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Name of Author: **Daniel Ernest Cole**

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Dan Cole
5208 - 125 Street
Edmonton, Alberta
T6H 3V5

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Effect of Competition on Growth of Ox-eye Daisy (*Chrysanthemum leucanthemum* L.) in Pastures and Hay Land

by

Daniel Ernest Cole

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled **Effect of competition on growth of ox-eye daisy (*Chrysanthemum leucanthemum* L.) in pastures and hay land** submitted by Daniel Ernest Cole in partial fulfillment of the requirements for the degree of Master of Science in Plant Science.

Dr. J. R. King

Dr. W. H. Vanden Born

Dr. V. J. Lieffers

Date April 17, 1998

DEDICATION

To Susan, Tracey and Laura

ABSTRACT

Within the last decade there has been an increase in the occurrence of ox-eye daisy (*Chrysanthemum leucanthemum* L.) as a weed in pastures and hay land in Alberta. Current control methods are not adequate to address this problem. Field and greenhouse experiments were conducted to investigate how a range of management tools (herbicide, fertilizer, forage species, seeding rate, row spacing) could be used to alter the relative competitiveness of the weed and forage stand to provide a cost-effective method of ox-eye daisy control.

Ox-eye daisy was out-competed by the forage species when fertilizer was spring-applied to hay land for two consecutive years. When a herbicide, used to control ox-eye daisy, killed the legumes in the forage stand, spring-applied fertilizer stimulated grass growth and prevented ox-eye daisy from re-establishing.

In a newly established sward, ox-eye daisy had an average biomass of 2.5 grams per plant one year after seeding when growing with meadow bromegrass compared to 21 grams per plant when growing with Kentucky bluegrass. A high seeding rate and narrow row spacing increased the competitive ability of Kentucky bluegrass against ox-eye daisy.

When artificially shaded, ox-eye daisy biomass decreased linearly with decreasing light intensity. An 85% reduction in light intensity reduced ox-eye daisy rosette biomass by 70% and seedling biomass by 92%. When severely shaded, ox-eye daisy did not respond to fertilizer applications.

Increasing the competitive ability of a forage stand provides a cost effective means of suppressing ox-eye daisy in pastures or hay land.

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Chapter I

Introduction and Objectives

OX-EYE DAISY (*Chrysanthemum leucanthemum* L.)

Ox-eye daisy is a perennial weed in pastures and hay land across Canada and the northern United States. It is one of the more visible plants when it blooms in July with large, white and yellow flowers (Plate I-1).

Taxonomy. Ox-eye daisy belongs to the family Compositae.

Howarth and Williams (1958) reviewed the taxonomic information. Ox-eye daisy is described as a variable species, with five subspecies identified in central Europe and many variants named. Diploid and tetraploid races of ox-eye daisy may be regarded as two species, *Chrysanthemum leucanthemum* s. str. and *C. ircutiamum* Turcz. s. lat., respectively (Bocher and Larsen 1957). The tetraploid race has a slightly larger flower diameter and regularly toothed lower leaves while the diploid race has irregularly alternating lobes or teeth on the lower leaves. Mulligan (1958), in Canada, regarded the diploid race to be var. *pinnatifidum*, 2n = 18, and the tetraploid race to be var. *leucanthemum*, 2n = 36. Kumar (1982) also distinguished between the two distinct groups of C. leucanthemum by flower size. He was of the view that tetraploidy might have arisen through the diploidization of autopolyploids rather than by a process of hybridization and subsequent doubling of chromosomes of the hybrid. Bocher and Larsen (1957) determined that the diploids are found more in north-western Europe while the tetraploids prevail in north-eastern Europe and in the mountains in the south. Both races occur intermixed in central Europe. Both races are found in Quebec, Canada (personal communication, P. Moressit, Universite Laval, Laval, Quebec) but it is uncertain whether the tetraploid race is found in western Canada.

There are hexaploid and octaploid races that occur in Europe as well, also considered to be separate species. *C. montanum* All. is hexaploid and *C. heterophyllum* (Willd.) Fav. is octaploid (Favarger 1959).

Also as an indication of the variability of the *C. leucanthemum* species, distinct maritime and high mountain ecotypes are found in Europe (Salisbury 1961). Bogle (1983) found a *C. leucanthemum* plant in England with inheritable discoid heads without ray florets.

Luther Burbank in Santa Rosa, California, developed the ornamental flower, Shasta daisy, between 1884 and 1925 from ox-eye daisy through selection and crossing (Hornback 1982). He crossed *C. leucanthemum* with *C. maximum* from Europe, *C. lacustre* from Germany, and *C. nipponicum* from Japan to develop at least 33 cultivars of Shasta daisy. Most references list Shasta daisy as *C. maximum* although it has been listed as C. x *superbum*, which acknowledges its status as a hybrid species. This ornamental species has a tendency to sterility so that the original Shasta daisies were propagated by root division. This has changed more recently so that colonies of at least one cultivar have re-seeded themselves along highway U.S. 101 in northern California as part of a beautification project. The development of the Shasta daisy has complicated ox-eye daisy weed control efforts in Alberta. Under the Alberta Weed Control Act, ox-eye daisy is listed as a noxious weed and it is difficult to differentiate between the two species.

Growth and Reproduction. Howarth and Williams (1968) describe ox-eye daisy as a shallow-rooted perennial herb that spreads by rhizomes and seeds. It has a short, curved main root with many adventitious roots (Plate I-2). There is limited rooting of more prostrate basal stems or rhizomes. There are usually one or two erect, simple or slightly branched flowering stems per plant. The stems are usually 30 to 80 cm in height but sometimes reach 200 cm in height. The basal leaves are stalked, spatulate to round, dentate (10 to 25 cm long and 3 to 7 cm wide); stem leaves are smaller, mostly sessile, narrow lanceolate or ligulate with coarse teeth and often lobed at the base. The leaves are sparsely pubescent and three-nerved. The whole ox-eye daisy plant is glabrous to sparsely pubescent. The flower heads are usually solitary on long terminal peduncles and are 2.5 to 7.5 cm in diameter. White ray florets are 1 to 2 cm long, ligulate and 3-toothed; yellow disk florets are 4 mm long and tubular. The flower heads are mainly heterogamous with female ray florets and hermaphrodite disk florets. The seeds are achenes lacking a pappus, obovoid to cylindrical, 2-3 mm long and 0.8-1 mm wide for both disk and ray florets. The seeds are gray-silvery with 5 to 10 equal raised ribs (Plate I-2).

When crushed, all parts of the ox-eye daisy plant have a disagreeable sour odor (Alex and Switzer 1974). Cattle and pigs avoid eating ox-eye daisy because of its bitter smell and taste (Howarth and Williams 1968).

In western Canada, in the first year of growth from seed the plant forms a vegetative rosette (Plate I-2); in subsequent years flowers are produced.

Ox-eye daisy reproduces by seed and limited rooting of prostrate stems above and below the soil surface. Extended spread is by seed from second and subsequent year flowering plants. The seedling root system starts to be replaced by a well developed system of relatively shallow lateral roots at about the 6-leaf stage of ox-eye daisy (Howarth and Williams 1968).

Ox-eye daisy is an obligate long-day plant (Spectar 1956) with bolting and flowering occurring from June to August. It is not uncommon to see white pastures and hay land in July in west-central Alberta. Seeds are shed in August to September when the inflorescences are desiccating and dying.

Chiefly insect-pollinated, the disk florets have a male stage when pollen is produced prior to the female stage, thus promoting outbreeding (Howarth and Williams 1968). Stigmas of disk and ray florets are receptive at about the same time.

Salisbury (1942) reported between 1 and 15 inflorescences per plant in meadows with 111 to 290 viable seeds formed per inflorescence. He estimated an average reproductive capacity of 2688 potential offspring per plant. Dorph-Petersen (1925) recorded 1300 to 4000 seeds per ox-eye daisy plant, with vigorous plants producing up to 26,000 seeds. One thousand seeds weighed between 0.16 and 0.38 g (Howarth and Williams 1968).

Ox-eye daisy seed is usually dispersed by wind but may be spread in dung. Up to 40% of the seed passing through cattle may be viable (Howarth and Williams 1968). Seeds can germinate as soon as they are shed as there does not appear to be a dormancy mechanism in the ox-eye daisy seed (Povilaitis 1956). Light was found to be very beneficial to germination. Povilaitis (1956) recorded that germination in darkness was generally low but was much higher at 20°C than at 30°C. A "prolonged" stratification (moist seeds at 1 to 7°C) reduced the sensitivity to light and the seeds were able to germinate "to a reasonable extent" in the dark. The majority of the seed germinates in the spring, although it can germinate throughout the growing season. The seeds produced by the disk florets and the ray florets are similar in size, weight and germination. Ox-eye daisy seed can also remain viable for an extended period of time if conditions are not conducive for germination. Toole and Brown (1946) obtained 82% viability after 6 years and 1% viability after 39 years.

Distribution and Habitat. Ox-eye daisy is a relatively new weed problem in Alberta, becoming more widespread and of more concern in the last 10 years. Frankton and Mulligan (1987) reported it as being "rare in most of Alberta" in 1987. It is now fairly common in the western, west-central and north-eastern areas of Alberta. There is some ox-eye daisy located in the Peace region of Alberta (Darwent, personal communication). It is common in British Columbia as well as Ontario, Quebec and the maritime provinces (personal observation). Ox-eye daisy is widely distributed throughout the United States, especially in the north-eastern states and along the northern states down to California (Muenscher 1955).

Native to Europe, ox-eye daisy is distributed throughout Europe in northern Scandinavia and Lapland to latitude 70°N, south to northern Italy and across the European continent through Russia and Asia (Howarth and Williams 1968). From Europe it has spread with agricultural practices to other parts of the world, including Canada, United States, New Zealand and Australia.

Ox-eye daisy occurs mainly on roadsides, native grasslands, rangeland, pastures, hay fields, abandoned croplands, railway embankments and waste ground. It is not commonly found on cultivated land.

Since ox-eye daisy is found distributed over a wide latitude and a wide range of elevations in Eurasia, it is unlikely to be limited by climate variation in Alberta.

Ox-eye daisy can grow over a wide range of edaphic and environmental conditions. It prefers moist conditions and the rhizomes are able to lift the rosette to the soil surface under very wet conditions, with the adventitious roots stabilizing the plant. Ox-eye daisy is also drought-tolerant. The deeper-rooted dandelion (*Taraxacum officinale* Weber) has been observed to wilt before ox-eye daisy (Howarth and Williams 1968). It is not limited by soil factors as Howarth and Williams (1968) noted that ox-eye daisy was widespread on nutrient-rich clays and in limestone grasslands. In Europe, it is reported to be more common on basic and neutral soils and less common on acid soils. Ferdinandsen (1918) rated it as a basophile growing best at pH 6.5 to 7.0. In western Alberta, ox-eye daisy grows well in pasture land with a pH of 5.9 to 6.1 (Chapter II).

Fertility level is reported to have only a slight effect on ox-eye daisy from sand culture experiments conducted in England (Howarth and Williams 1968). Schipstra (1957) associated brown, drying ox-eye daisy leaf margins with potassium deficiency.

Ox-eye daisy presence and abundance seems to be "closely associated with the intensity of cutting and grazing" in pastures and hay land in England according to Howarth and Williams (1968). "The species is not a striking feature of grasslands which are little grazed." This suggests that ox-eye daisy may establish more easily when neighboring plants are selectively grazed or there is disturbance of the existing forage stand. From data collected in Europe by Kydd (1964), ox-eye daisy was more prevalent on overgrazed pasture than on lightly grazed pasture or cut hay land, in two of three years. The plants resisted cutting, trampling and grazing. Norman (1957) reported that ox-eye daisy increased more with continuous season-long cattle grazing than with close rotational grazing by cattle or sheep, or continuous grazing by sheep in Europe. Olson et al. (1997) found that 5.5 to 9 days of intensive cattle grazing in July over two years, on introduced grass pasture in Montana, reduced densities of ox-eye daisy seedlings and rosettes. The ox-eye daisy mature stem density was not changed.

Aerial remote multispectral digital imagery can be used to detect, delineate and map ox-eye daisy infestations (Lass and Callihan 1997). When images are taken at the appropriate phenological stage (full bloom for ox-eye daisy), levels of precision and accuracy appear to be sufficient for management purposes.

THE PROBLEM

Ox-eye daisy is considered to be a weed in Europe (Howarth and Williams 1968), Australia (Lamp and Collet 1979), USA (Gilkey 1957; Muenscher 1955; Dorn 1984) and Canada (Alex and Switzer 1974; Looman and Best 1979). It is listed as a noxious weed in the Alberta Weed Control Act (Alberta Agriculture, Food and Rural Development 1991), providing local and provincial jurisdictions the authority to enforce control of the weed. Ox-eye daisy is also listed as a

Class 2 Primary Noxious Weed Seed in the Canada Seeds Act (Agriculture and Agri-Food Canada 1986). No ox-eye daisy seed is permitted in Canada Foundation, Registered or Certified seed of most crop categories.

Ox-eye daisy is considered to be a weed problem in pastures and hay land as cattle avoid eating it because of its bitter taste and smell (Howarth and Williams 1968). Cattle will graze the more desirable plant, such as grass, allowing the undisturbed ox-eye daisy to expand, go to seed and spread (Gilkey 1957).

Under high stocking density in an intensive grazing system, cattle will eat ox-eye daisy (Olson et al. 1997) as will sheep, goats and horses. The protein level of ox-eye daisy at the early flowering stage is only about 6%, which is equivalent to that of cereal straw. When eaten by dairy cattle, ox-eye daisy can impart a disagreeable taste to the milk (Johnston et al. 1975).

Ox-eye daisy seed can be present as an impurity in crop seed (Broad 1952) and can be difficult to remove from small-seeded grass crops such as timothy (Alberta Agriculture, Food and Rural Development 1983).

The moisture and disturbance along roadside ditches tend to provide an ideal habitat for ox-eye daisy. Roadside ditches also give ox-eye daisy an efficient means of rapid spread by seed with air and water movement (Howarth and Williams 1968). Because it can spread very quickly with its large production of light, readily dispersible seed and because it has a very showy flower, ox-eye daisy is a very obvious weed problem where it occurs. Ox-eye daisy may not be noticed the first year that it germinates in a new area, as only low-growing rosettes are produced without flowering stems (Howarth and Williams 1968). New seeded pasture or hay land and less well managed pasture can be "white" the year after ox-eye daisy establishes.

Many pastures and hay lands in western Alberta are not managed for intensive production and many of them have never been fertilized (J. Lickacz, personal communication). As less value is assigned to pasture and hay land as compared to cultivated crop land, fertilizer, reduced grazing, timely grazing and other good management practices are often not used on this land.

CONTROL OF OX-EYE DAISY

A number of methods and combinations of methods have been used to control or suppress ox-eye daisy with variable success. A safe, economical and proven recommendation for the control of ox-eye daisy in pasture or hay land, while maintaining the forage stand, has not yet been determined.

Herbicides. Ox-eye daisy is a difficult plant to control with herbicides. It is fully resistant to 2,4-DB and MCPB and moderately resistant to 2,4-D, MCPA and mecoprop (Howarth and Williams 1968). According to Howarth and Williams (1968), ox-eye daisy is susceptible to the very high rate of 5.6 kg ha^{-1} 2,4-D. Coiteux and Cartier (1957) reported that two applications of 2,4-D amine at 1.12

kg ha^{-1}, one in the spring and another one in the fall, were needed to "assure good control" of ox-eye daisy at L'Assomption, Quebec. Applications of 2,4-D amine 2.2 kg ha^{-1}, 2,4-DB 1.7 kg ha^{-1}, MCPA amine 2.2 kg ha^{-1}, and dicamba 2.2 kg ha^{-1} at the bud stage in June provided some suppression of ox-eye daisy three weeks after spraying at two locations in west-central Alberta (Maurice and Cole 1987). However, new, healthy stems emerged from the base of the plants by eight weeks after spraying. Metsulfuron at 21 g ha^{-1} reduced the number of ox-eye daisy stems by 83% eleven weeks after spraying at the bud stage. Picloram at 0.84 kg ha^{-1} killed all the ox-eye daisy for at least two years but it also removed all the broad-leaved plant component, including legumes, from the forage stand. Picloram is costly and available only to authorized pesticide applicators (Alberta Agriculture, Food and Rural Development 1997). Picloram must be used with a great deal of care and understanding as it can persist in the soil for up to five years and prevent the establishment of sensitive crops, as well as being soluble and mobile in water. This herbicide can be used to spot-spray and prevent the spread of new infestations.

More recent observations (Cole et al. 1994) indicate that herbicide application timing is critical to the success of ox-eye daisy control. Early spring application of 2,4-D ester at 1.68 kg ha^{-1} resulted in 92% less ox-eye daisy biomass than on the untreated control three months after application in west-central Alberta. Metsulfuron at 18 g ha^{-1} completely controlled ox-eye daisy in the year of application when sprayed in May when the ox-eye daisy was 3 cm in height. Later spraying, once the ox-eye daisy had produced a flowering stem, resulted in regrowth from the base of the plant in July and August.

Unfortunately, the herbicides that control ox-eye daisy also remove or suppress any legumes growing in the pasture or hay land. Not only is a valuable component of the forage stand removed but there is less competition for the ox-eye daisy. In a field experiment in east-central Alberta (personal observation, not yet reported) the removal of the legume component of the forage with metsulfuron resulted in significantly more ox-eye daisy plants the year after spraying than in the untreated check.

Cultivation. Cultivation will control ox-eye daisy. Muenscher (1955) recommended a short rotation including a cultivated crop at least once every three years to control this weed.

Mowing. Muenscher (1955) recommended mowing infested meadows early, as soon as the first flowers appear, mainly to prevent the further production and spread of seed. However, Howarth and Williams (1968) report that ox-eye daisy abundance appears to be related to the cutting or grazing intensity and that ox-eye daisy was not affected by cutting.

Grazing. Howarth and Williams (1968), Kydd (1964) and Norman (1957) provided information that ox-eye daisy increased with increased season-long grazing. Olson (1997) recently supplied information that two years of short-duration (5.5 to 9 days) per season of intensive grazing reduced ox-eye daisy seedling and rosette densities.

Biological Control. Effective biological control by insects or pathogens has not been developed for ox-eye daisy. An insect biological control agent will most likely not be pursued as ox-eye daisy is closely related to the ornamental Shasta daisy.

Fertilizer. High fertilization of grass lands resulted in a slight decrease in ox-eye daisy biomass (Howarth and Williams 1968). The authors also reported that ox-eye daisy had a moderate requirement for nitrogen.

Competition. Howarth and Williams' (1968) observation that ox-eye daisy "is not a striking feature of grasslands which are little grazed" indicates that competition may be an effective means of managing this weed. More locally, the observation that ox-eye daisy tends to be more prevalent in less well managed pastures and hay lands while not present in adjoining better managed pastures and hay lands (personal observation), suggests that research on competition is a good avenue to pursue in attempting to find a solution to the ox-eye daisy problem.

Use of competition also provides a more "environmentally friendly" approach to the control of ox-eye daisy. There is increased public concern with the use of herbicides and herbicides may not be applied close to water (Alberta Environmental Protection). Enhancing plant competition can provide a long term solution to the problem and, at the same time, increase the productivity of the land base.

COMPETITION

Competition can be defined as "an interaction between individuals brought about by a shared requirement for a resource in limited supply and leading to a reduction in the survivorship, growth, and /or reproduction of the individuals concerned" (Begon et al. 1986). Or it can simply be defined as "a reciprocal negative interaction between two organisms" (Connell 1990). There is no universally accepted definition of competition. It tends to be a very broad term with different perceptions, connotations, backgrounds and underlying principles. There are operational definitions (i.e., measuring competitive effect) and more philosophical or conceptual definitions. In fact, Harper (1977) preferred not to use the term "competition" as he felt it was too vague and used terms like "density stress", "interference" and "proximity of neighbors". Silvertown (1982) also suggested that "interference" might be a better term than "competition".

There seem to be two main schools of thought on how competition should be defined operationally (Grace and Tilman 1990). Grime (1979) defined competition as "the tendency of neighbouring plants to utilize the same quantum of light, ion of a mineral nutrient, molecule of water, or volume of space". Begon et al. (1986) used a similar definition. These definitions refer to the mechanism of resource capture and a more competitive plant is able to capture more of the resources. It can be determined by comparing the biomass of the target species in the absence of some or all of its neighbors to the biomass attained in the presence of all of its neighbors (Grace and Tilman 1990). The increase in biomass attained after the removal of competitors is the competitive effect of those plants on that species.

The second main school of thought in defining competition uses intensity of competition per unit biomass. This is a little more involved as "the total competitive effect of all neighbors is divided by the amount of biomass removed to obtain a measure of the intensity or strength of competition" (Grace and Tilman 1990). This measure can be used to determine competition both within and among plant communities. This type of quantitative measurement provides the relative yields used to analyze replacement series experiments. Tilman's (1982) resource-based theory of competition predicts the species with lowest minimum resource requirement to be the superior competitor at equilibrium.

It is important to understand that there are many biological factors involved in the performance of a plant in a mixture. The growth stage (e.g., seedling vs. established), time (short vs. long term), age, size, growth rate, canopy architecture, reproductive strategy, type of neighbor, type of competition (interspecific vs. intraspecific) all determine the end result of competition. According to Firbank and Watkinson (1990), survivorship is the ultimate determiner of competitive ability.

There tend to be two types of simple relationships between plant yield and population density (Silvertown 1982). An asymptotic relationship is common where yield is measured in terms of whole plant weight or some vegetative part of the plant, such as the tubers of a potato plant. A parabola-shaped relationship is often observed in crops grown for grain or seed such as wheat. This occurs as fewer seed capsules per plant or fewer seeds per capsule are produced at higher densities.

Plants in mixtures, unless there is some sort of niche separation, are usually competing for light, moisture, nutrients or physical space (Silvertown 1982 and Grime 1979). Nutrient levels are the easiest to adjust in non-irrigated hay and pasture land with the use of surface applied fertilizer. The crop may gain the competitive advantage over a weed if it has better access to the fertilizer (e.g., roots closer to the fertilizer) or if the crop responds more to the fertilizer than the weed.

There are many examples in the literature of management practices employing the principles of competition to suppress or control weeds, usually by enhancing the crop. Groves and Williams (1975) found that when subterranean clover (*Trifolium subterraneum*) was sown as the main component of a pasture, a 60% reduction in abundance of skeletonweed (*Chondrilla juncea*) could be achieved in four years. There was no effect of the skeletonweed on the clover.

When a hay field in the Netherlands received NPK-fertilization every year for 30 years, the number of plant species dropped from 38 species to 9 species while an unfertilized plot area in the same field only decreased from 36 to 28 species in the same time period (Van den Bergh 1979; Elberse et al. 1983).

Berendse and Elberse (1990) reported that the woody evergreen, *Erica tetralix*, could maintain itself as the dominant species in a stand with the perennial grass, *Molinia caerulea*, in wet heathlands in the Netherlands under unfertilized conditions. When there was an increase in nitrogen and phosphorus, the *Molinia* replaced *Erica* as the dominant species. The authors explained this as the *Erica* being more successful in nutrient-poor environments because "it is more economical of the nutrients that it has acquired". However, the relative nitrogen requirement of *Molinia* is about three times as high as that of *Erica* (Berendse and Elberse 1990) and *Molinia* is able to respond much more rapidly than *Erica* to an increase in the nutrient availability "by investing more carbohydrates and nutrients in photosynthetic tissues". This larger photosynthetic ability allows the *Molinia* to rapidly convert increased nutrient uptake into higher biomass production.

