalfa?

5. Can the spread of Setaria lutescens in alfalfa fields be

slowed by a change in cultural practices?

6. Is spring or fall planting more favorable to the establishment of alfalfa in fields known to be infested with Setaria lutescens seed?

7. What type of alfalfa, dormant, semi-dormant, non-dormant has the best chance of competing with Setaria lutescens?

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