Competition principles should be kept in mind when managing pastures and hay land. Increased production of the more desirable plant species and a decrease of the less desirable plant species can sometimes be obtained by altering their relative competitive ability. Understanding the biology of the plants and how they respond to competition can aid in taking advantage of differences in response.

RESEARCH OBJECTIVES

The overall objectives of this research were to determine the relative competitive ability of ox-eye daisy with grass species and to identify methods of ox-eye daisy control in pastures and hay land. This included:

- reviewing the information available on ox-eye daisy and basic applicable competition principles (Chapter I),
- determining the effect of surface-applied fertilizer on ox-eye daisy growth in forage stands and investigating factors involved (Chapter II),
- determining the effect of grass competition on ox-eye daisy emergence and growth and examining the competitive interactions. Varying grass seeding rate and row spacing was investigated as a means of altering the relative competitive ability of the grass (Chapter III), and
- developing control recommendations (Chapter IV).

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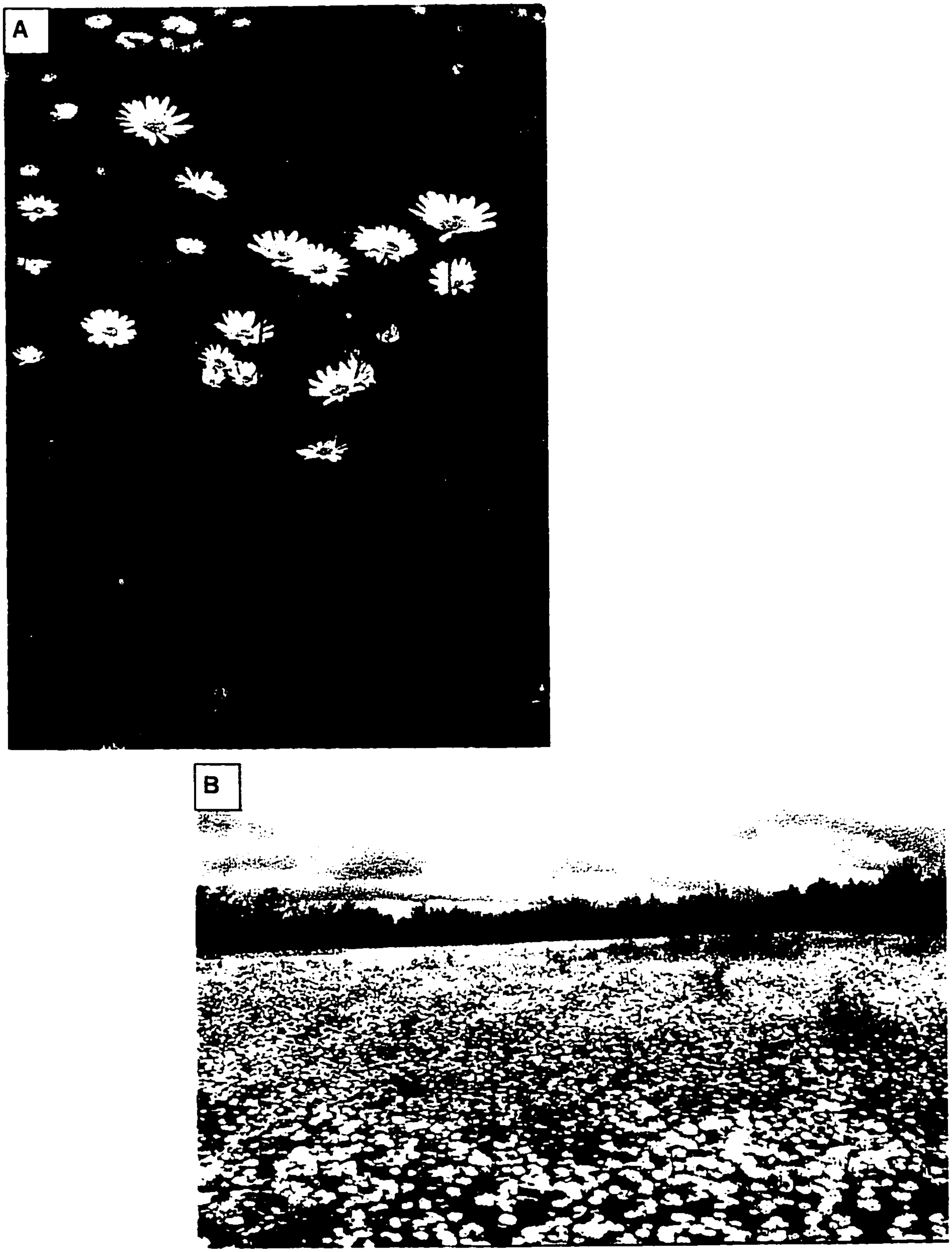

Plate I-1: Ox-eye daisy (A) flowering plant, (B) pasture infestation near Vilna, Alberta.

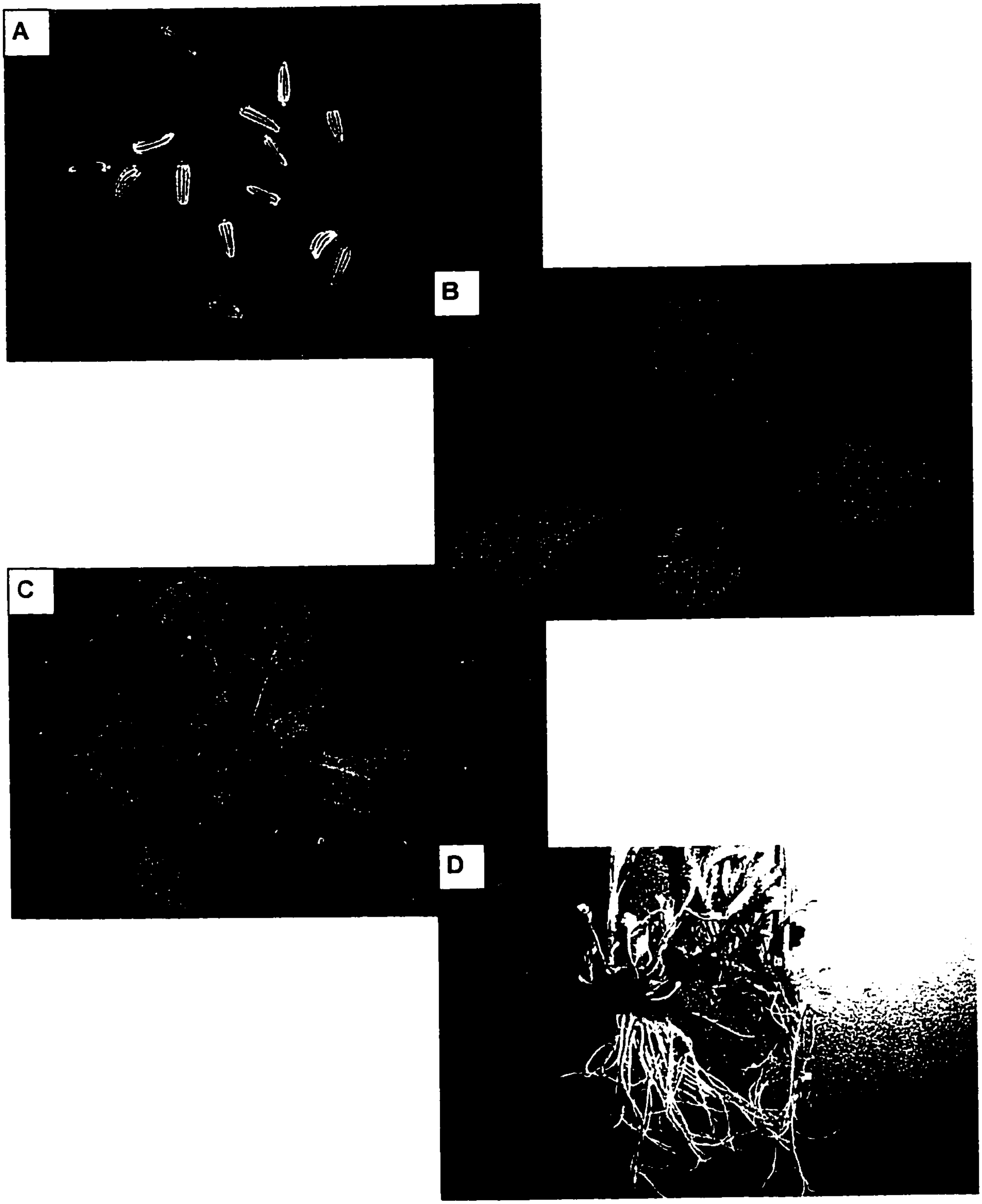

Plate I-2: Ox-eye daisy (A) seed, (B) seedling, (C) rosette and (D) roots and basal stems.

Chapter II

Effect of Surface-Applied Fertilizer on Ox-eye Daisy (*Chrysanthemum leucanthemum* L.) Growth in Forage Stands

INTRODUCTION

Ox-eye daisy is a perennial weed of pastures and hay land in British Columbia, Alberta, Ontario, Quebec, the Maritime provinces and the northern United States (personal communication - Cranston, Alex and Moressit). It is also commonly found along roadsides, railway embankments and on waste ground in the areas of infestation (Howarth and Williams 1968). Cattle avoid eating ox-eye daisy because of its bitter taste and smell (Howarth and Williams 1968) and it has been reported that ox-eye daisy imparts a disagreeable taste to milk (Johnston et al. 1975). This non-native species, introduced to North America from Europe, is difficult and costly to control with herbicides (Howarth and Williams 1968).

Fertilizer has been used to enhance crop competition and reduce weed growth. Bebawi (1988) obtained a five-fold reduction in witchweed (*Striga hermonthica*) when applied nitrogen (N) increased forage sorghum (*Sorghum bicolor*) tiller density approximately two-fold and greenfeed yield approximately ten-fold. These results were corroborated in another study in which N applications resulted in a 93% reduction in the incidence of witchweed in maize (*Zea mays*) (Farina et al. 1985). Gray and Call (1993) used mowing and fertilizer to reduce survival of Indian mockstrawberry (*Duchesnea indica*) in a tall fescue (*Festuca arundinacea*) lawn. Blue violets (*Viola papilionacea*) in the tall fescue lawn did not respond to fertilization but were virtually eliminated by mowing at biweekly intervals. Williams (1984) found that infrequent cutting, especially with fertilizer, discouraged *Cerastium fontamum* ssp. *glabrescens* and *Trifolium repens* but encouraged *Rumex acetosa* in permanent grassland. Very high rates of N, 224 and 448 kg ha^{-1}, caused a marked decline in Canada thistle (*Cirsium arvense*) populations in forage stands (Thrasher et al. 1963) while the use of N- or phosphorus(P)-based fertilizers did not suppress the growth of fireweed (*Senecio madagascariensis*) in Australian pastures (Sindel and Michael 1992).

Ox-eye daisy is reported to show a moderate requirement for N (Ellenberg 1950). Howarth and Williams (1968) stated in their "Biological Flora of the British Isles" series on *C. leucanthemum* that high fertilization of grasslands resulted in a slight decrease in ox-eye daisy biomass. They supported this statement with results from a sand culture experiment in which ox-eye daisy grown in 250 ppm N had significantly less dry weight yield than ox-eye daisy grown in 100 ppm N. There was no significant difference in yield between the 100 ppm N and 50 ppm N treatments.

Additions of nitrogen fertilizer may enhance the competitive ability of the crop by the taller, greater leaf area of a crop shading the weed. It is difficult to separate out competition for light from competition for nutrients, water and physical space because of the dynamic complex interactions that are occurring when two plants are growing close together, but several studies have shown light to play an important role in plant competition. Bello et al. (1995) demonstrated that 76% shade suppressed velvetleaf (*Abutilon theophrasti*) growth while 30% did not. Using a shade cloth with 9% light transmittance reduced velvetleaf, green foxtail (*Setaria viridis*) and common lambsquarters (*Chenopodium album*) establishment while a hairy vetch residue, used as a mulch in corn (*Zea mays*), reduced common lambsquarters establishment (Teasdale 1993). Common cocklebur (*Xanthium strumarium*) shoot interference and competition for light within a soybean (*Glycine max*) canopy reduced soybean yield (Regnier et al. 1989). McLachlan et al. (1993) found that the rate of leaf appearance of redroot pigweed was affected substantially by corn canopy-induced shading. Spotted knapweed (*Centaurea maculosa*) root and crown growth were adversely affected by increasing competition from bluebunch wheatgrass (*Pseudoroegneria spicata*) (Kennett et al. 1992). It was also shown that spotted knapweed foliage, root and crown growth were reduced when plants received half light as compared to full light. In another light study, Weaver and Tan (1987) found that weeds can compete with tomatoes for light when they grow taller than the tomato and cause a decrease in available photosynthetically active radiation. Cogongrass (*Imperata cylindrica*) produced three times as much dry weight and leaf area in full sunlight as in 56% of full sunlight, and 20 times as much in full sunlight as in 11% of full sunlight (Patterson 1980). Field bindweed (*Convolvulus arvensis*) leaf area decreased as light level decreased, but Russian knapweed (*Centaurea repens*) leaf area increased as light level decreased (Dall'Armellina and Zimdahl 1988).

Ox-eye daisy growth in the first year is a basal rosette, typically under 5 cm in height. This plant bolts in the second and subsequent years and produces narrow flowering stalks with reduced leaves. Such a plant structure is vulnerable to shading by taller vegetation.

If the crop has a higher level of response to increased fertility levels than the accompanying weed, the crop may increase the level of interference against the weed by inhibiting light availability.

The objectives were to determine the effect of surface-applied fertilizer on ox-eye daisy growth in forage stands and to investigate the factors involved in this effect.

MATERIALS AND METHODS

Fertilizer field experiment. The experiment was conducted on a fenced-off pasture site near Winfield, Alberta (52° 58' 30" N 114° 28' 00" W) from 1994 to

1996. The soil was a clay loam to loam (31% sand, 47 % silt and 22% clay) Orthic Gray Luvisol developed on a till parent material. Soil samples collected in October of 1993 indicated low levels of N, P and S and adequate level of K for plant growth. Analysis of the samples determined a pH of 5.9, 6% organic matter, 6.7 kg available N ha^{-1}, 6.7 kg available P ha^{-1}, 280 kg available K ha^{-1} and 3.6 kg available S ha^{-1}. There was no record of fertilizer being applied to the pasture in the previous 10 years.

At the time that the experiment was established, the sward consisted of heavily grazed timothy (*Pleum pratense*), Canada bluegrass (*Poa compressa*) and alsike clover (*Trifolium hybridum*). The pasture had been grazed annually by cattle for at least 10 years. Some dandelion (*Taraxacum officinale*) was also present. Ox-eye daisy was uniformly distributed throughout the pasture with an average of 100 shoots per square meter. Shoots were counted as it is difficult to differentiate between plants in heavy infestations of ox-eye daisy. In most pasture and hay land situations in western Alberta individual ox-eye daisy plants have from 1 to 4 shoots (most commonly 1) arising from the plant crown just below the soil surface (personal observation).

The experiment was conducted using a randomized complete block design with four replications. Each plot was 1.5 m by 7 m. Treatments consisted of (i) an untreated control, surface-applied (ii) N P K S, (iii) P K S, (iv) N K S, (v) N P S and (vi) N P K in a Jenny experimental design (Tisdale et al. 1985). The application rates used in all the treatments were 100 kg N ha^{-1} as ammonium nitrate (34% N), 45 kg P_2O_5 ha^{-1} as monocalcium phosphate (45% P_2O_5), 44 kg K_2O ha^{-1} as potassium chloride (60% K_2O) and 15 kg S ha^{-1} as ammonium sulphate (21% N and 24% S) and potassium sulphate (50% K_2O and 17% S). The fertilizer treatments were broadcast with a push type Hege 33 Fertilizer Distributor "System SKW" (Hege Equipment, Inc., Colwich, Kansas, USA) on the vegetation surface on May 24, 1994 and reapplied on the plots on May 10, 1995. The fertilizer treatments were not applied in 1996 but data were collected to determine the effect of two years of fertilizer application on the following year's production.

At the time of fertilizer application in 1994 the ox-eye daisy had 4 to 13 leaves at 1 to 6 cm in length with approximately 20% of the plants in the early bud stage. The timothy had three to four leaves and was 12 to 15 cm in height while the Canada bluegrass had three leaves and was 5 to 13 cm in height. The alsike clover had 2 to 18 trifoliate leaves and was 1 to 10 cm in height. On May 10, 1995, the ox-eye daisy had one to eight leaves that were 1 to 4 cm in length and did not have budding stems. The grass and legume components of the sward were at a correspondingly earlier growth stage.

Ox-eye daisy seedling, rosette and flowering stem counts were made in a 1-m^2 area on July 25, 1995 and July 31, 1996.

Photosynthetically active radiation (PAR) measurements were taken with a Model SF-80 PAR/Sunfleck ceptometer (Decagon Devices, Inc., Pullman, Washington, USA) in the fertilizer field experiment on July 31, 1996 to correlate with the greenhouse shade experiment results as discussed later in this chapter. The measurements were obtained on a clear day between 1100 and 1300 h Mountain Daylight Saving Time.

Two 0.25 m by 0.25 m areas were cut at approximately 5 cm in height and separated into ox-eye daisy stems, grass, legume and other broadleaved plants on August 10, 1994, August 16, 1995 and August 19, 1996. The samples were dried at 60°C until constant weight was achieved.

The entire experimental area was mowed at approximately 5 cm above the soil surface and the vegetation was removed immediately after plant samples were collected in August of each of the three years.

Fertilizer and herbicide field experiment. The experiment was conducted on heavily grazed pasture near Evansburg, Alberta (53° 34' 30" N 115° 03' 00" W) in 1995 and 1996. The soil was a clay loam to loam (23% sand, 28% silt and 49% clay) Orthic Gray Luvisol developed on a till parent material. Soil samples collected in May of 1995 indicated low levels of N, P and S and adequate level of K for plant growth. Analysis of the soil samples determined a pH of 6.1, 7.4% organic matter, 0 kg available N ha^{-1}, 6.7 kg available P ha^{-1}, 428 kg available K ha^{-1} and 7.4 kg available S ha^{-1}. There was no record of fertilizer being applied to the pasture in the previous 10 years.

The experimental site was fenced off from the rest of the pasture in May, 1995 and treated as a single-cut hay system for the duration of the experiment.

Besides a heavy and uniform distribution of ox-eye daisy (approximately 22 shoots/plants per square meter) and tall buttercup (*Ranunculus acris*) (approximately 73 plants per square meter), the sward consisted of timothy, Canada bluegrass, alsike clover and other broadleaved plants (mainly dandelion).

The experimental design was a split plot randomized complete block with four replications or blocks. The main factor was herbicide treatment with each plot being 2 m by 9 m. The herbicide treatments, (i) untreated control, (ii) 1.7 kg 2,4-D amine a.e. ha^{-1} and (ii) 1.7 kg 2,4-D ester a.e. ha^{-1} were applied on May 30, 1995. They were applied with a hand-held CO_2 sprayer (R & D Sprayers, Inc., Opelousas, Louisiana, USA) using 80015 XR (Spraying Systems Ltd., Calgary, Alberta, Canada) nozzles at 138 kPa delivering 100 L of spray solution ha^{-1}. The nozzles were 46 cm above the vegetation canopy height. At the time of spraying, the ox-eye daisy had 3 to 20 leaves (average of 6 leaves) and a height of 1 to 11 cm (average of 6 cm); less than 10% of the plants were in the early bud stage. The timothy had 3 to 4 leaves at a height of 10 to 19 cm, the Canada bluegrass had 2 to 3 leaves at a height of 10 to 19 cm, and the alsike clover had 3 to 5 trifoliate leaves at an average height of 3 cm. The herbicide treatments were applied only in 1995.

The split factor was surface-applied fertilizer, either (i) no fertilizer or (ii) fertilizer at 100 kg N ha^{-1} as ammonium nitrate (34% N) and P, K and S to soil test recommendation (45 kg P_2O_5 ha^{-1} as monocalcium phosphate (45% P_2O_5), 44 kg K_2O ha^{-1} and 15 kg S ha^{-1} as potassium sulphate (50% K_2O and 17% S)). The fertilizer treatment was applied to either the front or back half (a 2 m by 4.5 m subplot area) of each of the main plots. The fertilizer was applied by hand on the vegetation surface on May 30, 1995 (same day, plant stages and heights as the herbicide application) and reapplied on the same treatment areas on May 16, 1996. At the time of the second fertilizer application, the ox-eye daisy had 1 to 12 leaves and a height of 1 to 7 cm, with the grass and legume at a correspondingly earlier growth stage than at the 1995 application date.

Permanently marked 1-m^2 quadrats were placed in approximately the center of each subplot area and ox-eye daisy counts were taken on May 30, 1995 (same day as the herbicide application), July 26, 1995 and July 23, 1996. The ox-eye daisy rosettes and seedlings were counted together and not differentiated for the July 26, 1995 count. A 0.25 m by 0.25 m area was harvested from each of these quadrats at approximately 5 cm in height, to simulate hay mowing, on August 15, 1995 and August 22, 1996. The harvested samples were separated into ox-eye daisy, grass, legume and other broadleaved plants and dried at 60°C until constant weight was achieved.

The whole experimental area was mowed at approximately 5 cm above the soil surface and the vegetation was removed immediately after plant samples were collected in August of 1995 and 1996.

Shade greenhouse experiment. Ox-eye daisy was seeded into Metro-mix peat-perlite (W. R. Grace & Co. of Canada, Ajax, Ontario) in 25 cm x 50 cm trays on December 10, 1995 with a second seeding on January 14, 1996. On January 30, 1996 the 7-week old plants were transplanted, one ox-eye daisy rosette per 12.7 cm diameter pot (15 cm high), while the 2-week old plants were transplanted as two ox-eye daisy seedlings per 12.7 cm diameter pot on January 30, 1996. The pots were filled with a mix of 50% peat, 30% perlite and 20% soil, amended with 1.3 g of dolomite lime kg^{-1} soil mix, and were irrigated as required.

The experiment commenced on February 9, 1996 when the rosette ox-eye daisy plants were 7 to 12 cm in height, had 24 to 56 leaves and 5 to 10 stems. The seedling ox-eye daisy plants had 4 to 7 leaves and were 2 to 5 cm in height. The treatments consisted of (i) 0% light reduction, (ii) 52% light reduction, (iii) 85% light reduction and (iv) 94% light reduction. The varying light levels were obtained by suspending 65 cm x 76 cm wooden frames covered with three densities of woven black monofilament polypropylene shade cloth (DeWitt Co., Sikeston, Missouri) above the plants and below high pressure sodium light fixtures. The frames were wrapped with the shade cloth so that the bottom of the 46-cm high skirt reached to the bench surface (top of shade cloth 31 cm above the pots and suspended 79 cm below the lights). The 16-hr photoperiod of approximately 212 $\mu mol\ m^{-2}\ s^{-1}$ provided by the high pressure sodium lights was supplemented with natural light to provide a maximum measurement at solar noon on a clear day of approximately 1780 μmol m^{-2} sec^{-1}. The day/night temperatures were 21°C/18°C both outside and under the different shade cloths. Six ox-eye daisy rosette pots interspersed with six seedling pots were arranged under each shade treatment and light fixture so that there was no interference between the plants. All pots were rotated 45° and relocated systematically under each shade cloth on a weekly basis to minimize the effect of environmental variation within the greenhouse. Each pot also received 0.2 g of 20:20:20 (N:P:K, Plant Products Co. Ltd., Brampton, Ontario, Canada) dissolved in 100 ml of water once a week. Light measurements were taken with a LI-COR LI-188 Integrating Quantum/Radiometer/Photometer (LI-COR, Ltd, Lincoln, Nebraska, USA) on a weekly basis to determine light reduction caused by the different shade cloth treatments. An LI-1800 portable spectroradiometer (LI-COR, Ltd, Lincoln, Nebraska, USA) was used to measure light quality with and without shade cloth. These measurements indicated that the R:FR ratio was not affected by the shade cloth.

The experimental design was a randomized complete block design with four replications and six pots each of the two growth stages in each treatment replication. The plants were measured and harvested for dry weight 8 weeks after the shade treatments were applied. The leaves and roots were harvested separately and dried at 65°C until constant weight was achieved. An area meter model LI-300 (LI-COR, Ltd, Lincoln, Nebraska, USA) was used to take leaf area measurements.

Shade and fertilizer greenhouse experiment. Ox-eye daisy was seeded into Metro-mix in 12.7-cm diameter plastic pots on September 24, 1995 and, after germination, thinned to four plants per pot. The pots were irrigated when required and fertilized every 2 weeks with approximately 2.2 g of 20:20:20 (N:P:K, Plant Products Co. Ltd., Brampton, Ontario, Canada) per pot.

The treatments commenced on December 31, 1995 when the ox-eye daisy plants had an average of 50 leaves, 6 basal stems and an average canopy height of 13 cm.

The experiment was conducted as a split plot randomized complete block with three replications and two pots per split factor. The main factor was light reduction with (i) an untreated control (0% light reduction) and (ii) 94% light reduction. The low light level was obtained by shading the pots as described for the shade greenhouse experiment. The 16-h photoperiod of approximately 182 $\mu mol\ m^{-2} sec^{-1}$ provided by the high pressure sodium lights was supplemented with natural light up to approximately 290 $\mu mol\ m^{-2} sec^{-1}$ at solar noon of a clear day. PAR in the greenhouse was lower in January than in February and March in the shade greenhouse experiment. The day/night temperatures were 21°C/18°C both outside and under the shade cloth.

The split factor was fertilizer application with half the pots under each light treatment (i) no longer receiving fertilizer; and half (ii)receiving 2.2 g of 20:20:20 (N:P:K) dissolved in 200 ml of water at each of three different applications at 14-day intervals. Four pots with ox-eye daisy rosette plants, including two not receiving fertilizer and two receiving fertilizer, were arranged under each light. All pots were rotated 45° and rearranged systematically under the same light on a weekly basis to minimize the effect of environmental variation within the greenhouse. Light measurements were taken with a LI-COR LI-188 Integrating Quantum/Radiometer/Photometer every two weeks to determine light levels at canopy height for the shaded and unshaded treatments.

The ox-eye daisy plants were harvested for dry weight with leaf number and leaf area measurements taken five weeks after the shade and fertilizer treatments were applied. The leaves and roots were dried at 65°C until constant weight was achieved. An area meter model LI-300 (LI-COR, Ltd, Lincoln, Nebraska, USA) was used to obtain leaf area measurements.

RESULTS AND DISCUSSION

Fertilizer field experiment. Surface application of fertilizer in the spring for two years to ox-eye daisy infested fenced-off pasture significantly affected ox-eye daisy population size and harvested dry weight, and grass and legume dry weight in the second and third year of the experiment (Table II-1).

One spring fertilizer application did not significantly affect ox-eye daisy (Table II-1). Ox-eye daisy numbers were significantly reduced when fertilizer was applied in the spring for two years, in the various nutrient combinations (Figure II-1, Plate II-1). This suppression of ox-eye daisy was maintained into the third year. None of the different nutrient combinations significantly affected ox-eye daisy density more than any other, indicating that one nutrient was not necessarily contributing to the ox-eye daisy response more than the others.

The significant reduction in total ox-eye daisy density resulted from a decline in the number of plants in the flowering and rosette stages (Figure II-2).

Ox-eye daisy was not a large component of the total above ground biomass in any of the treatments as indicated in Figure II-3. When the plots were harvested in August of each of the three years, the ox-eye daisy had finished flowering and the plants were beginning to desiccate. Also, ox-eye daisy is a low growing plant with most of its mass as rosette leaves growing below the 5 cm harvest height. There was still a significant difference in ox-eye daisy biomass between treatments in year two and year three.

Most of the fertilizer treatments produced a significant increase in total forage production in each of the three years (Figure II-3). The fertilizer treatments containing N had significantly higher grass production than the unfertilized control treatment. The PKS fertilizer treatment had significantly more legume and less grass growth than the other fertilizer treatments in year 2 and year 3.

The excellent response in grass growth to the fertilizer application was anticipated from the low level of N found at the start of the experiment and the good growing conditions (Appendix II-A and B).

Increased forage production over two years was required to reduce the ox-eye daisy biomass. The first year of fertilizer application may have had more of an effect on rosette and seedling ox-eye daisy, which would have resulted in fewer flowering ox-eye daisy plants the following year.

The fertilizer treatments resulted in increased forage biomass and this in turn resulted in reduced ox-eye daisy biomass. The increased forage production would have provided a higher level of competition for ox-eye daisy.

Fertilizer and herbicide field experiment. Both 2,4-D and fertilizer application to fenced-off pasture had a significant effect on ox-eye daisy density and forage yield in year 1 (Table II-2 and Plate II-1). There was no significant interaction between the herbicide and fertilizer treatments in year 1.

In year 1, fertilizer reduced the ox-eye daisy density to about half the number found in the unfertilized plots, over all three herbicide treatments (Figure II-4). This effect was mainly on the rosette and seedling ox-eye daisy and not on the number of flowering stems.

The herbicide 2,4-D ester, over both fertilized and unfertilized treatments, also reduced total ox-eye daisy numbers to about half of the unsprayed check in the year of application. In this case, however, the 2,4-D ester reduced the number of flowering stems from 20 to 1 flowering stem m^{-2} and did not affect the combined rosette and seedling number.

The 2,4-D amine treatment suppressed flowering of ox-eye daisy from 20 flowering stems to 4 flowering stems m^{-2} but did not reduce the total number of ox-eye daisy (Figure II-4). There was a significant increase in the number of rosette and seedling ox-eye daisy (from 28 m^{-2} in the unsprayed check to 49 m^{-2} in the 2,4-D amine treatment). This increase was most likely due to suppression of the legume growth in the sward from the 2,4-D amine application and the resulting reduced competition.

In year 2, herbicide and especially fertilizer had a significant effect on ox-eye daisy density and forage yield (Table II-2). There was also a significant herbicide by fertilizer interaction for ox-eye daisy rosette and flowering stem number. The interaction effects were assessed with the data provided in Figure II-5. The 2,4-D treatments resulted in a significant increase in the number of ox-eye daisy plants the year after application where fertilizer was not applied but there was not this increase where fertilizer was applied.

The fertilizer treatments provided a significant reduction in total ox-eye daisy density compared to the non-fertilized treatments (Figure II-5). In fact, the addition of fertilizer mostly counters the large increase in ox-eye daisy following the application of 2,4-D amine and 2,4-D ester in the previous year. This is most likely due to the increased grass growth that more than compensates in competitive ability for the suppressed legume growth. The application of 2,4-D ester without fertilizer resulted in 125 flowering, rosette and seedling ox-eye daisy m^{-2} while the addition of fertilizer with 2,4-D ester resulted in a total of only 18 ox-eye daisy m^{-2}. These results can be compared to the untreated control plots that received no herbicide or fertilizer and had 49 ox-eye daisy m^{-2} and the fertilizer alone plots with 8 ox-eye daisy m^{-2}.

The large increase in total number of ox-eye daisy in year 2 in the unfertilized and sprayed treatments, as compared to the unsprayed treatments, is largely accounted for by the increase in flowering ox-eye daisy (Figure II-5). There were on average 79 and 81 flowering stems m^{-2} in the 2,4-D amine and 2,4-D ester treatments, respectively, treatments without fertilizer application. Without herbicide or fertilizer, there was an average of 30 flowering stems. A significant increase in the number of ox-eye daisy rosettes in year 2 also accounts for some of the total increase in the 2,4-D amine and ester treatments without fertilizer. Seedling numbers did not differ between treatments.

Fertilizer, applied alone or in combination with herbicide, reduced the number of flowering, rosette and seedling ox-eye daisy plants in year 2 (Figure II-5).

Fertilizer, averaged over all herbicide treatments, significantly increased mean grass production from 30 to 222 g m^{-2} in year 1 (1995) and from 196 to

576 g m^{-2} in year 2 (1996) (Figure II-6). The legume growth, averaged over all herbicide treatments, was not affected significantly by the fertilizer treatment in either year. The other vegetation, mostly tall buttercup and dandelion, increased in yield with fertilizer application in year 1 but decreased in yield as compared to the unfertilized plots in year 2.

The 2,4-D treatments, and especially the 2,4-D ester, suppressed a large proportion of the legume and ox-eye daisy growth, with the grass component replacing the legume and ox-eye daisy in these plots. Figure II-6 also indicates a significant grass yield increase in year 1 and in year 2 in the herbicide-treated plots. This may be due to the low levels of nitrogen in the soil and the increased availability to the grass when the legumes were suppressed by the herbicide.

The addition of fertilizer to the herbicide treated plots substantially increased the grass growth and reduced the ox-eye daisy growth in the second year.

Fertilizer alone at 100 kg N ha^{-1}, and P, K and S to soil test recommendation, applied to the soil surface in the spring for two years, significantly reduced ox-eye daisy growth. The herbicide 2,4-D amine did not completely control ox-eye daisy but rather allowed increased growth the year after spraying by suppressing most of the legume competition for the daisy. Although 2,4-D ester caused some initial suppression of ox-eye daisy, fertilizer was needed to increase the grass growth and to compensate for the loss of competition from the legume.

A combination of 2,4-D ester and surface-applied fertilizer applied in the spring before the ox-eye daisy bolts, may be a option for the control of ox-eye daisy in grass hay land. Fertilizer alone applied for two years is a better alternative for grass-legume forage stands.

Shade greenhouse experiment. In the greenhouse, reducing the light level by 96% using shade cloth for 8 weeks, reduced the growth and dry weight yield of ox-eye daisy (Tables II-3 and II-4). Most of the ox-eye daisy seedlings died under this reduced light regime.

Rosette and seedling ox-eye daisy total plant dry weight decreased linearly with decreasing light intensity (Figure II-7). Linear correlation coefficients were 0.91 for rosettes and 0.94 for seedlings. There was a reduction in leaf and root dry weight as light decreased from full light to 52% to 85% light reduction with the first two shade treatments (Table II-3). However, the weight of the roots declined more rapidly than the leaf weights (Figure II-8 and II-9). Zimdahl et al (1991) made this same observation on the more rapid decline of root weight when they measured of the effect of reduced light intensity on Canada thistle. The ox-eye daisy root weight declined by about 50% with only a 45% reduction in light for the rosettes and a 35% reduction in light for the seedlings. This compares to requiring approximately a 70%

reduction in light for the rosettes and a 55% reduction in light for the seedlings to result in a 50% reduction in dry weight of the leaves. In fact, the root weight declined more rapidly with reduced levels of light than any other plant growth measurement made, suggesting that ox-eye daisy uses its root reserves to try and maintain plant production and growth. Thus root reserves are allocated to top growth under reduced light. Another possibility is that the roots did not grow under low light conditions.

Ox-eye daisy height, leaf number, leaf area, specific leaf area, and apical meristem number also generally declined with decreasing light levels.

There was a direct relationship between the number of apical meristems and the number of leaves on a plant. The number of apical meristems and the number of leaves did not respond to reduced light as quickly as leaf and root dry weight (Figure II-10 and II-11). It required approximately an 85% reduction in light to reduce the number of apical meristems and leaves on an ox-eye daisy rosette plant to 50% and approximately a 75% reduction in light to result in a 50% reduction in these plant growth parameters in seedling plants.

The ox-eye daisy rosettes were not reduced to 50% of their full canopy height, as measured from the soil surface, until the light level was reduced by approximately 95% and the seedlings were not reduced in height to 50% until the light level was reduced by approximately 85% (Figure II-12).

An 85% reduction in light for rosettes and a 75% reduction in light for seedlings was required to reduce leaf area by 50%. At these low light intensity levels, there is most likely not enough photosynthate being produced to maintain leaf area.

The specific leaf area increased with reduced light even up to 94% light reduction (Figure II-14). This increase has been observed in other plant species (Bjorkman et al. 1972; Jurik et al. 1982).

When PAR measurements were taken in the fertilizer field experiment near Winfield, readings of 89 μmol m^{-2} s^{-1} were obtained within the timothy - alsike clover stand of the NPKS treatment at ox-eye daisy rosette average height (approximately 7 cm above the soil surface). This measurement was 94% less than the average PAR readings of 1560 μmol m^{-2} s^{-1} obtained just above the forage canopy height. This was a similar level of light reduction to that obtained in the greenhouse study.

The decrease in ox-eye daisy plant growth with decreasing light levels in the greenhouse correlates with reduced growth in the field when the plants were severely shaded by the forage. This increased competition for light may account for some of the reduction in ox-eye daisy growth when fertilizer is applied to a forage stand.

Shade and fertilizer greenhouse experiment. Both reduced light and the addition of fertilizer had a significant effect on a range of ox-eye daisy growth parameters (Table II-5). The shade by fertilizer interaction was significant for most of the parameters measured. Although there was no significant interaction between shade and fertilizer effects on ox-eye daisy harvested petiole dry weight, or total dry weight, the shade alone had a significant effect on both of these parameters.

Shading established ox-eye daisy plants to 6% of available light in the greenhouse for 5 weeks, both with and without fertilizer, caused a significant reduction in a number of plant growth parameters including the number of apical meristems, leaf number, leaf area, leaf dry weight and root dry weight (Table II-6 and Plate II-2). The application of fertilizer to the ox-eye daisy, however, resulted in a different response depending on whether the plants were shaded or not . Under full light, ox-eye daisy responded with increased apical meristem number, leaf number, leaf area, specific leaf area and leaf dry weight to the fertilizer application (Plate II-2). Under a reduced light regime, the number of apical meristems, leaf number, leaf area, leaf dry weight and root dry weight did not increase with the addition of fertilizer (Plate II-2).

Ox-eye daisy root dry weight decreased with fertilizer application under full light conditions, while leaf dry weight increased (Table II-6). This resulted in lower total dry weight of the plant. In the absence of fertilizer, the ox-eye daisy grew more roots under full light conditions.

Ox-eye daisy average height and specific leaf area increased under both unfertilized and fertilized shade treatments (Table II-6). An increase in height at reduced light levels has been previously documented (Corre 1983; Smith 1986; Cannell and Grace 1993). An increase in specific leaf area with reduced light has also been reported for several other plant species (McGiffen et al. 1992; Bunce et al. 1977; Bjorkman and Holmgren 1963; Jurik et al. 1982) and is suggested as a response to enable the plant to intercept more light per unit leaf tissue (Regnier and Harrison 1993; Bjorkman 1981).

Providing fertilizer to shaded ox-eye daisy resulted in a significant reduction in average plant height and specific leaf area compared to unfertilized and shaded ox-eye daisy (Table II-6). This is just the opposite response to providing fertilizer to ox-eye daisy plants growing in full light.

Continuing the use of fertilizer under the full light regime significantly increased the apical meristem number, leaf number, leaf area, specific leaf area, and leaf dry weight after 37 days as compared to the ox-eye daisy no longer receiving fertilizer (Table II-6). However, under reduced light conditions, the ox-eye daisy was not able to take advantage of the fertilizer.

CONCLUSION

Fertilizer applied in the spring for two years can suppress ox-eye daisy growth in a hay stand.

Fertilizer application may need to be maintained in subsequent years to prevent ox-eye daisy re-establishment from seed. This may be particularly important in years when moisture levels are high as increased moisture may increase ox-eye daisy germination and growth. At the same time, there tends to be a larger response by forage to fertilizer application.

The use of a herbicide to control or suppress ox-eye daisy in a grass-legume hay stand may not be as successful as the use of fertilizer. The herbicides 2,4-D amine and 2,4-D ester tend to remove the legume component of a mixed forage stand and thus open the canopy. With more light reaching lower levels in the canopy, ox-eye daisy has more opportunity to establish and and grow in the stand.

When herbicides for ox-eye daisy control are applied in a mixed forage stand, fertilizer applications may assist the stand in compensating for the reduction in legume growth that may occur. In grass stands, herbicide and fertilizer treatments should complement each other.

Fertilizer application can provide a competitive advantage to the forage. The fertilizer enhances the forage growth to reduce the amount of light reaching the ox-eye daisy located lower in the canopy. In this manner the forage can out-compete the ox-eye daisy. Ox-eye daisy seedlings are affected more by light reduction than ox-eye daisy rosettes as most of the seedlings died when subjected to 94% light reduction.

Results from the greenhouse study indicate that the ox-eye daisy root dry weight is more affected by reduced light intensity than the rest of the plant as an allocation strategy of the plant.

Light levels measured at the base of a vigorous forage stand in the field were similar to those that severely restricted ox-eye daisy growth in the greenhouse shade experiment. These levels were found within the forage canopy where fertilizer had been applied and ox-eye daisy was no longer present.

While ox-eye daisy grows better with fertilizer under high light conditions, the addition of fertilizer to ox-eye daisy growing under reduced light conditions did not enhance its growth. This correlates to the observation that fertilizer application in the field does not assist the ox-eye daisy growing in shaded conditions under the forage canopy but aids only the taller forage.

Fertilizer applied to enhance forage competition can result in the removal of ox-eye daisy from a hay or pasture stand. Increased competition for light appears to be the principle factor involved.

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Table II-1: ANOVA statistics for effect of fertilizer on ox-eye daisy and the other sward components near Winfield, Alberta.

	Ox-eye Daisy Count			Dry Weight			
	Seedling	Rosette	Flowering	Ox-eye Daisy	Grass	Legume	Other
Year 1(1994)				ns	***	*	**
Year 2(1995)	ns	***	***	***	***	***	ns
Year 3(1996)	*	***	***	***	**	***	ns

***0.01 < P < 0.05, **0.001< P < 0.01, ***P < 0.001**

Table II-2: Split-plot ANOVA statistics for effects of herbicides (H), fertilizer (F) and their interactions on ox-eye daisy and the other sward components.

	Ox-eye Daisy Count			Dry Weight			
Factor	(Seedling	Rosette)	Flowering	Ox-eye Daisy	Grass	Legume	Other
Year 1 (1995)							
H	*		**	ns	**	***	ns
F	*		ns	ns	***	ns	*
H x F	ns		ns	ns	ns	ns	ns
Year 2 (1996)							
H	ns	*	**	ns	**	**	ns
F	***	***	***	***	***	ns	*
H x F	ns	*	*	ns	ns	ns	ns

***0.01 < P < 0.05, **0.001< P < 0.01, ***P < 0.001**

Table II-3: Effect of reduced light for 8 weeks on ox-eye daisy rosettes grown in the greenhouse with 1 plant per 12.7 cm pot. Measurements are on a per plant basis.

% Light Reduc.	Average Height (cm)	Meristem Number	Leaf Number	Leaf Area (cm^2)	Area per Lf (cm^2)	Specific Lf Area (cm^2g^{-1})	Lf(Shoot) Weight (g)	Root Weight (g)	Total Weight (g)
0	10.5 b	55 a	319 a	1708 a	5.5 a	129 c	13.3 a	12.5 a	25.8 a
52	13.5 a	49 a	290 a	1896 a	6.8 a	195 b	9.8 b	4.9 b	14.7 b
85	9.7 b	25 b	201 b	1124 b	5.7 a	270 a	4.1 c	1.2 c	5.3 c
94	4.7 c	7 c	64 c	132 c	2.0 b	256 a	0.5 d	0.2 c	0.7 d

Means within the same plant measurement with the same letter are not significantly different (Student-Newman-Keuls test, $p<0.05$).

Table II-4: Effect of reduced light for 8 weeks on ox-eye daisy seedlings grown in the greenhouse with 2 plants per 12.7 cm pot. Measurements are on a per plant basis.

% Light Reduc.	Average Height (cm)	Meristem Number	Leaf Number	Leaf Area (cm^2)	Area per Lf (cm^2)	Specific Lf Area (cm^2g^{-1})	Lf(Shoot) Weight (g)	Root Weight (g)	Total Weight (g)
0	12.6 a	24.4 a	147 a	820 a	5.7 a	132 c	6.3 a	4.8 a	11.1 a
52	13.8 a	19.3 b	118 b	796 a	6.8 a	236 b	3.5 b	1.2 b	4.7 b
85	8.0 b	4.4 c	30 c	159 b	5.0 a	335 a	0.5 c	0.1 c	0.6 c
94	0.6 c	0.1 d	1 d	3 c	2.8 b	235 b	0.0 c	0.0 c	0.0 c

Means within the same plant measurement with the same letter are not significantly different (Student-Newman-Keuls test, $p<0.05$).

Table II-5: Split-plot ANOVA statistics for effects of shade (S), fertilizer (F) and their interactions on ox-eye daisy grown in the greenhouse.

Factor	Average Height	Meristem Number	Leaf Number	Leaf Area	Specific Lf Area	Leaf Weight	Petiole Weight	Root Weight	Total Weight
S	ns	*	**	**	*	**	*	*	**
F	ns	***	ns	*	ns	*	ns	**	ns
S x F	**	***	**	***	***	*	ns	**	ns

***0.01 < P < 0.05, **0.001< P < 0.01, ***P < 0.001**

Table II-6: Effect of shade and fertilizer on ox-eye daisy growth in the greenhouse with four plants per 12.7 cm pot. Measurements are on a per plant basis. Shade treatment is with shade cloth providing 6% of full light and fertilizer treatment is 1.3 g of N, P_2O_5, and K_2O applied per pot in total as three applications over 37 days.

Treatments	No Fertilizer	Fertilizer	Difference
		Average Height, cm	
No Shade	17.0 c[1]	18.5 bc	-1.5
Shade	22.7 a	19.3 b	3.4
Difference	-5.7	-0.8	
		Meristem Number	
No Shade	16.6 b	30.6 a	-14.0
Shade	10.1 c	9.9 c	0.2
Difference	6.5	20.7	
		Leaf Number	
No Shade	120 b	174 a	-54
Shade	98 c	82 bc	16
Difference	22	92	
		Leaf Area, cm^2	
No Shade	496 b	793 a	-297
Shade	342 c	256 c	86
Difference	154	537	
		Specific Leaf Area, $cm^2\ g^{-1}$	
No Shade	32 d	38 c	-6
Shade	53 a	43 b	10
Difference	-21	-5	
		Leaf Dry Weight, g	
No Shade	3.86 b	5.25 a	-1.39
Shade	1.64 c	1.52 c	0.12
Difference	2.22	3.73	
		Petiole Dry Weight, g	
No Shade	1.01	0.73	0.28
Shade	0.25	0.25	0.00
Difference	0.76	0.48	
		Root Dry Weight, g	
No Shade	2.94 a	1.61 b	1.33
Shade	0.42 c	0.29 c	0.13
Difference	2.52	1.32	
		Total Dry Weight, g	
No Shade	7.81	7.60	0.21
Shade	2.30	2.05	0.25
Difference	5.51	5.55	

[1] Within parameters, means followed by the same letter are not significantly different at $P< 0.05$.

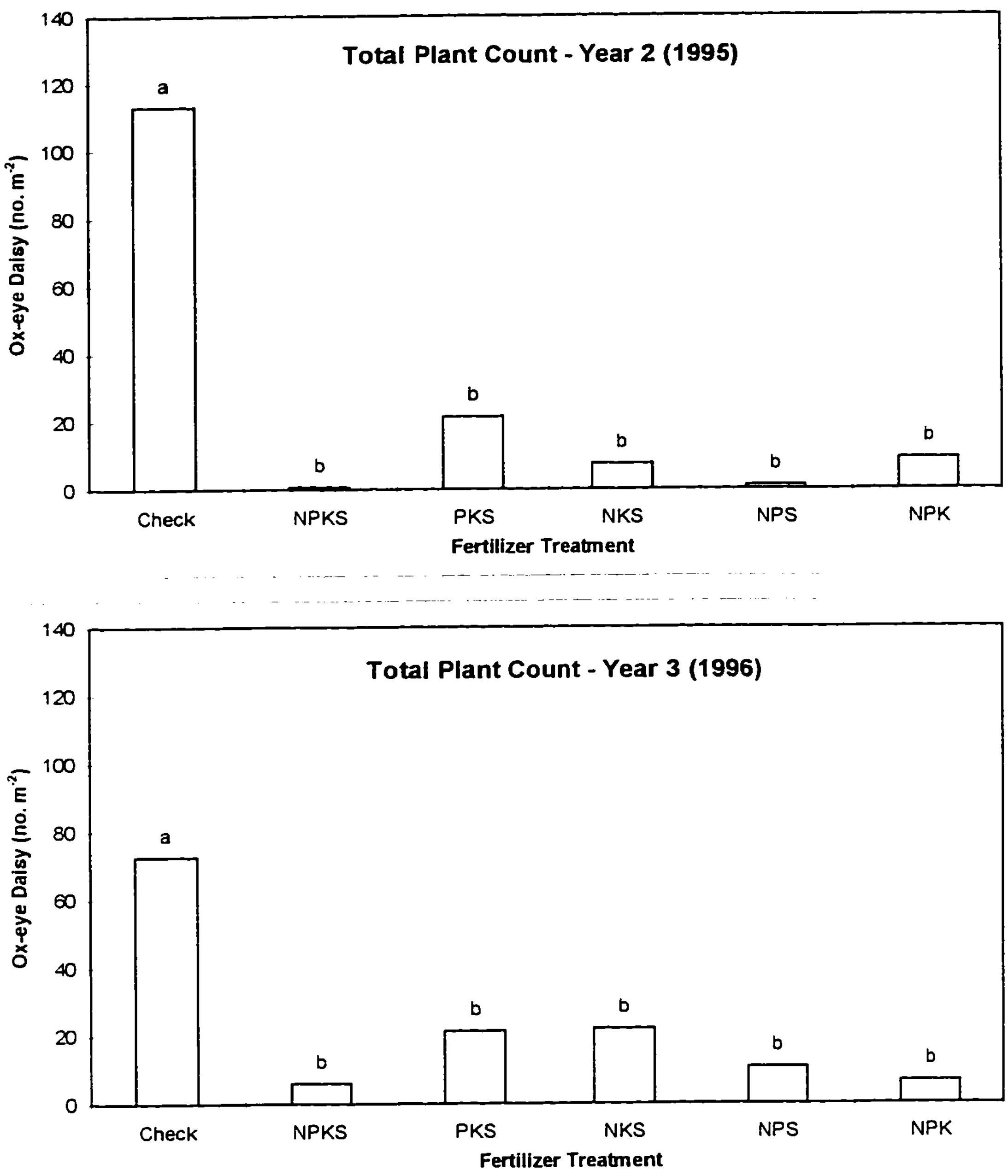
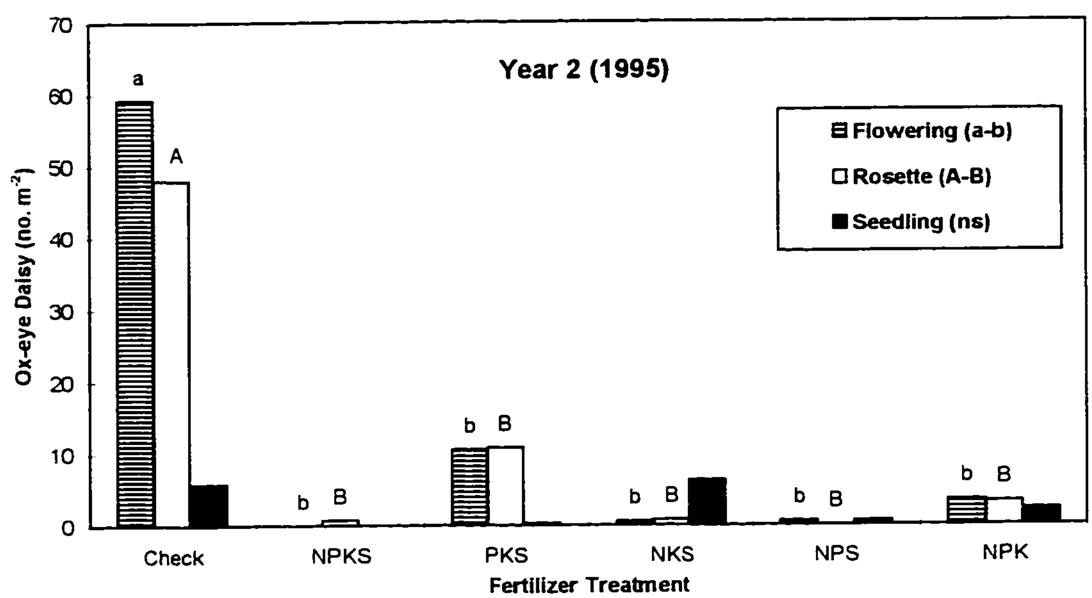


Figure II-1: Effect of fertilizer on ox-eye daisy plant count near Winfield, Alberta in year 2 (1995) and year 3 (1996) after spring surface application of fertilizer treatments in year 1 (1994) and year 2 (1995). Rates used in both applications were 100 kg N ha^{-1}, 45 kg P_2O_5 ha^{-1}, 44 kg K_2O ha^{-1} and 15 kg S ha^{-1}. Means with the same letter above are not significantly different (Student-Newman-Keuls test, $p<0.05$).



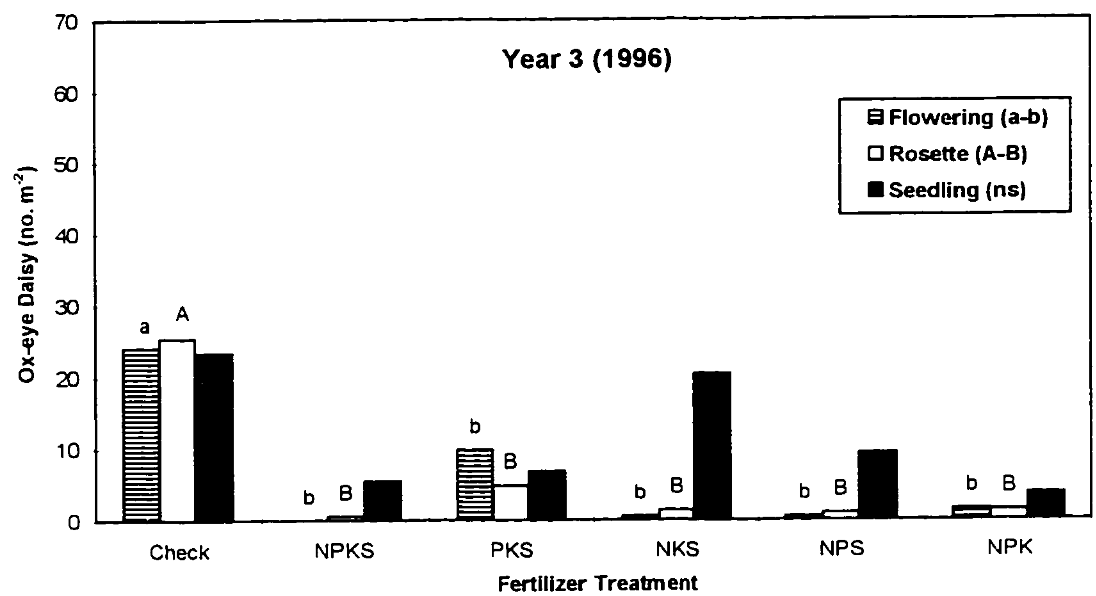


Figure II-2: Effect of fertilizer on ox-eye daisy growth stages near Winfield, Alberta in year 2 (1995) and year 3 (1996) after spring surface application of fertilizer treatments in year 1 (1994) and year 2 (1995). Rates used in both applications were 100 kg N ha^{-1}, 45 kg P_2O_5 ha^{-1}, 44 kg K_2O ha^{-1} and 15 kg S ha^{-1}. Means within the same growth stage (flowering, rosette or seedling) with the same upper case or lower case letter above are not significantly different (Student-Newman-Keuls test, $p<0.05$).

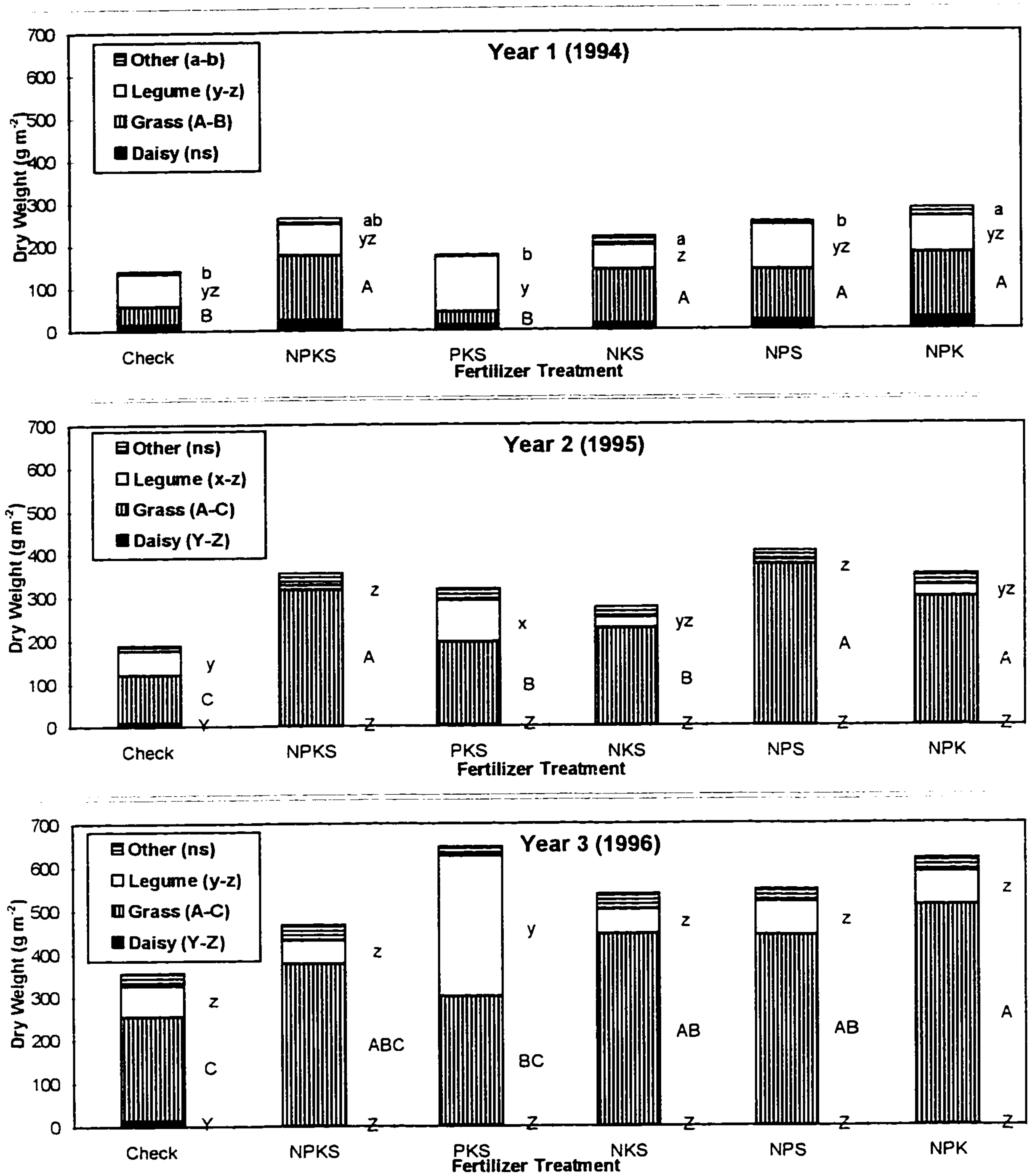


Figure II-3: Growth response (mean harvested dry weight) of ox-eye daisy and the other sward components over three years to spring surface application of fertilizer treatments in year 1 (1994) and year 2 (1995). Rates used in both applications were 100 kg N ha^{-1}, 45 kg P_2O_5 ha^{-1}, 44 kg K_2O ha^{-1} and 15 kg S ha^{-1}. Means within the same sward component (ox-eye daisy, grass, legume or other) with the same upper case or lower case letter beside are not significantly different (Student-Newman-Keuls test, $p<0.05$).

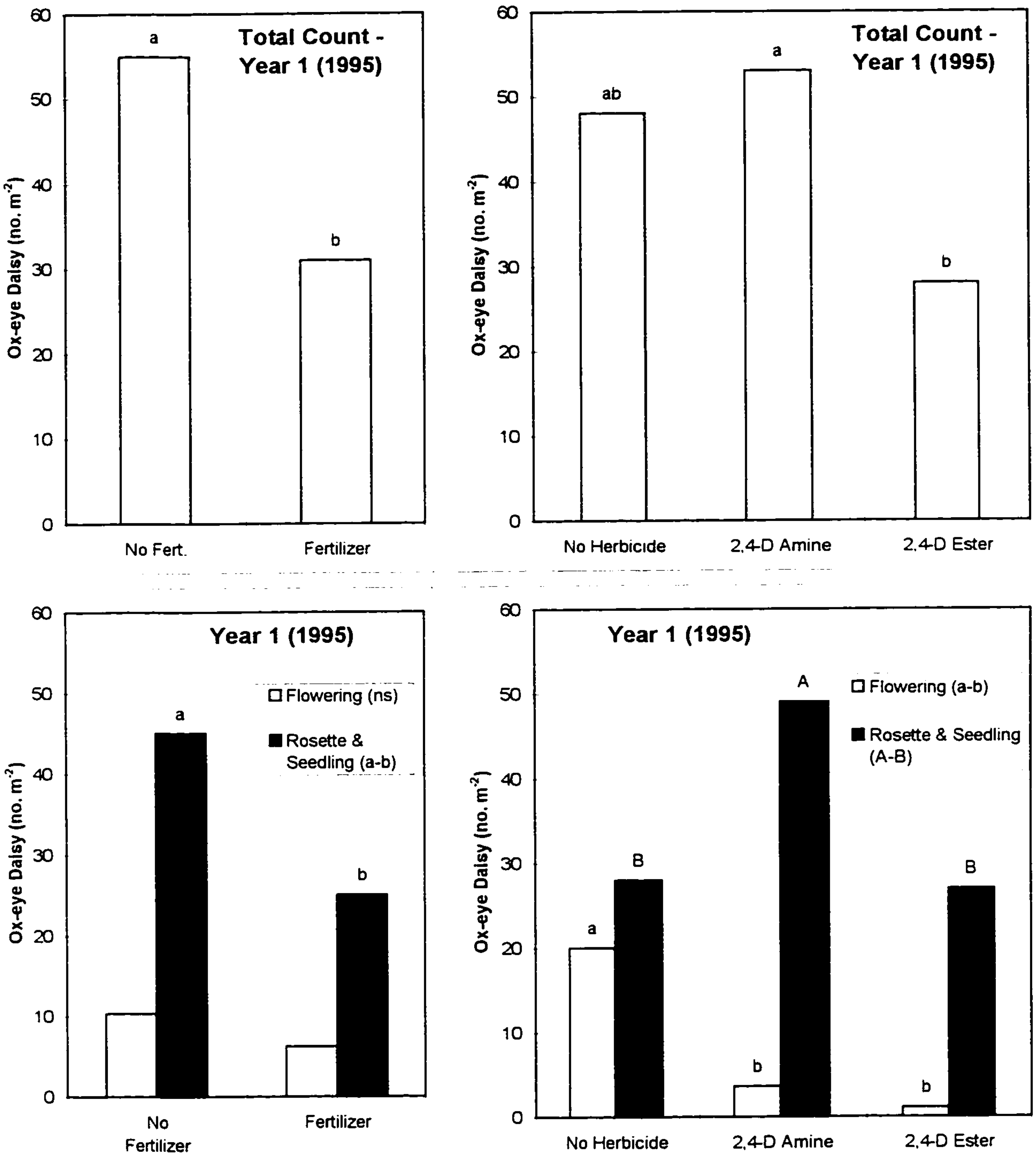


Figure II-4: Effect of fertilizer and 2,4-D herbicide on ox-eye daisy total and separate growth stage counts near Evansburg, Alberta in year 1 (1995) after spring application of fertilizer and 2,4-D treatments. Means within the same growth stage (flowering or rosette and seedling) with the same upper or lower case letter above for each graph are not significantly different (Student-Newman-Keuls test, $p<0.05$).

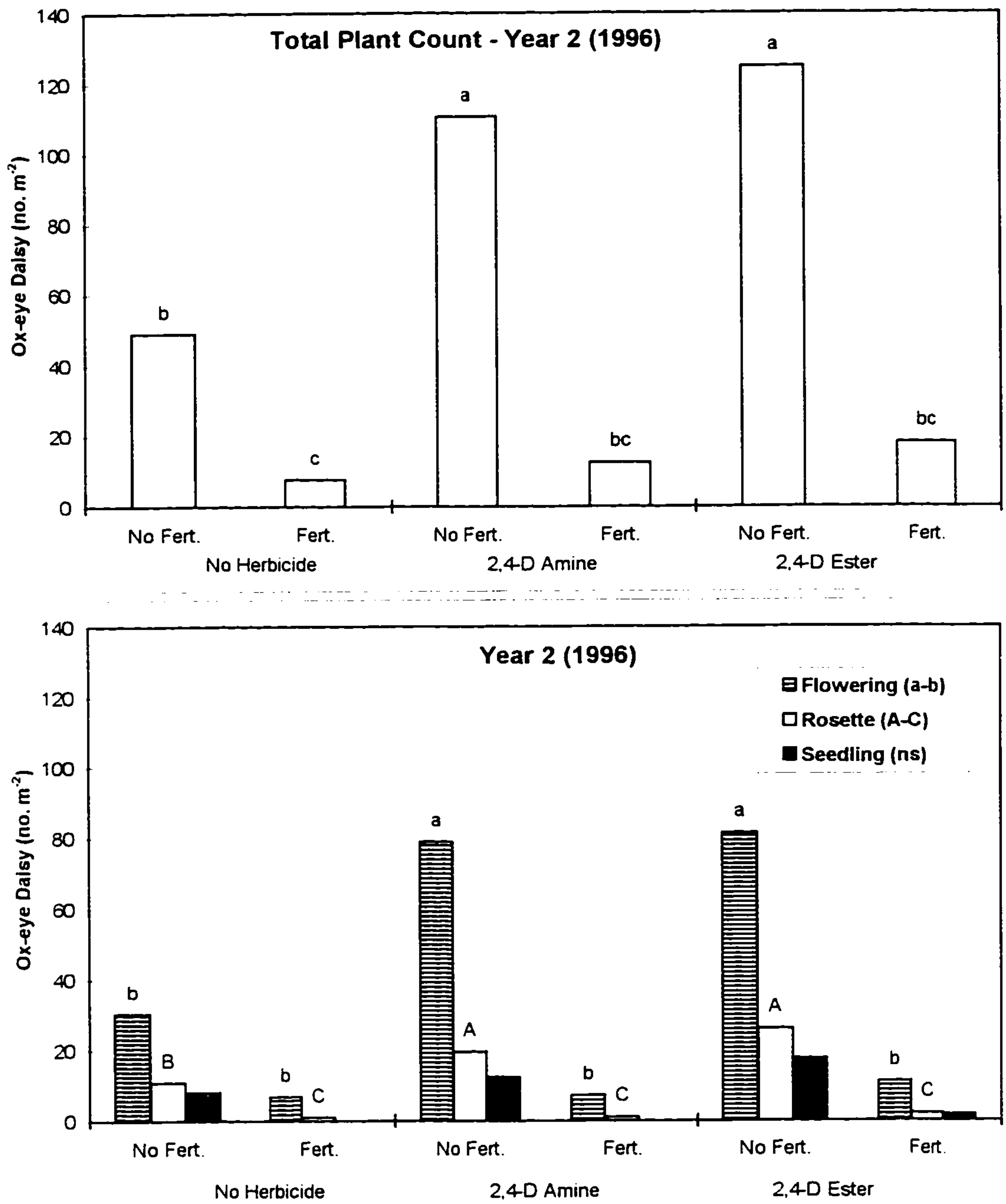


Figure II-5: Effect of fertilizer and 2,4-D herbicide on ox-eye daisy total and separate growth stage counts near Evansburg, Alberta in year 2 (1996) after spring application of fertilizer and 2,4-D treatments. Means within the same growth stage (flowering, rosette or seedling) with the same upper or lower case letter above for each graph are not significantly different (Student-Newman-Keuls test, $p<0.05$).

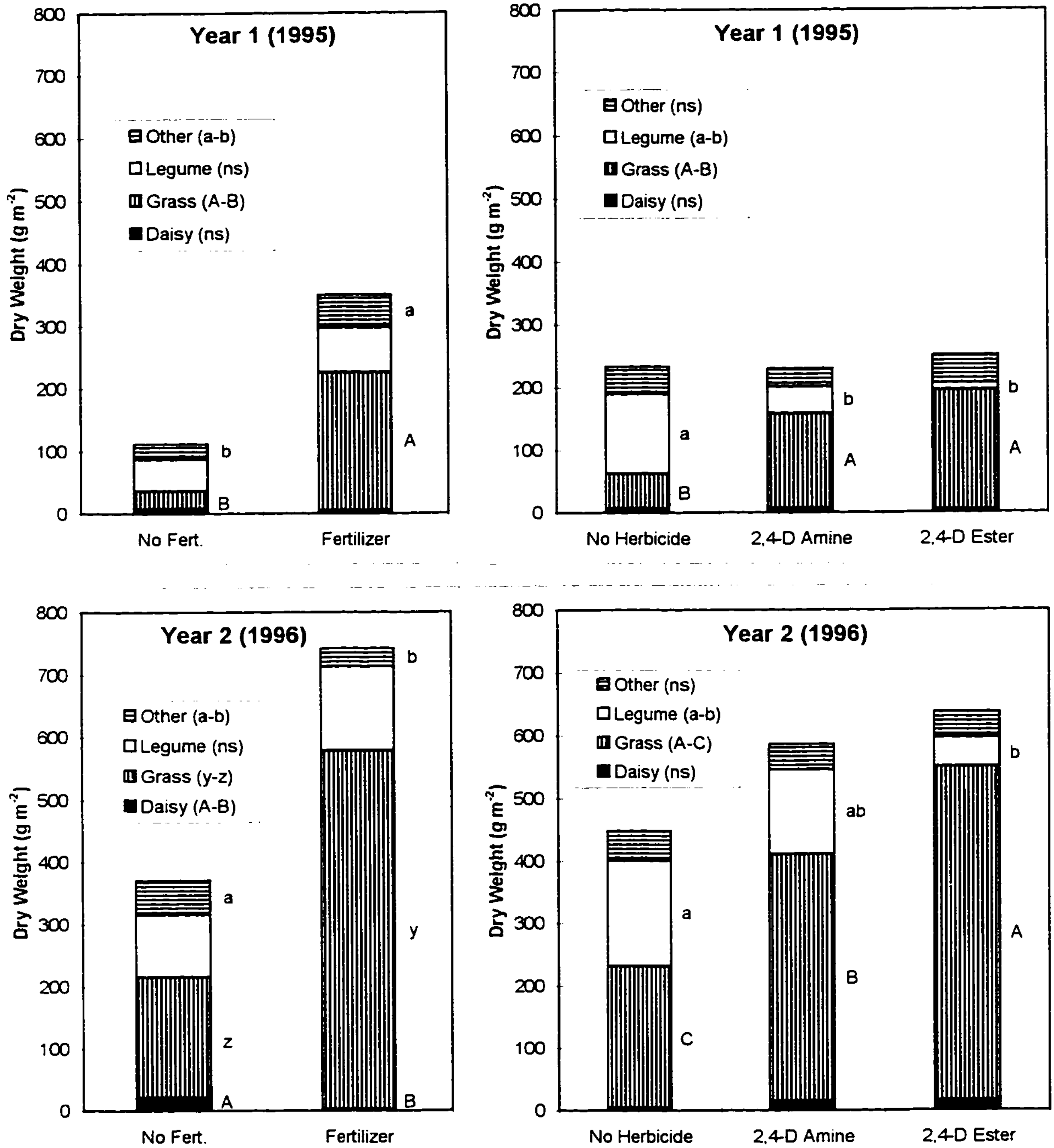


Figure II-6: Growth response (mean harvested dry weight) of ox-eye daisy and the other sward components over two years to spring application of 2,4-D application in year 1 (1995) and spring surface application of fertilizer treatments in year 1 (1995) and year 2 (1996). Means within the same sward component (ox-eye daisy, grass, legume or other) with the same upper case or lower case letter beside for each graph are not significantly different (Student-Newman-Keuls test, $p<0.05$).

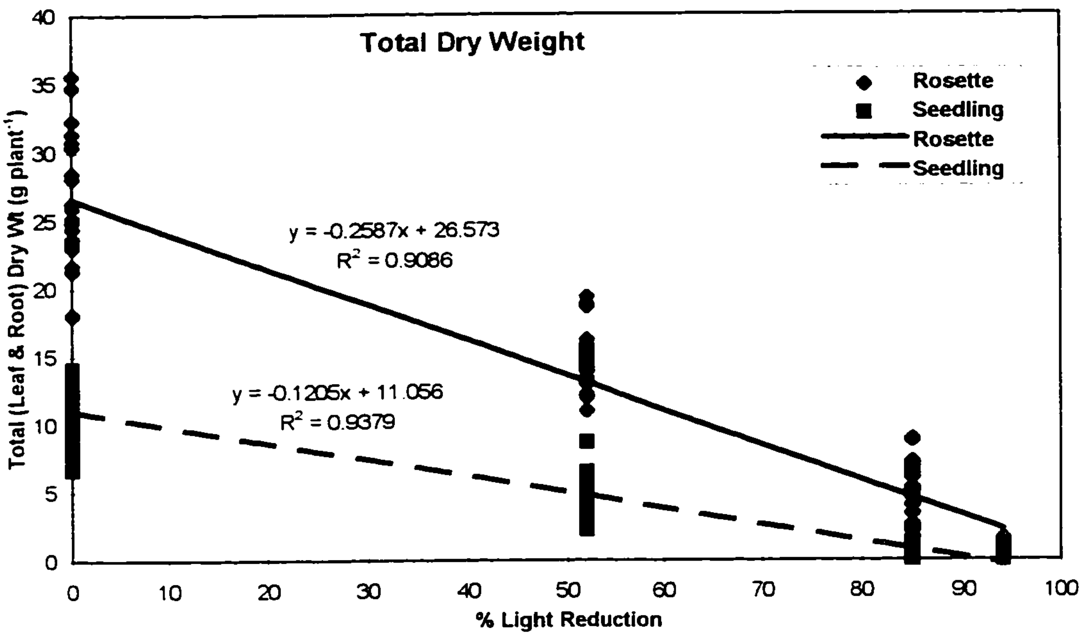


Figure II-7: Effect of reduced light (shade) for 8 weeks on ox-eye daisy total (leaf and root) dry weight (g) per plant in the greenhouse with 1 rosette or 2 seedlings per 12.7 cm pot. Rosette has a regression equation of Y = -0.2587(% shade) + 26.573, r^2 = 0.9086. Seedling has a regression equation of Y = -0.1205(% shade) + 11.056, r^2 = 0.9379.

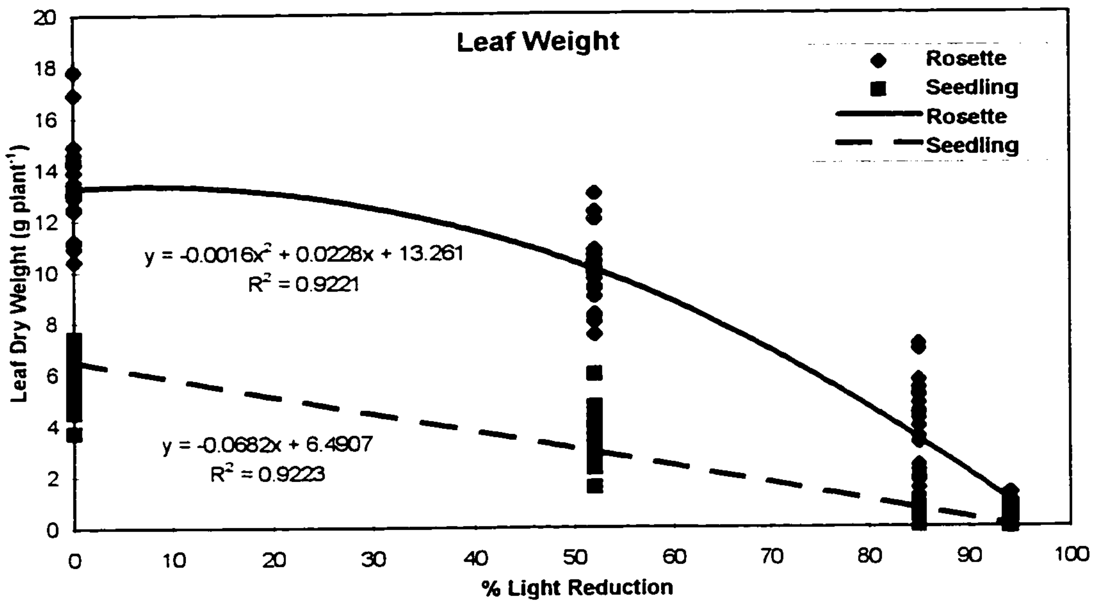


Figure II-8: Effect of reduced light (shade) for 8 weeks on ox-eye daisy leaf dry weight (g) per plant in the greenhouse with 1 rosette or 2 seedlings per 12.7 cm pot. Rosette has a regression equation of Y = -0.0016(% shade)^2 + 0.0228(% shade) + 13.261, r^2 = 0.9221. Seedling has a regression equation of Y = -0.0682(% shade) + 6.4907, r^2 = 0.9223.

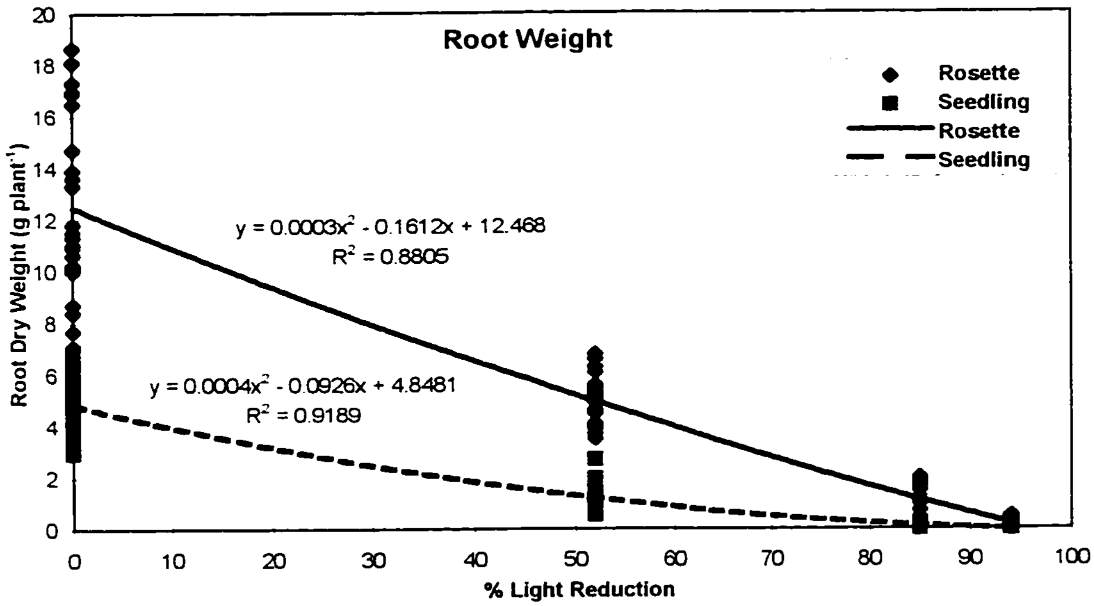


Figure II-9: Effect of reduced light (shade) for 8 weeks on ox-eye daisy root dry weight (g) per plant in the greenhouse with 1 rosette or 2 seedlings per 12.7 cm pot. Rosette has a regression equation of Y = 0.0003(% shade)^2 - 0.1612(% shade) + 12.468, r^2 = 0.8805. Seedling has a regression equation of Y = 0.0004(% shade)^2 - 0.0926(% shade) + 4.8481, r^2 = 0.9189.

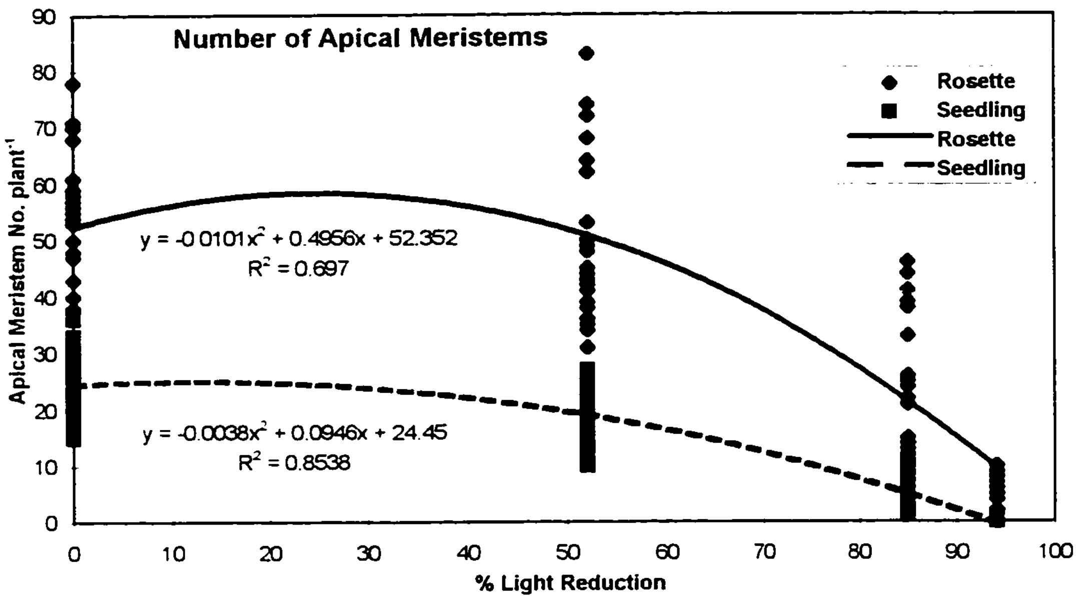


Figure II-10: Effect of reduced light (shade) for 8 weeks on ox-eye daisy number of apical meristems per plant in the greenhouse with 1 rosette or 2 seedlings per 12.7 cm pot. Rosette has a regression equation of Y = -0.0101(% shade)^2 + 0.4956(% shade) + 52.352, r^2 = 0.697. Seedling has a regression equation of Y = -0.0038(% shade)^2 + 0.0946(% shade) + 24.45, r^2 = 0.8538.

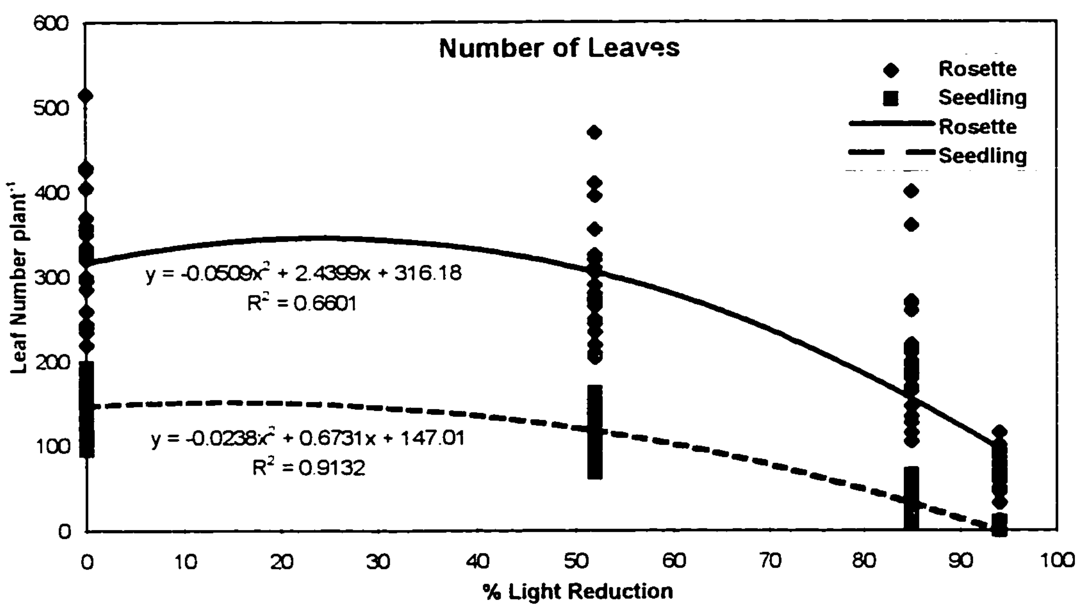


Figure II-11: Effect of reduced light (shade) for 8 weeks on ox-eye daisy number of leaves per plant in the greenhouse with 1 rosette or 2 seedlings per 12.7 cm pot. Rosette has a regression equation of Y = -0.0509(% shade)^2 + 2.4399(% shade) + 316.18, r^2 = 0.6601. Seedling has a regression equation of Y = -0.0238(% shade)^2 + 0.6731(% shade) + 147.01, r^2 = 0.9132.

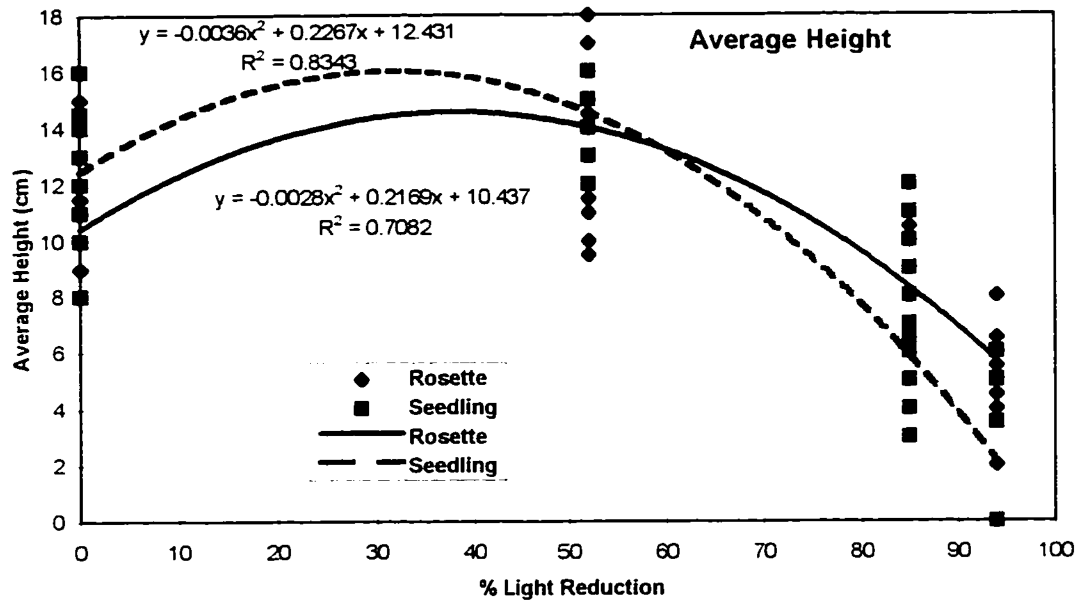


Figure II-12: Effect of reduced light (shade) for 8 weeks on ox-eye daisy average height (cm) in the greenhouse with 1 rosette or 2 seedlings per 12.7 cm pot. Rosette has a regression equation of $Y = -0.0028(\%\ shade)^2 + 0.2169(\%\ shade) + 10.437$, $r^2 = 0.7082$. Seedling has a regression equation of $Y = -0.0036(\%\ shade)^2 + 0.2267(\%\ shade) + 12.431$, $r^2 = 0.8343$.

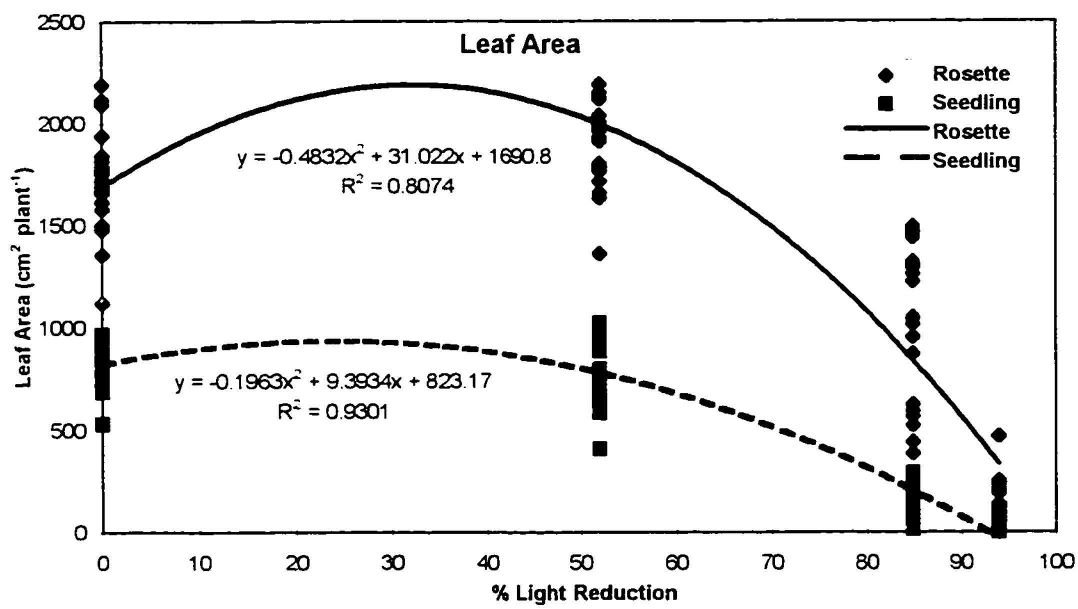


Figure II-13: Effect of reduced light (shade) for 8 weeks on ox-eye daisy leaf area (cm^2) per plant in the greenhouse with 1 rosette or 2 seedlings per 12.7 cm pot. Rosette has a regression equation of $Y = -0.4832(\%\ shade)^2 + 31.022(\%\ shade) + 1690.8$, $r^2 = 0.8074$. Seedling has a regression equation of $Y = -0.1963(\%\ shade)^2 + 9.3934(\%\ shade) + 823.17$, $r^2 = 0.9301$.

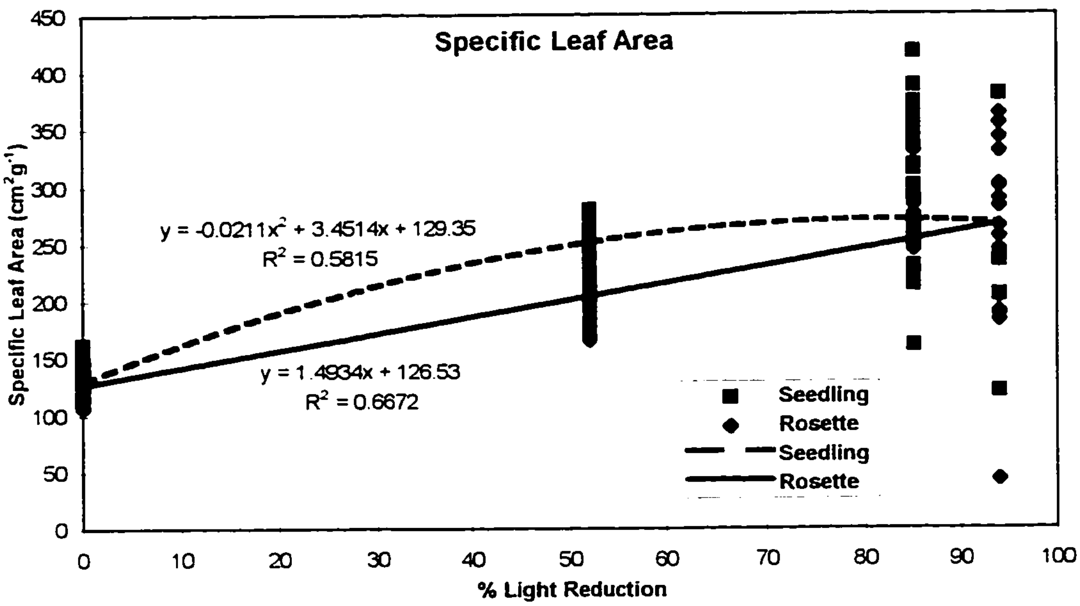


Figure II-14: Effect of reduced light (shade) for 8 weeks on ox-eye daisy specific leaf area (cm^2 g^{-1}) in the greenhouse with 1 rosette or 2 seedlings per 12.7 cm pot. Rosette has a regression equation of Y = 1.4934(% shade) + 126.53, r^2 = 0.6672. Seedling has a regression equation of Y = -0.0211(% shade)^2 + 3.4514(% shade) + 129.35, r^2 = 0.5815.

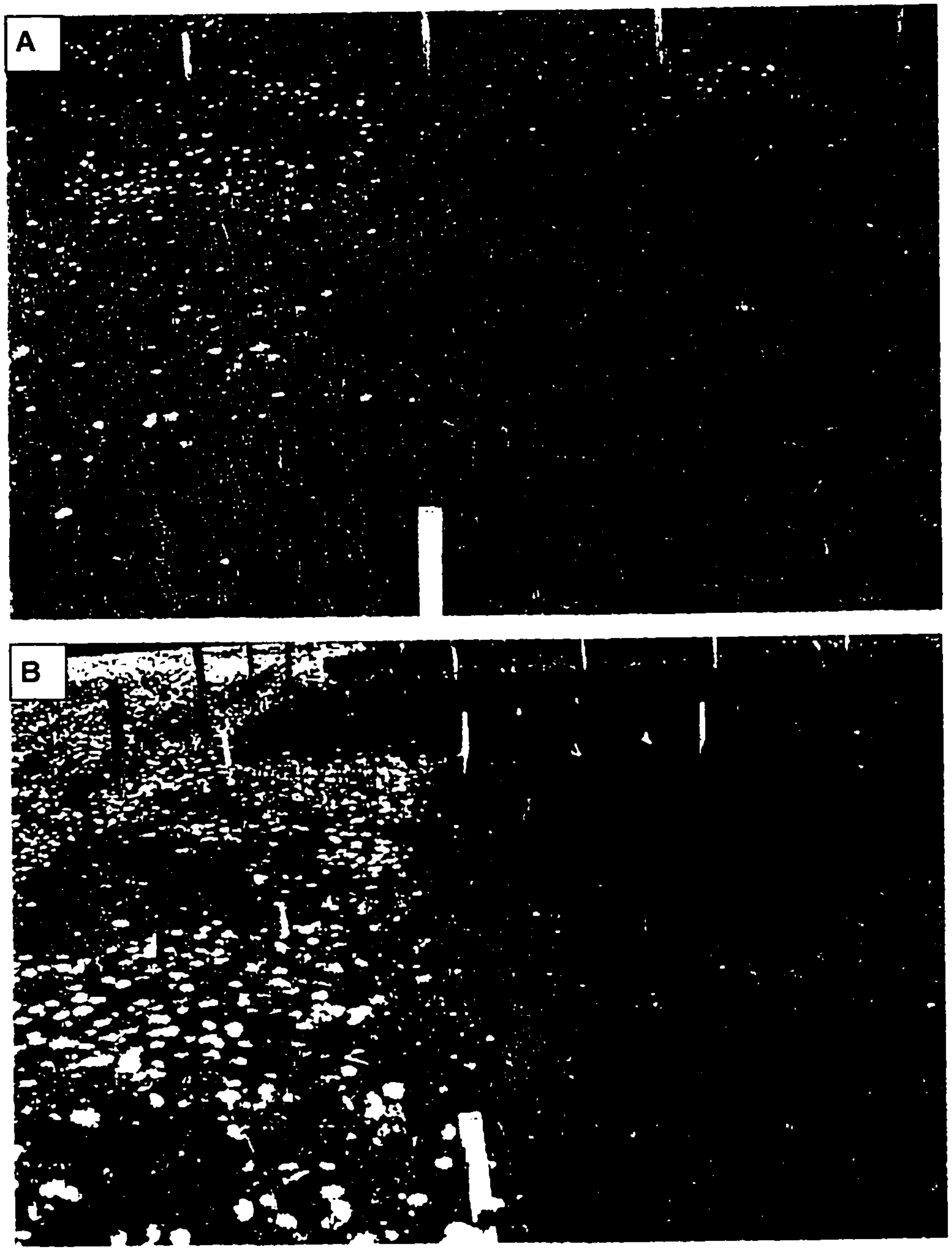


Plate II-1: (A) Effect of fertilizer on ox-eye daisy near Winfield, Alberta in year 2 (1995) after spring surface application of 100 kg N ha^{-1}, 45 kg P_2O_5 ha^{-1}, 44 kg K_2O ha^{-1} and 15 kg S ha^{-1} in year 1 (1994) and year 2 (1995) on the right. The unfertilized check is on the left. (B) Effect of 1.7 kg 2,4-D ester ha^{-1} on ox-eye daisy near Evansburg, Alberta in year 1 (1995) on the right. The unsprayed check is on the left. The back of both plots had spring surface application of 100 kg N ha^{-1}, 45 kg P_2O_5 ha^{-1}, 44 kg K_2O ha^{-1} and 15 kg S ha^{-1}.

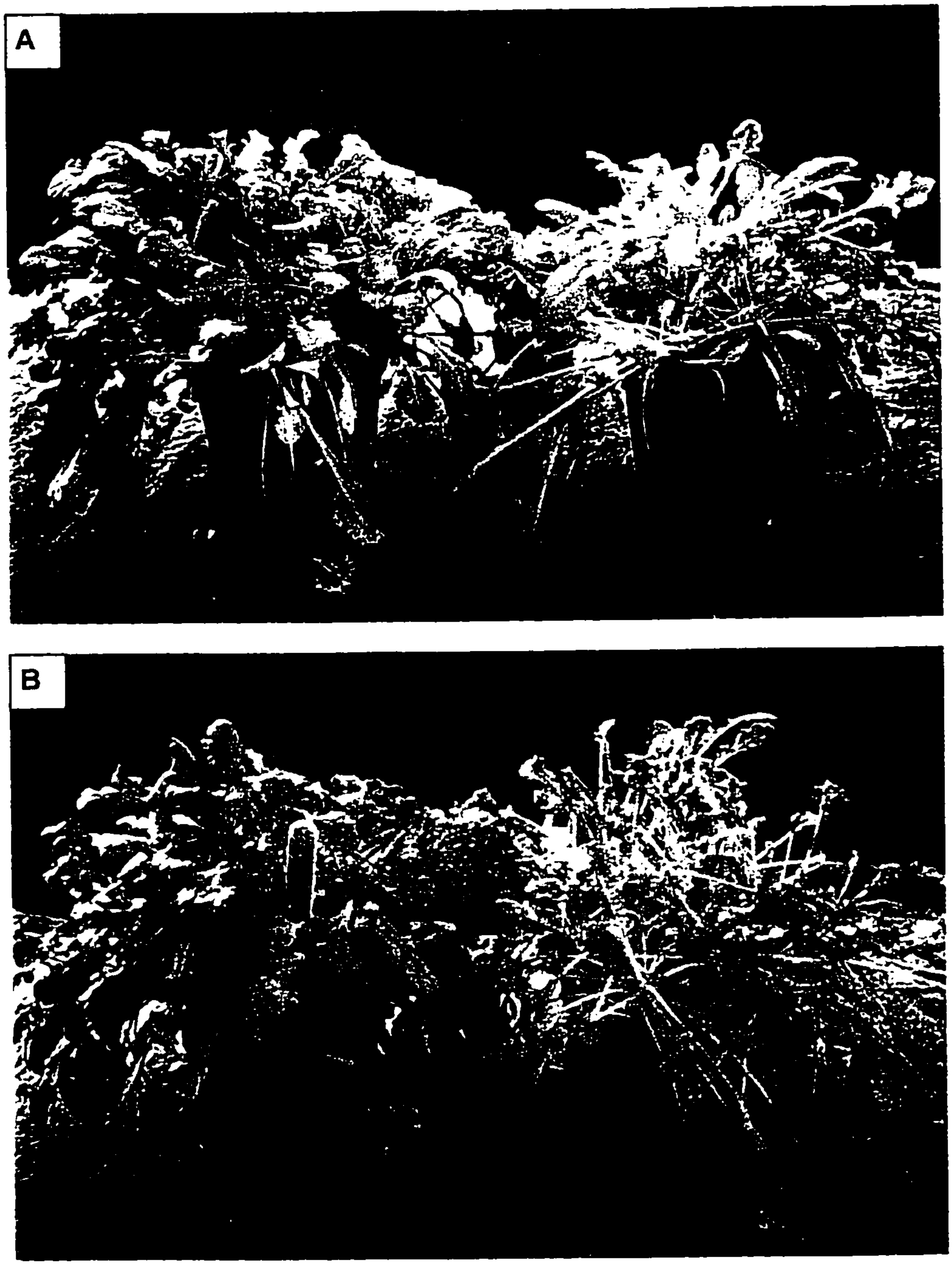


Plate II-2: Effect of shading ox-eye daisy to 6 % of available light (right) on unfertilized (A) and fertilized (B) plants in the greenhouse. The unshaded ox-eye daisy is on the left in both pictures.

Chapter III

Effect of Grass Competition on Ox-eye Daisy (*Chrysanthemum leucanthemum* L.) Emergence and Growth

INTRODUCTION

Ox-eye daisy is a weed of pastures and hay land in a number of areas across Canada and the northern United States. It is not usually found on cultivated land as tillage will kill ox-eye daisy (Howarth and Williams 1968).

Because ox-eye daisy is difficult and costly to control with herbicides (Howarth and Williams 1968) and because there are increasing environmental concerns with the use of herbicides (Pimentel et al. 1991), alternative methods of control in forage stands are being pursued.

One of these alternative methods is the use of competitive crops. An investigation into the relative competitive ability of different forage species on nodding thistle (*Carduus nutans* L.) was conducted in a New Zealand pasture (Wardle et al. 1995). The grass species were found to be more competitive with this weed than the legume species. Pasture species composition has also been shown to be important in the growth inhibition of several weed seedlings including milk thistle (*Silybum marianum*) (Michael 1968), gorse (*Ulex* *europaeus*) (Popay et al. 1990) and mouse-eared chickweed (*Hieracium pilosella*) (Scott et al. 1990).

Several experiments were conducted on the suppression of Canada thistle [*Cirsium arvense* (L.) Scop.] with competitive forages. Tall fescue (*Festuca arundinacea* Schreb.) was more competitive than bluegrass (*Poa pratensis* L.), and white clover (*Trifolium repens* L.) was more competitive than birdsfoot trefoil (*Lotus corniculatus* L.) (Thrasher et al. 1963). In this same experiment, high rates of nitrogen increased the competitive ability of the grasses. Ang et al. (1995) found that tall fescue provided more competition than crownvetch (*Coronilla varia* L.) as the legume growth was slower. The forages kept out other dicotyledonous weeds as well as suppressing the Canada thistle. Growers will rotate into alfalfa (*Medicago sativa* L.) to address a serious Canada thistle problem (Schreiber 1967). Schreiber (1967) showed that alfalfa could suppress Canada thistle, with thistle density declining after 4 years of alfalfa production.

Another perennial weed, yellow toadflax (*Linaria vulgaris* Mill.), was reduced to 1% of the original toadflax when growing in smooth bromegrass (*Bromis inermis*) for six years. This was compared to a reduction to 6% when growing in creeping red fescue (*Festuca rubra*) (Carder 1963).

Grass competition has been recognized as a method of leafy spurge (*Euphorbia esula*) suppression for a number of years. It has also been determined that the competitiveness of the different grass species against leafy spurge varies by region. Lym and Tober (1997) evaluated twelve different grass genotypes for competitiveness with leafy spurge. 'Reliant' intermediate wheatgrass [*Elytrigia intermedia* (Host) Nevski.] produced an 85% reduction of leafy spurge 2 years after seeding, in a silty clay soil at Fargo, North Dakota. This same grass reduced leafy spurge stem density by 72% 3 years after seeding in a loamy sand soil at Jamestown, North Dakota and averaged approximately 2,000 kg ha^{-1} of herbage production annually for 3 years. In Minnesota, mixtures of native species that included little bluestem [*Schizachyrium scoparium* (Michx.) Nash] established well and reduced leafy spurge as compared to other grass species (Biesboer et al. 1993). In Montana, crested wheatgrass [*Agropyron cristatum* (L.) Gaertn.] and intermediate wheatgrass were the most competitive with leafy spurge (Wallander and Olson 1995). 'Luna' pubescent wheatgrass [*Elytrigia intermedia* (Host) Nevski.] and 'Bozoisky' Russian wildrye [*Psathyrostachys juncea* (Fisch.) Nevski.]reduced leafy spurge by over 90% in Wyoming (Ferrell et al. 1993) but these same two species were among the least competitive against leafy spurge in Minnesota (Biesboer et al. 1993). In Saskatchewan, competition from crested wheatgrass along with 2,4-D [(2,4-dichlorophenoxy)acetic acid] applied twice per year provided leafy spurge root eradication after 3 years (Selleck et al. 1962).

Weed biomass was reduced more in areas seeded to alfalfa and yellow sweet clover [*Melilotus officinalis* (L.) Lam.] than in areas seeded with birdsfoot trefoil, cicer milkvetch (*Astragalus cicer* L.), red clover (*Trifolium pratense* L.), and sainfoin (*Onobrychis viciaefolia* Scop.) in an experiment conducted in Nebraska over three years (Wilson 1994). The alfalfa and yellow sweet clover plant density, height and biomass were greater than those of the other legumes.

When the effects of competition on a grassy weed, downy brome (*Bromus tectorum* L.), were investigated by Aguirre and Johnson (1991), 'Hycrest' crested wheatgrass [*Agropyron desertorum* (Fisch. ex Link) Schult. X *A. cristatum* (L.) Gaertn.] seedlings were found to be more effective competitors with downy brome than 'Whitmar' bluebunch wheatgrass [*Pseudoroegneria spicata* (Pursh) Löve] seedlings.

Another method for using plant competition to suppress weed growth when establishing a crop, is to increase the crop seeding rate or decrease the crop row spacing when seeding (Kirkland 1993). The effect of crop seeding rate and row spacing on weed growth has been shown in a number of studies, mainly with cereal and oilseed and other annual crops. There have been several reports on forage crops as well.

Kilcher (1961) observed that intermediate wheatgrass [*Agropyron intermedium* (Host) Beauv.] and crested wheatgrass grown in rows more than 30 cm apart became weedy in Swift Current, Saskatchewan. The weed growth reduced the intermediate wheatgrass yields. Darwent and Elliott (1979) found at Beaverlodge, Alberta that intermediate wheatgrass, crested wheatgrass, smooth bromegrass (*Bromus inermis* Leyss.), meadow fescue (*Festuca elatior* L.), creeping red fescue and timothy (*Phleum pratense* L.) when seeded at 30 cm or less row spacing were able to compete vigorously with dandelion (*Taraxacum officinale* Weber). Not only was the size of the dandelion reduced as the grass row spacing decreased from 100 cm to 20 cm, but the dandelion density was also reduced. There was no significant difference in dandelion density between grass species at these row spacings. However, another grass species, Russian wild ryegrass (*Elymus junceus* Fisch.), had only a minor effect on dandelion, regardless of row spacing. This species established and developed more slowly than the other grass species.

In a mixture of grasses, the density of dandelion decreased as the height and density of the grasses increased. Molgaard (1977) attributed this decrease to a direct cover effect as well as a shading effect.

When legume species were planted at different row spacing (Pankiw et al. 1977), red clover, alsike clover (*Trifolium hybridum* L.) and birdsfoot trefoil competed with weeds when seeded in rows spaced 15 to 30 cm apart but not when seeded in rows spaced 45 to 60 cm apart.

Alfalfa seed yields tended to be maximum with 36 cm row spacing as compared to 72 and 108 cm row spacing and at 3.0 kg ha^{-1} broadcast seeding rate as compared to 0.33 and 1.0 kg ha^{-1} seeding rates in trials conducted on irrigated land at Tilley and Lethbridge, Alberta (Moyer et al. 1991). The dry matter yields of weeds decreased as row spacing decreased or the seeding rate increased.

There is very little information available on the competitiveness of ox-eye daisy. It is reported to be more abundant in Europe on land with higher intensities of cutting or grazing (Howarth and Williams 1968). Determining the competitive ability of ox-eye daisy with other plant species would assist in developing management strategies to address problems in hay or pasture land. A replacement series experiment is a fairly efficient means of determining the relative competitiveness of one plant species with another plant species.

A replacement series experiment compares the performance of two species in mixtures with their performance in monoculture using their relative yields (de Wit 1960). Relative yields are determined by comparing the individual species yield within the mixture with its yield in a pure stand. The total plant density is held constant while the mixture proportions of the species vary. Results are usually represented graphically as "replacement diagrams" in which the relative yields of both species are plotted against their proportions in the mixture. The results can also be used to express various indices that quantify competition such as the relative crowding coefficient (Silvertown 1982).

The de Wit (1960) replacement series experimental design, diagram and indices have been used to evaluate competition between the components of binary mixtures for over 35 years. One reason for the design's popularity is the fact that it is based on relatively small experiments (Firbank and Watkinson 1990), and competitive and non-competitive processes can be distinguished (Hall 1974). The total plant density does not vary to confound the results

(Silvertown 1982). It is especially useful for comparing the outcome of competition between two plant species under different growing conditions (Dunan and Zimdahl 1991). The replacement series design can also be used to determine the relative effects of intraspecific and interspecific interference (Radosevich 1987).

There are several important considerations when the replacement series design is employed. De Wit (1961) himself pointed out that the results and thus the interpretation of the results depend on the total plant density chosen and the duration of the experiment. It cannot be assumed that the proportions in a mixture have the same influence at different densities (Silvertown and Doust 1993). The replacement series curves for a two-species mixture can have different shapes at different planting densities (Rejmánek et al. 1989). The plant density may even be too small to allow for competition between plant species. The relative timing of growth by the species in a mixture is often crucial in allowing one species to capture resources and space at the expense of the other (Silvertown 1982). Results can be totally different if seedlings are being grown with well established plants compared to starting the experiment with both species as seedlings. It is difficult to set up a replacement series experiment where interference between two species is balanced and symmetrical. For example, consideration needs to be given to the fact that ox-eye daisy has two main growth phases, one as a rosette and the other as a flowering plant. Outcome may also vary with growing conditions, e.g., wet versus dry.

Wall (1995) conducted a replacement series greenhouse experiment to compare the relative competitiveness of three annual cruciferous weeds. He found that wild mustard (*Sinapis arvensis* L.) was more competitive than either ball mustard [*Neslia paniculata* (L.) Desv.] or dog mustard [*Erucastrum gallicum* (Willd.) O. E. Schutz], and that ball mustard was more competitive than dog mustard.

The perennial weed yarrow (*Achillea millefolium* L.) was less competitive than the annual crop pea (*Pisum sativum* L.) when grown in various combinations in a replacement series greenhouse experiment (Kannangara and Field 1985). Both species were grown from seed planted at the same time in this experiment.

Barley (*Hordeum vulgare* L.) was a stronger competitor than wild oats (*Avena fatua* L.) (Dunan and Zimdahl 1991) while wheat (*Triticum aestivum* L.) and wild oats were equivalent in competitiveness (Cudney et al. 1989).

Vangessel and Renner (1990) found that 'Atlantic' and 'Russet Burbank' potatoes (*Solanum tuberosum* L.) and barnyard grass [*Echinochloa crus-galli* (L.) Beauv.] were more competitive than redroot pigweed (*Amaranthus retroflexus* L.).

A replacement series experiment has also been used to determine the relative fitness of two chickweed (*Chenopodium album*) biotypes in Quebec (Leroux 1993). The biotype susceptible to *s*-triazine herbicides produced a greater relative proportion of biomass and seeds than the tolerant biotype when the two biotypes were in a mixture.

Replacement series experiments have also been employed to investigate differential resource use by plants, including several studies on the relative competitive ability of two plant species when growing at different nutrient levels. Hall (1974) discovered that, at low levels of potassium, the tropical grass, *Setaria anceps* cv. 'Nandi' severely restricted the growth of the tropical legume, *Desmodium intortum* cv. 'Greenleaf'. At high levels of potassium, the *Setaria's* competitive advantage declined.

When the effect of nitrogen on growth of maize (Zea mays L.) and redroot pigweed was investigated by Teyker et al. (1991), it was determined that redroot pigweed responded more than did maize to supplemental nitrogen. More importantly, redroot pigweed was more likely to compete with maize when high levels of NO_3-N were used instead of NH_4^+-N.

The purpose of these experiments was to determine if grass competition could be used to suppress or control ox-eye daisy in pasture or hay land. The experiments were established to examine several densities of ox-eye daisy alone and with Kentucky bluegrass (*Poa pratensis* L.) and meadow bromegrass (*Bromus biebersteinii*), to compare the competitive ability of these two grass species against ox-eye daisy, to determine if grass seeding rate and row spacing can affect ox-eye daisy and to determine the relative competitive ability of ox-eye daisy and meadow bromegrass grown from seed in a replacement series experiment. The influence of nitrogen on the relative competitive ability of ox-eye daisy and meadow bromegrass was also examined. Kentucky bluegrass and meadow bromegrass were chosen for their different growth habits; Kentucky bluegrass is slower growing, does not grow as tall and usually does not produce as much biomass as meadow bromegrass.

MATERIALS AND METHODS

Two field experiments and a greenhouse experiment were conducted. The two field experiments were established in 1995 and again in 1996 and were conducted over two to three field seasons. The greenhouse experiment was conducted only once, over three months in 1996.

Grass species and ox-eye daisy density field experiment. The experiment was established at the University of Alberta field research station in Edmonton, Alberta (53° 29' 30" N 113° 32' 30" W) in 1995 and in 1996. The Malmo silty clay loam (14% sand, 34% silt and 52% clay) Eluviated Black Chernozem developed on lacustrine parent material soil was fallow for 2 years prior to establishing the experiment. Analysis of soil samples collected in May, 1995 indicated a pH of 6.0, 10.4% organic matter, 92 kg available N ha^{-1}, 49 kg available P ha^{-1}, 712 kg available K ha^{-1} and 23 kg available S ha^{-1}.

The experimental design was a split plot randomized complete block with four replications. The main treatments were (i) no crop, (ii) Kentucky bluegrass and (iii) meadow bromegrass each in plots 1.8 m x 12.5 m. Each main treatment plot was divided into five equally spaced and marked 1.5 m x 1.5 m areas (with surrounding untreated areas). Five seeding rates of ox-eye daisy; (i) 0, (ii) 26, (iii) 130, (iv) 260 and (v) 1040 seeds m^{-2}, were randomly assigned to these 1.5 m x 1.5 m areas.

(a) 1995-Seeded experiment. The 1995 experiment had the two grasses seeded on June 9, 1995 as six rows per plot at a 30-cm row spacing. They were seeded with a three-point hitch cone seeder, with depth bands on the disk openers to seed 1 cm deep. Kentucky blue grass was seeded at 4 kg ha^{-1} and meadow brome grass at 7 kg ha^{-1}. The area was packed with a heavy Brillion seeder crossways to the direction of seeding to remove seeding ridges. Ox-eye daisy seed was spread by hand on June 9, 1995 and lightly incorporated into the soil surface with a leaf rake.

The plots were hand-weeded in June and July to remove mainly common groundsel (*Senecio vulgaris* L.), redroot pigweed *(Amaranthus retroflexus* L.) and barnyard grass [*Echinochloa crusgalli* (L.) Beauv.]. On October 5, 1995, the meadow brome grass was cut at a height of 15 cm and removed to simulate a haying operation but not damage the ox-eye daisy. The Kentucky bluegrass was not cut as it had not reached 15 cm in height. As the ox-eye daisy germination and establishment was delayed, no data was collected in 1995.

In 1996 the plots were harvested twice, on June 13, 1996 and August 29, 1996. The August 29 harvest was a harvest of the regrowth following the June 13 harvest. Data collected included ox-eye daisy plant, flower bud, and stem number, per 1.5 m x 1.5 m plot. The ox-eye daisy and the two center rows of grass in each 1.5 m x 1.5 m plot were cut to a height of 7.5 cm, separated, dried at 60°C for 48 hours and weighed. In the plots without a forage crop, the ox-eye daisy alone was counted and harvested.

Following the harvests, the entire experimental area was mowed at approximately 7.5 cm and the mown material was removed from the plots.

(b) 1996-Seeded experiment. The experiment was repeated in 1996 with the Kentucky blue grass and meadow brome grass seeded with a hand-push single row cone seeder on May 29. The ox-eye daisy was seeded by hand on June 17, after barnyard grass, common groundsel, and redroot pigweed had been removed from the experiment by roguing and hoeing between the grass rows. Higher ox-eye daisy seeding rates were used than in the 1995-seeded experiment: (i) 0, (ii) 80, (iii) 400, (iv) 800 and (v) 3200 seeds m^{-2}.

The experimental area was rogued for weeds in July and September, and average heights of the ox-eye daisy and grasses were measured on September 25.

Ox-eye daisy plants and stems were counted and then harvested in each 1.5 m x 1.5 m area on September 27, 1996. The two center rows of grass in each 1.5 m x 1.5 m area were cut at 7.5 cm, dried at 60°C for 48 hours and weighed. The ox-eye daisy was counted and harvested in each of the five areas of the treatment without a forage crop.

Regression curves were fitted to the ox-eye daisy dry weight, stem density, flower bud density, dry weight per plant and grass yield over the range of ox-eye daisy plant densities for the experiment seeded in 1995. There was not enough growth and data were too variable in the experiment seeded in 1996 for statistically significant regression curves. The data were averaged over the four seeding rates of ox-eye daisy to compare the grass species treatments for both seeding times using analysis of variance.

Grass species seeding rate and row spacing field experiment. This experiment was conducted at the University of Alberta field research station in both 1995 and 1996.

The experimental design was a randomized complete block with four replications. The treatments were Kentucky blue grass or meadow brome grass each seeded at the following row spacing and recommended seeding rate: (i) 30 cm and 1x, (ii) 30 cm and 0.5x, (iii) 30 cm and 2x, (iv) 22.5 cm and 1x, (v) 15 cm and 1x. The Kentucky blue grass seeding rates were 4 kg ha^{-1} (1x recommended seeding rate), 2 kg ha^{-1} (0.5x) and 8 kg ha^{-1} (2x). The meadow brome grass seeding rates were 7 kg ha^{-1} (1x recommended seeding rate), 3.5 kg ha^{-1} (0.5x) and 14 kg ha^{-1} (2x) (Alberta Agriculture, Food and Rural Development 1993). Each plot was 1.8 m by 6 m with half of the plot receiving approximately 8100 ox-eye daisy seeds. Ox-eye daisy was seeded alone without grass to compare with the grass treatments.

The ox-eye daisy germinated and emerged into established grass in the 1995-seeded experiment and into seedling grass in the 1996-seeded experiment.

(a) 1995-Seeded experiment (Established grass). The Kentucky blue grass and meadow brome grass were seeded with a hand-push single row cone seeder at 1 cm depth on July 28, 1995. The entire experimental area was sprayed with bromoxynil at 0.34 kg a.i. ha^{-1} on August 24, 1995 to control a heavy infestation of common groundsel. The grass was at the three-leaf stage when sprayed and was not injured by the herbicide application. The ox-eye daisy seed was uniformly spread by hand on half of each plot on August 26, 1995. The ox-eye daisy seed did not germinate in the fall of 1995, most likely due to dry conditions (Appendix III-B). There was good establishment of the grass species in the fall so that the ox-eye daisy emerged into well developed grass stands in May, 1996.

Ox-eye daisy plants were counted in each 1.8 m x 3 m area on June 26, 1996. They were not harvested as they were below 5 cm in height. The grass was cut at 7.5 cm high on July 5, 1996 and the mown material was removed the same day.

Ox-eye daisy plants were counted again and harvested on September 10, 1996. Plants were cut at 5 cm in height in the center 1 m^2 of each seeded plot, dried at 60°C for 48 hours and weighed. The two grasses were harvested at the same time from the center two rows for 1 m. The remaining growth outside the harvested quadrat was cut at 5 cm and removed on September 11, 1996.

In 1997, two additional counts and harvests were conducted, including ox-eye daisy flower counts. The seedling, rosette and bolted ox-eye daisy plants were counted and harvested above 5 cm on June 19, 1997. The regrowth was counted and harvested in the same manner on September 11, 1997. The center two rows for 1 m of Kentucky blue grass and meadow brome were harvested at both times and the remainder of the forage was cut and removed.

(b) 1996-Seeded experiment (Seedling grass). In 1996, the two grasses were seeded on June 10 and the ox-eye daisy seed was spread by hand on June 24. Both grasses and ox-eye daisy emerged and grew well.

Initial ox-eye daisy plant counts were made on September 3, 1996 with an ox-eye daisy and grass harvest on October 3, 1996.

Ox-eye daisy seedlings, rosettes and bolted plants were counted on June 24, 1997 and September 11, 1997. The ox-eye daisy and grass were harvested on the same days and the remaining growth cut at 5 cm and removed from the plots.

Grass seeding rate data were analyzed separately from grass row spacing data, using linear and quadratic contrasts with a separate contrast for grass species. The data were also averaged over the grass seeding rates and row spacings for both grasses to compare with the no crop treatment using analysis of variance. The data for the two seeding times were analyzed separately as the one seeding time compared grass seeding rate and row spacing effects in established grass (seeded in 1995) and the other compared them in seedling grass (seeded in 1996).

Replacement series greenhouse experiment. The replacement series experiment was conducted in the greenhouse from May 28 to August 10, 1996. Meadow bromegrass and ox-eye daisy were grown in monoculture, or as mixed populations, in 17 cm diameter by 12 cm deep plastic pots, filled with a 50% peat, 30% perlite and 20% loam soil mix. Two monocultures and three mixtures of 75:25, 50:50 and 25:75 planting ratios were used. For both monocultures and mixtures, planting density was four plants per pot. This was equivalent to 176 plants m^{-2}.

Fertilizer was applied at 45 kg P_2O_5 ha^{-1} as monocalcium phosphate (45% P_2O_5), 250 kg K_2O ha^{-1} as potassium chloride (60% K_2O) and potassium sulphate (50% K_2O), 15 kg S ha^{-1} as potassium sulphate (17% S), and 11 kg ha^{-1} as trace elements (7% Fe, 0.40% Zn, 0.10% Cu, 1.3% B, 0.06% Mo, 4.7% Mg). Dolomite lime was also mixed into the growing medium at a rate of 377 kg ha^{-1} to bring the pH to 6.0.

Ammonium nitrate (34% N) was mixed into the growing medium at 5 kg N ha^{-1} for half of the pots and 100 kg N ha^{-1} for the other half.

Seedlings of ox-eye daisy and meadow bromegrass were grown in the greenhouse in trays with plastic covers. There was over 60% germination of the ox-eye daisy seed. Natural light was supplemented with high pressure sodium lights for a 16-hour photoperiod while maintaining day/night temperatures at 21°C/18°C.

The meadow brome seedlings had two leaves and were 15 to 21 cm in height and the ox-eye daisy seedlings had three leaves and were 1 to 3 cm in height when they were transplanted into the prepared pots on May 28, 1996. Woven black monofilament polypropylene shade cloth (De Witt Co., Sikeston, Missouri, USA) rated at 52% light reduction was wrapped around the pots and moved up as the plants grew to minimize lateral illumination and to simulate neighboring plants (Plate III-3). High pressure sodium lights provided approximately 212 $\mu E\ m^2\ sec^{-1}$ for a 16-hr photoperiod. Natural light provided a maximum measurement at solar noon on a clear day of approximately 1780 $\mu E\ m^2\ sec^{-1}$. The day/night temperatures were 21°C/18°C in the greenhouse. The "self-watering" pots were watered through the storage compartment at the base of the pots so that there was no loss of nutrients from drainage, and water was never limiting. The 100 kg ha^{-1} N pots were interspersed with the 5 kg ha^{-1} N pots and all pots were relocated systematically on a weekly basis to minimize the effect of environmental variation within the greenhouse.

The experimental design was a randomized complete block design with six replications of each of the five planting ratios by two nitrogen levels (60 pots in total).

Plants were measured and harvested 74 days after transplanting by cutting shoots at soil level and separating the species. The roots were also gently washed and separated in a sieve. The harvested shoots and roots were dried at 65°C for 48 hours to constant weight. An area meter, model LI-300 (LI-COR, Ltd, Lincoln, Nebraska, USA), was used to measure leaf area.

At the time of harvest, ox-eye daisy was at the rosette stage and between 13 and 20 cm in height. Only two meadow brome plants were headed out and the meadow brome was between 94 and 120 cm in height.

Leaf area ratio was calculated by dividing the total leaf area for the species by the total above ground dry weight of the species ($cm^2\ g^{-1}$).

Relative yields (r) and relative yield total (RYT_{bd}) were calculated according to the following formulae (Wall 1995):

Relative yield;

$$r_b = X_{bd}/X_{bb} \quad (1)$$

$$r_d = X_{db}/X_{dd} \quad (2)$$

Relative yield total;

$$RYT_{bd} = r_b + r_d \tag{3}$$

where, r_b and r_d are relative yields of species *b* and *d*, respectively; X_{bd} is the yield of species *b* grown in mixture with species *d* ; X_{db} is the yield of species *d* grown in mixture with species *b*; X_{bb} and X_{dd} are monoculture yields of species *b* and *d*, respectively.

Replacement diagrams (de Wit 1960) were constructed using the r and RYT_{bd} values to aid in analysis. Yield-to-mixture response curves in the replacement diagrams are interpreted as follows (Radosevich 1987):

if both curves are linear along the expected relative yields, either the ability of each species to interfere with the other is equivalent or the two species are located so far apart that not interaction can occur between them;

if one curve is concave and the other curve is convex, one species is more competitive than the other (indicating that the interaction between species is for a common resource(s) and that one species gains more than the other);

if both curves are convex, a mutually beneficial relationship is indicated; and

if both curves are concave, a mutually antagonistic relationship is indicated.

Replacement diagrams and other results are presented for total (shoot + root) plant means only, since calculations using either root or shoot weights independently did not lead to substantially different results.

For a given mixture comparison (Bridgemohan and McDavid 1993):

a RYT_{bd} value > 1.0 indicates that the crop and weed are exploiting the resources in different ways or somehow benefiting each other so that the total yield in the mixture is greater than would be expected from the yields that occur in monoculture;

a RYT_{bd} value = 1.0 indicates that the crop and weed are competing for the same limiting resources; and

a RYT_{bd} value < 1.0 indicates that mutual antagonism by both species, or allelopathy is occurring.

The RYT_{bd} value is only valid for the particular density and proportion of the species used in the experiment (Silvertown and Doust 1993).

Relative Crowding Coefficient (RCC) equation, as modified by Bridgemohan and McDavid (1993) from de Wit (1960), was used to analyze competitive ability of the two species, meadow bromegrass and ox-eye daisy:

Relative Crowding Coefficient;

$$K_{bd} = (CYP/CTY)/(WYP/WTY) \qquad (4)$$

where K_{bd} = the Relative Crowding Coefficient (RCC) of meadow bromegrass with respect to ox-eye daisy; CYP = crop dry weight per plant in the mixture; CTY = crop total dry weight in the pure stand at the density used; WYP = weed dry weight per plant in the mixture; WTY = weed total dry weight in the pure stand at the density used.

For a given mixture:

a K_{bd} value > 1.0 indicates that meadow bromegrass had a greater competitive ability than ox-eye daisy;

a K_{bd} value < 1.0 indicates that the ox-eye daisy was more competitive than the meadow bromegrass; and

a K_{bd} value = 1.0 indicates that the two species were equal competitors.

As with the replacement diagrams and RYT_{bd} value, the RCC value derived is density-dependent (Rejmanek et al. 1989).

Aggressivity was another means of quantifying and analyzing the competitive ability of ox-eye daisy against meadow bromegrass in this experiment. It was computed by subtracting the average relative yields of meadow bromegrass in the three mixtures from the average relative yields of ox-eye daisy (Cudney 1989).

Relative competitiveness and the type of interaction was investigated using the equations and model statements of Bridgemohan and McDavid (1993) as developed by Spitters and Van den Bergh (1982):

Plant Relative Yield (on a per plant basis);

$$PRY_b = X_b/Y_b \quad (5)$$

$$PRY_d = X_d/Y_d \quad (6)$$

where the subscripts b and d signify meadow bromegrass and ox-eye daisy, respectively; X = total dry weight per plant grown in the mixture; Y = total dry weight per plant grown in monoculture.

For a given comparison:

a PRY_b or PRY_d value = 1.0 indicates that the effects of intra- and interspecific competition are similar;

a PRY_b or PRY_d value < 1.0 indicates that inter-specific competition is more severe than intraspecific competition; and

a PRY_b or PRY_d value > 1.0 indicates that intraspecific competition is more severe than interspecific competition.

The effect of low vs. high nitrogen in the soil medium on relative competitive ability was examined, as well as relating competitive ability at the two rates of nitrogen over a number of growth parameters.

Realizing the limitations of the replacement series, the results have to be qualified as to density and time restraints included in the experiment.

For both replacement diagrams, analysis of the orthogonal regression components of the total dry weight relative yields of each species were done separately. In each analysis the different relative densities of the species were the treatments. A significant deviation from the linear trend of relative yield indicated the presence of interference. Similar analyses were done for the relative yield totals (RYT_{bd}), with significant deviations from the linear trend indicating that the two species were not mutually exclusive (de Wit and Van den Bergh 1965). Fertilizer effect was analyzed separately for each species as well, with a comparison made at each proportion.

RESULTS AND DISCUSSION

Grass species and ox-eye daisy density field experiment. Germination tests on filter paper provided 75% germination, however only an average of 5 to 6% of the ox-eye daisy seed spread on the soil surface in the 1995 experiment established as seedlings (Table III-1). In the 1996 seeded experiment, 2 to 4% of the seed established.

Although there was no significant difference between treatments in establishment and persistence of ox-eye daisy in the 1995 seeded experiment, there was significantly better establishment from seed in the 1996 seeded experiment in the meadow brome grass than in the Kentucky bluegrass and no crop treatments (Table III-1). The better ox-eye daisy establishment may have resulted from an increased protective canopy cover provided by the faster growing meadow brome grass. The grass canopy may have furnished a micro environment with less moisture loss and higher humidity conducive to better seed germination and seedling survival.

The ox-eye daisy density declined over time under all three growing environments in the 1995 seeded experiment, possibly from physical injury when harvesting (Table III-1).

Increasing ox-eye daisy density resulted in a significant increase in ox-eye daisy above ground biomass m^{-2}, stem number m^{-2} and flower bud number m^{-2} when growing alone or in competition with Kentucky bluegrass (Figures III-1, 2 and 3). However, increasing the ox-eye daisy plant density up to approximately 40 plants m^{-2} in meadow bromegrass did not significantly affect the ox-eye daisy dry weight m^{-2}, stem number m^{-2} or flower bud number m^{-2} (Figures III-1, 2 and 3, Plate III-1). When Kentucky bluegrass was the companion species, ox-eye daisy growth was approximately half that of ox-eye daisy growing alone (Plate III-1).

The relationship in the no crop treatment between ox-eye daisy biomass m^{-2} and plants m^{-2} was curvilinear ($y = -0.2566x^2 + 21.677x$) with a large increase in ox-eye daisy biomass for increases in density (Figure III-1). The relationship in the Kentucky bluegrass treatment was linear ($y = 5.3543x$) with less increase in ox-eye daisy biomass for increases in density. There was no increase in ox-eye daisy yield with increasing ox-eye daisy density in the meadow brome grass treatment. At the same ox-eye daisy density, meadow brome grass provided more competition than Kentucky bluegrass. The small size of the ox-eye daisy plants growing in competition with meadow bromegrass suggests that meadow bromegrass was a stronger competitor. This was probably due to its rapid growth (Plate III-1).

Ox-eye daisy stem density (Figure III-2) and flower bud density (Figure III-3) followed the same relationship as ox-eye daisy dry weight for increases in ox-eye daisy density when growing with a grass species. The ox-eye daisy stem number m^{-2} response to increasing density, in the absence of competition, was linear (Figure III-2).

Ox-eye daisy growing alone showed a nonlinear relationship between ox-eye daisy dry weight per plant and density (Figure III-4), characteristic of many plant species (Silvertown and Doust 1993). Large individual ox-eye daisy plants were harvested from plots with low densities while smaller plants with less dry weight per plant were harvested from higher densities. The fact that individual plant size declines as density increases suggests significant intraspecific competition when ox-eye daisy grew alone. Buchanan et al. (1990) found that increasing densities of sicklepod (*Cassia obtusifolia*) and redroot pigweed (*Amaranthus retroflexus*) caused an increasing loss of cotton yield with less of a loss at the highest weed densities of each weed. It was surmised that both weeds began to interfere with themselves at the highest weed densities.

Unlike the ox-eye daisy growing alone, the ox-eye daisy growing in Kentucky bluegrass and meadow brome grass had more of a linear relationship between dry weight per plant and density, with the dry weight per plant remaining more or less the same over the different ox-eye daisy densities (Figure III-4). When growing in competition with the grass species, individual ox-eye daisy dry weight was relatively constant. The large individual plants of the no crop treatment were not found in either of the grass treatments.

Over the range of ox-eye daisy densities, the ox-eye daisy dry weight per plant without a crop was higher than the dry weight per plant of the ox-eye daisy growing in Kentucky bluegrass and this was higher than the dry weight per plant of the ox-eye daisy growing in meadow brome grass (Figure III-4). Both grass species affected the ox-eye daisy individual plant weight, with meadow brome grass causing more of a reduction than Kentucky bluegrass.

When averaged over the four ox-eye daisy densities, the amount of ox-eye daisy above-ground biomass was inversely related to the amount of forage dry weight in the three different cropping treatments (Figure III-5). By the fall of the year of seeding, meadow brome grass had produced approximately 30 times more above ground dry matter than Kentucky bluegrass. This resulted in approximately half the amount of ox-eye daisy above ground dry weight in the meadow brome grass as in the Kentucky bluegrass. Even with only 11 g m^{-2} of Kentucky bluegrass, the ox-eye daisy dry weight was reduced by 50% as compared to the dry weight produced in the absence of forage competition.

The ox-eye daisy suppression by the companion grasses was also apparent in the year after seeding. At both harvests in 1996 of the 1995 seeded experiment, the meadow brome grass treatment had approximately one eighth the dry weight of ox-eye daisy compared to the Kentucky bluegrass treatment (Figure III-6). The Kentucky bluegrass treatment had approximately half the ox-eye daisy dry weight of the no crop treatment.

Ox-eye daisy, averaged over the four seeding rates, was further compared in the three cropping treatments in Tables III-2 and 3. Even though there was no difference in the number of ox-eye daisy plants in the three different cropping treatments, the ox-eye daisy plants growing without a crop were significantly larger with more stems per plant and more dry weight per plant than the ox-eye daisy growing with a grass crop (Table III-2). This suggests that the companion grass was competing with the weed for water, nutrient, light and/or space resources.

In the fall of the year of seeding, the ox-eye daisy growing with meadow brome grass was significantly taller than the ox-eye daisy growing with Kentucky bluegrass but they had significantly fewer stems per plant and significantly less mass per plant (Table III-2). The taller, more competitive growth habit of the meadow brome grass compared to the Kentucky bluegrass resulted in tall, spindly ox-eye daisy. The 21-cm high ox-eye daisy was growing to the light in the 76-cm high meadow brome grass with a closed canopy. Howarth and Williams (1968) reported that ox-eye daisy can respond to interference from other plants by adjustment in the leaf position with enhanced petiole development.

The difference in ox-eye daisy growth between cropping treatments was even more pronounced in the year after seeding of the 1995 seeded experiment (Table III-3). One year after seeding both species, competition from the meadow brome grass resulted in ox-eye daisy plants weighing only 1 g per plant with 3 stems per plant, in contrast to an average of 22 g per plant with 36 stems per plant when growing alone. The ox-eye daisy seeded with meadow brome grass also had significantly fewer stems, fewer flower buds and less dry weight per plant than the ox-eye daisy seeded with Kentucky bluegrass at both the June and August harvests. But the Kentucky bluegrass provided some effect as the ox-eye daisy had significantly fewer stems, flower buds and dry weight per plant than the ox-eye daisy seeded without a forage crop.

It appears that ox-eye daisy is not an aggressive competitor since an ox-eye daisy density of up to 45 plants m^{-2} did not affect meadow brome or Kentucky bluegrass yield in the June, 1996 harvest of the 1995 seeded experiment (Figure III-7). The August, 1996 harvest data indicate that the higher densities of ox-eye daisy may have had some effect on Kentucky bluegrass yield (Figure III-8).

Grass species seeding rate and row spacing field experiment. As in the 1996 seeded "grass species and ox-eye daisy density" field experiment, significantly more ox-eye daisy plants established from seed in meadow brome grass than in Kentucky bluegrass or without a crop (Figure III-9). The tall meadow brome grass provided a more dense canopy that may have produced a moist soil microclimate environment for the germinating ox-eye daisy. However, ox-eye daisy establishment from seed overall was low, at 1 to 7% of the seed spread on the soil surface. This may be indicative of the sensitivity of the seed to an unsuitable environment for germination and emergence. The ox-eye daisy seed was exposed to fluctuations in moisture and temperature as the seed was spread on the soil surface.

Over the three harvests of the two experiments, the grass species had more of an effect on ox-eye daisy than the grass seeding rate or the grass row spacing (Tables III-4 to 7). There was a significant difference between Kentucky bluegrass and meadow bromegrass in nearly all measured parameters over all three harvests of both experiments.

There was significantly less ox-eye daisy above ground dry weight, dry weight per plant and flower number in meadow brome grass than in Kentucky bluegrass (Tables III-4 to 7). This difference was especially pronounced in the 1996 seeded experiment with seedling grass as compared to the 1995 seeded experiment with established grass (Tables III-4 to 7, Figures III-10 to 13, Plate III-2).

Ox-eye daisy above-ground dry weight was reduced substantially when growing with Kentucky bluegrass and meadow brome grass compared to when growing alone (Figures III-10 to 13, Plate III-2).

Even though there were significantly more ox-eye daisy plants in the meadow brome grass of the 1995 seeded experiment, these plants were smaller and yielded less than the ox-eye daisy in the Kentucky bluegrass (Tables III-4 and 6). There were more ox-eye daisy plants as well as a higher yield of ox-eye daisy in the Kentucky bluegrass than in the meadow brome grass of the 1996 seeded experiment (Tables III-5 and 7).

Comparing the three different crops in the year of seeding, ox-eye daisy had significantly fewer stems and significantly less dry weight per plant when grown with meadow brome grass as compared to Kentucky bluegrass or no crop (Table III-8). In the year after seeding, the ox-eye daisy had significantly fewer stems and significantly less dry weight per plant in both meadow brome grass and Kentucky bluegrass as compared to the no crop (Table III-9). This was an indication that Kentucky bluegrass was starting to grow and compete with the ox-eye daisy. Kentucky bluegrass was also producing a mat of litter. Grime (p. 127, 1979) suggests that litter, "either by shading or by physical impedance of germination, establishment and growth, restricts the frequency of smaller or slower-growing species". The ox-eye daisy growing alone was significantly taller than the ox-eye daisy growing with either forage crop in the year after seeding.

Whether growing in seedling grass or established grass, ox-eye daisy above ground dry weight, plant number, dry weight per plant and flower number significantly decreased as Kentucky bluegrass and meadow brome grass seeding rates increased (Table III-4, III-5) or row spacing decreased (Table III-1, III-7) for one or more harvests.

Generally over the three harvests of the two experiments, grass seeding rate had a greater effect on ox-eye daisy than row spacing (Tables III-4 to 7). There were more significant linear contrasts among parameters measured for seeding rate effect than for row spacing effect.

Ox-eye daisy above ground dry weight, dry weight per plant and flower number were more affected by grass seeding rate and row spacing when seeded with Kentucky bluegrass than when seeded with meadow brome grass (Tables III-4 to 7). There was less potential for the ox-eye daisy to be affected in meadow brome grass with the reduced ox-eye daisy biomass in the meadow brome grass treatments.

The grass seeding rate and row spacing did not affect the density of ox-eye daisy as much as the biomass and flower production of the individual plants (Tables III-4 to 7).

The grass seeding rate and row spacing treatments had the most effect on ox-eye daisy above ground dry weight, dry weight per plant and flower number in the June, 1997 harvest as compared to the other two harvest times (Tables III-4 to 7). This harvest had the largest grass and ox-eye daisy yields of the three harvests in the 1996 seeded trial.

There tended to be more of a reduction in ox-eye daisy dry weight, plant number and flower number when the seeding rate was increased from 0.5x to 1x recommended seeding rate than when the rate was increased from 1x to 2x recommended seeding rate (Figures III-14 to III-19). However, the trend to reduced ox-eye daisy dry weight, plant number and flower number with narrower row spacing continued through from 30 to 15 cm row spacing.

There were more significant seeding rate and row spacing linear contrasts when ox-eye daisy was seeded into established grass (1995 seeded experiment) than when it was seeded into seedling grass (1996 seeded experiment) (Table III-4 to 7). A more advanced grass crop should be more competitive.

There were significantly larger ox-eye daisy plants growing in the seedling Kentucky bluegrass of the 1996 seeded experiment than in the established Kentucky bluegrass of the 1995 seeded experiment (Tables III-4 to 7 and Figures III-10 to 13).

Increased grass seeding rate and reduced row spacing did not result in significantly increased grass biomass in most harvests of either experiment (Tables III-4 to 7). Where significant trends were recorded, grass yield was usually highest at the narrow row spacing. The excellent growing conditions with substantial moisture (Appendix III-A and B) allowed even the lower seeding rates and wider row spacing to produce a heavy grass biomass and tillering to fill in between the rows.

There was generally an inverse relationship between the grass biomass and the ox-eye daisy biomass (Figure III-20, III-21, Plate III-2). However, there were no reciprocal effects of ox-eye daisy on the grass, as can often occur with two plant species growing together (Silvertown 1982).

Replacement series greenhouse experiment. The replacement diagram (Figure III-22) indicates that the meadow bromegrass, grown under greenhouse conditions with ox-eye daisy at a density equivalent to 176 total plants m^{-2}, was more competitive than the ox-eye daisy rosettes. The meadow bromegrass relative yields in the mixtures are higher than the relative yields expected if both plant species were equally competitive while the ox-eye daisy relative yields are lower than the expected relative yields. The convex curve in the replacement diagram for meadow bromegrass and the concave curve for ox-eye daisy indicates a competitive relationship. There was an interaction for a common resource and the meadow bromegrass gained more than the ox-eye daisy (Radosevich 1987).

Meadow bromegrass was more competitive than ox-eye daisy rosettes at both the 5 kg ha^{-1} and the 100 kg ha^{-1} rates of nitrogen application to the pots (Figure III-22). The main difference between 5 and 100 kg ha^{-1} nitrogen in the replacement diagrams was the higher meadow bromegrass relative yield in the 75-25 meadow bromegrass:ox-eye daisy mixture. The higher level of nitrogen increased the proportion of meadow bromegrass relative to the ox-eye daisy.

The Relative Yield Totals (RYT_{bd}) were greater than 1.0 for all three species mixtures suggesting that the meadow bromegrass and the ox-eye daisy were using the resources in different ways or benefiting each other so that the total yield for the mixture was higher than the yield expected by looking at the monoculture yields (Table III-10). This may be due to the low plant density (176 plants m^{-2}) used in the experiment resulting in less competition between the two species. Higher densities were employed by Leroux (1993) with 400 plants m^{-2}, Dunan and Zimdahl (1991) with 390 plants m^{-2}, and Cudney et al. (1989) with 210 and 268 plants m^{-2} in their replacement series greenhouse experiments seeded in pots. The decrease in meadow bromegrass biomass on a per plant basis as the number of bromegrass plants increased indicates intraspecific competition (Table III-11). The meadow bromegrass intraspecific competition and the lack of inter-specific competition from ox-eye daisy might help account for the Relative Yield Totals > 1.

The Relative Crowding Coefficient (K_{bd}) values for all three planting proportions were greater than 1.0 indicating that meadow bromegrass had a greater competitive ability than ox-eye daisy at the 176 plants m^{-2} total density used in this greenhouse experiment (Table III-10). This was consistent with the results from the replacement diagrams. The Relative Crowding Coefficient has been used to compare 'competitive power' by a number of other researchers (Bakhuis and Kleter 1965; Harris 1970; Thomas 1970; Hall 1974).

The aggressivity value calculated for ox-eye daisy growing with meadow bromegrass at 5 kg ha^{-1} nitrogen was -0.24. This low value indicates that ox-eye daisy was not very competitive with meadow bromegrass in this experiment, also consistent with the replacement diagrams. The meadow bromegrass was most likely using more of the shared resources to the detriment of ox-eye daisy (Cudney et al. 1989). The low, prostrate growth habit of ox-eye daisy and the inability of the first year rosette to elongate in response to shading (Howarth and Williams 1968) will limit its aggressivity.

The Plant Relative Yields for meadow bromegrass (PRY_b) were greater than 1.0 for all three planting proportions indicating that intraspecific competition was more involved than interspecific competition for the meadow bromegrass in this experiment (Table III-10). The lower Plant Relative Yield (PRY_d) values of 0.83 to 0.86 for the ox-eye daisy pointed out that inter-specific competition was more detrimental to this species than intraspecific competition.

The meadow bromegrass total dry weight per plant increased with fewer meadow bromegrass plants per pot, at both the 5 kg ha^{-1} and the 100 kg ha^{-1} rates of nitrogen (Table III-11 and Figure III-23). This also suggests significant intraspecific competition among the bromegrass plants. There is no indication of intraspecific competition among the ox-eye daisy plants as the plants were larger in a pure stand than in the mixtures.

A nitrogen application of 100 kg ha^{-1} increased meadow bromegrass biomass compared to the 5 kg ha^{-1} rate for all three mixtures and the monoculture (Figure III-24). On a per plant basis, the meadow bromegrass above-ground biomass almost doubled in the three mixtures with 100 kg ha^{-1} nitrogen compared to 5 kg ha^{-1} (Table III-11, Plate III-3). However, nitrogen rate did not affect ox-eye daisy total biomass in any of the mixtures or when growing alone (Plate III-3). If the experiment had been continued, a fuller canopy of meadow bromegrass may have been obtained at the higher nitrogen rate resulting in significantly less ox-eye daisy total biomass in the higher nitrogen than in the lower nitrogen.

The meadow bromegrass root biomass response to the higher nitrogen level varied among mixtures (Table III-11). The ox-eye daisy growing in a mixture had significantly less root biomass at 100 kg ha^{-1} nitrogen than at 5 kg ha^{-1}. It could be speculated that the ox-eye daisy did not have to produce as extensive a root system at the higher nitrogen rate to locate nitrogen in the growth medium. The smaller root biomass per plant of the ox-eye daisy growing in the mixtures compared to growing alone at the higher nitrogen rate was most likely due to competition from the meadow bromegrass, although the reduction did not vary with the mixture. Root hair density has been found to be strongly affected by the supply of nutrients and the degree of shading (Brouwer 1962).

The decrease in ox-eye daisy root:shoot ratio with higher nitrogen is largely due to the decrease in root mass. The smaller root:shoot ratios for both plant species with the higher nitrogen rate is indicative of the plants using the higher nitrogen levels to expend more energy in above ground growth and the reduced requirement for root expansion to meet the plants' nitrogen requirements (Table III-11). Berendse and Elberse (1990) list root:shoot ratio as a plant measurement that provides an indication of ability to capture resources and thus competitiveness. A larger root system and consequently a higher root:shoot ratio may provide a plant with a competitive edge.

With more nitrogen available, it appears that meadow bromegrass also puts energy into producing more tillers as indicated by the 40 to 60% increase in apical meristems for meadow bromegrass in Table III-11. The ox-eye daisy apical meristem number per plant was not affected significantly by nitrogen level.

The 100 kg ha^{-1} nitrogen rate resulted in significantly higher meadow bromegrass leaf number and total leaf area per plant than the 5 kg ha^{-1} nitrogen rate (Table III-12). In the pure meadow bromegrass treatment, the leaf number increased from 20 to 32 leaves per plant and the leaf area increased from 224 to 466 cm^2 per plant with the higher rate of nitrogen. The ox-eye daisy leaf number and leaf area per plant were about the same at both nitrogen levels. The large difference in response in leaf area to nitrogen by the two species supports Dunan and Zimdahl's (1991) observation that leaf area is often the most sensitive measure of competition. Brouwer (1962) also states that shoot:root ratio and leaf area ratio are two additional plant parameters affected by the supply of nutrients and the degree of shading. The different parameters that provide a measure of competitive ability should be expected to change with a higher nutrient supply (Berendse and Elberse 1990).

Larger meadow bromegrass leaves, with more surface area, were harvested in the higher nitrogen treatment than in the lower nitrogen treatment (Table III-12). The ox-eye daisy did not respond to the higher nitrogen rate in leaf area ratio or leaf area per leaf. In fact, the ox-eye daisy produced significantly smaller leaves at the higher nitrogen level in the treatment with one ox-eye daisy plant and three meadow bromegrass plants.

Meadow bromegrass grew about 15 % taller at 100 kg ha^{-1} than at 5 kg ha^{-1} nitrogen (Table III-12). The ox-eye daisy did increase in height with more nitrogen when growing alone or in combination with meadow bromegrass. Ox-eye daisy height was 13 to 16 cm when growing with meadow bromegrass compared to 19 to 21 cm when growing alone. Light meter readings on the day of harvest indicated that three 94 to 120 cm tall meadow bromegrass plants reduced the amount of light reaching the ox-eye daisy rosette by approximately 75%. One meadow brome plant reduced the amount of light reaching the ox-eye daisy by approximately 37%.

Meadow bromegrass could be predicted to be more competitive than ox-eye daisy by growth habit alone. In central and west-central Alberta, meadow bromegrass usually grows taller and produces more shoots, roots and leaf area than ox-eye daisy, especially in the first year when ox-eye daisy grows as a rosette. Growing from seed, meadow bromegrass produced more biomass and produced this biomass at a more rapid rate than ox-eye daisy. According to Donald (1963), more production, at a more rapid rate are keys to success as a competitor.

CONCLUSION

Ox-eye daisy averaged 850 g of dry weight m^{-2}, 30 g per plant and 1660 flowers m^{-2} when growing alone the year after seeding under good fertility conditions (grass species and ox-eye daisy density field experiment).

Both meadow brome grass and Kentucky bluegrass suppressed ox-eye daisy growth, but meadow brome grass suppressed ox-eye daisy growth more than Kentucky bluegrass within the first two years of seeding. Even when present at relatively high densities of 40 plants m^{-2}, ox-eye daisy was reduced to 5 g of dry weight m^{-2}, 0.1 g per plant and 19 flowers m^{-2} when growing in meadow brome grass a year after seeding.

Ox-eye daisy was suppressed approximately half as much in Kentucky bluegrass as in meadow brome grass the year after seeding when the grass and weed were seeded at approximately the same time.

Ox-eye daisy was able to establish just as well or better in meadow brome grass as in Kentucky bluegrass or when seeded alone. The ox-eye daisy plants were even taller in meadow bromegrass than in Kentucky bluegrass in the year of seeding but the plants were very restricted in biomass. It may require several years for the Kentucky bluegrass to fill in between the seeding rows and establish a thatch which will suppress ox-eye daisy.

Increasing the seeding rate or reducing the row spacing may or may not significantly increase the competitive ability of the forage against ox-eye daisy.

Forage species selection is more critical. Seeding rate and row spacing may be more important for a less competitive forage species such as Kentucky bluegrass.

Even at high densities of 40 to 50 plants m^{-2}, ox-eye daisy did not significantly reduce meadow bromegrass or Kentucky bluegrass biomass.

Meadow bromegrass competed successfully with ox-eye daisy rosettes when both were grown from seed for 74 days in the greenhouse at a density of 176 plants m^{-2}.

Meadow bromegrass was more competitive than ox-eye daisy rosettes at both low and high levels of nitrogen. Meadow bromegrass responded very well to nitrogen while ox-eye daisy showed a lack of response to nitrogen. The main response by meadow bromegrass to increased nitrogen was increased leaf area per plant. At higher nitrogen levels, ox-eye daisy root biomass declined, especially when in competition with meadow bromegrass.

A competitive grass species such as meadow bromegrass, which establishes quickly, has high nutrient content and generally provides good long-term productivity, should be considered as a means of addressing an ox-eye daisy infestation in west-central Alberta.

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Table III-1: Effect of grass crop on establishment and persistence of ox-eye daisy (averaged over the four seeding rates of ox-eye daisy). Numbers in brackets are a percent of the number of ox-eye daisy seeds planted.

	Ox-eye Daisy Plants m^{-2} (% of seeded)			
	Seeded in 1995			Seeded in 1996
Grass Crop	October, 1995	June, 1996	August, 1996	September, 1996
No crop	19(5.3)	17(4.7)	12(3.3)	25(2.3) b
Kentucky bluegrass	21(5.9)	19(5.3)	12(3.3)	23(2.1) b
Meadow brome	21(5.9)	18(5.1)	13(3.5)	38(3.4) a

Means within the same column with the same letter are not significantly different (Student-Newman-Keuls test, p<0.05).

Table III-2: Effect of grass crop on ox-eye daisy average height, stem number per plant and dry weight per plant (averaged over the four seeding rates of ox-eye daisy) in September of the year of seeding (seeded in 1996).

	Grass	Ox-eye Daisy		
Grass Crop	Av.Ht(cm)	Average Height (cm)	No. of Stems per Plant	Dry Wt. per Plant (g)
No crop	0.0 c	17.9 b	18.3 a	4.3 a
Kentucky bluegrass	14.2 b	14.4 c	16.9 a	2.5 b
Meadow brome	76.2 a	20.9 a	3.6 b	0.5 c

Means within the same column with the same letter are not significantly different (Student-Newman-Keuls test, p<0.05).

Table III-3: Effect of grass crop on ox-eye daisy average stem number, flower bud number and dry weight per plant (averaged over the four seeding rates of ox-eye daisy) the year after seeding (seeded in 1995).

	No. of Stems per Plant		No. of Flower Buds per Plant		Dry Weight per Plant (g)	
Grass Crop	June, 1996	Aug. 1996	June 1996	Aug. 1996	June, 1996	Aug. 1996
No crop	35.7 a	37.6 a	27.5 a	122.7 a	22.2 a	80.3 a
Kentucky bluegrass	13.1 b	12.0 b	9.5 b	30.1 b	6.0 b	20.8 b
Meadow brome	3.4 c	2.9 c	1.2 c	2.8 c	0.9 c	2.5 c

Means within the same column with the same letter are not significantly different (Student-Newman-Keuls test, p<0.05).

Table III-4: Effect and contrasts of established Kentucky bluegrass and meadow bromegrass at three seeding rates on ox-eye daisy growth. Experiment seeded in 1995.

Seeding Rate	09/96		06/97		09/97	
(x recommended)	Bluegrass	Brome	Bluegrass	Brome	Bluegrass	Brome
			Ox-eye Daisy Dry Weight (g m^{-2})			
0.5	11.0	1.6	59.1	16.2	21.0	11.1
1	4.1	0.9	14.5	7.1	19.2	9.4
2	10.4	0.3	15.4	2.2	14.6	3.2
Average	8.5	0.9	29.7	8.5	18.3	7.9
Bluegrass vs Brome	*		**		**	
Rate Linear	ns	*	*	*	ns	*
Rate Quadratic	ns	ns	ns	ns	ns	ns
			Ox-eye Daisy Plant Number (no. m^{-2})			
0.5	14.0	22.0	30.0	62.5	14.3	35.3
1	17.5	12.0	18.3	35.3	17.0	30.8
2	14.8	5.5	15.8	22.8	12.0	20.3
Average	15.4	13.2	21.3	40.2	14.4	28.8
Bluegrass vs Brome	ns		*		***	
Rate Linear	ns	*	ns	*	ns	*
Rate Quadratic	ns	ns	ns	ns	ns	ns
			Ox-eye Daisy Dry Weight per Plant (g)			
0.5	0.6	0.07	2.0	0.25	1.5	0.34
1	0.3	0.08	0.8	0.18	1.0	0.31
2	0.7	0.10	1.0	0.06	1.3	0.27
Average	0.5	0.08	1.3	0.16	1.3	0.31
Bluegrass vs Brome	*		***		***	
Rate Linear	ns	ns	**	ns	ns	ns
Rate Quadratic	ns	ns	*	ns	ns	ns
			Ox-eye Daisy Flower Number (no. m^{-2})			
0.5	0.0	0.0	160.0	27.5	3.0	0.0
1	0.0	0.0	23.8	7.0	2.0	0.0
2	0.0	0.0	29.0	1.0	8.5	0.0
Average	0.0	0.0	70.9	11.8	4.5	0.0
Bluegrass vs Brome	ns		***		*	
Rate Linear	ns	ns	***	*	ns	ns
Rate Quadratic	ns	ns	**	ns	ns	ns
			Grass Dry Weight (g m^{-2})			
0.5	353	618	181	587	251	436
1	373	630	227	584	240	460
2	349	725	264	612	298	458
Average	358	658	224	594	263	451
Bluegrass vs Brome	***		***		***	
Rate Linear	ns	ns	ns	ns	ns	ns
Rate Quadratic	ns	ns	ns	ns	ns	ns

ns: Comparisons not sign different, different for *0.01 < P < 0.05, **0.001 < P < 0.01, ***P < 0.001.

Table III-5: Effect and contrasts of seedling Kentucky bluegrass and meadow bromegrass at three seeding rates on ox-eye daisy growth. Experiment seeded in 1996.

Seeding Rate	09/96		06/97		09/97	
(x recommended)	Bluegrass	Brome	Bluegrass	Brome	Bluegrass	Brome
			Ox-eye Daisy Dry Weight (g m^{-2})			
0.5	30.7	4.6	604.8	14.1	173.7	0.6
1	11.5	4.4	320.9	14.1	129.2	1.7
2	11.4	2.1	306.3	2.4	95.7	0.5
Average	17.9	3.7	410.7	10.2	132.9	0.9
Bluegrass vs Brome	***		***		***	
Rate Linear	**	*	*	*	*	ns
Rate Quadratic	*	ns	ns	ns	ns	ns
			Ox-eye Daisy Plant Number (no. m^{-2})			
0.5	18.3	11.3	36.0	14.5	21.0	4.0
1	10.5	16.5	24.0	18.5	23.3	13.5
2	14.0	11.3	34.0	10.5	17.3	2.0
Average	14.3	13.0	31.3	14.5	20.5	6.5
Bluegrass vs Brome	ns		**		**	
Rate Linear	***	ns	ns	ns	ns	ns
Rate Quadratic	***	ns	ns	ns	ns	*
			Ox-eye Daisy Dry Weight per Plant (g)			
0.5	1.7	0.40	17.4	1.2	8.8	0.10
1	1.1	0.22	14.2	0.8	6.4	0.07
2	0.8	0.15	9.7	0.2	6.2	0.28
Average	1.2	0.13	13.8	0.7	7.1	0.15
Bluegrass vs Brome	***		***		***	
Rate Linear	*	**	*	ns	ns	ns
Rate Quadratic	ns	ns	ns	ns	ns	ns
			Ox-eye Daisy Flower Number (no. m^{-2})			
0.5	0.0	0.0	1437	22.0	153.0	0.2
1	0.0	0.0	610	23.5	80.0	0.5
2	0.0	0.0	594	3.0	58.0	0.2
Average	0.0	0.0	880	16.2	97.0	0.3
Bluegrass vs Brome	ns		***		***	
Rate Linear	ns	ns	*	ns	*	ns
Rate Quadratic	ns	ns	ns	ns	ns	ns
			Grass Dry Weight (g m^{-2})			
0.5	39	307	169	839	113	558
1	51	327	215	747	195	488
2	67	405	221	805	174	685
Average	52	346	202	797	161	577
Bluegrass vs Brome	***		***		***	
Rate Linear	ns	*	ns	ns	ns	**
Rate Quadratic	ns	ns	ns	ns	ns	**

ns: Comparisons not sign different, different for *0.01 < P < 0.05, **0.001 < P < 0.01, ***P < 0.001.

Table III-6: Effect and contrasts of established Kentucky bluegrass and meadow bromegrass at three row spacings on ox-eye daisy growth. Experiment seeded in 1995.

Row Spacing	09/96		06/97		09/97	
(cm)	Bluegrass	Brome	Bluegrass	Brome	Bluegrass	Brome
			Ox-eye Daisy Dry Weight (g m^{-2})			
30	4.1	0.9	14.5	7.1	19.2	9.4
22.5	3.2	0.3	5.5	2.7	11.5	7.8
15	0.1	0.1	0.3	2.7	3.6	5.6
Average	2.5	0.4	6.8	4.2	11.4	7.6
Bluegrass vs Brome	*		ns		ns	
Row Sp Linear	ns	*	*	ns	ns	ns
Row Sp Quadratic	ns	ns	ns	ns	ns	ns
			Ox-eye Daisy Plant Number (no. m^{-2})			
30	17.5	12.0	18.3	35.3	17.0	30.8
22.5	6.8	7.5	18.0	43.0	11.3	33.3
15	1.3	3.0	4.5	31.0	4.2	28.5
Average	8.5	7.5	13.6	36.4	10.8	30.9
Bluegrass vs Brome	ns		***		***	
Row Sp Linear	*	*	*	ns	*	ns
Row Sp Quadratic	ns	ns	ns	ns	ns	ns
			Ox-eye Daisy Dry Weight per Plant (g)			
30	0.26	0.08	0.75	0.18	1.04	0.31
22.5	0.40	0.04	0.45	0.06	1.11	0.24
15	0.06	0.03	0.12	0.06	1.03	0.27
Average	0.24	0.05	0.44	0.10	1.06	0.27
Bluegrass vs Brome	*		**		***	
Row Sp Linear	ns	ns	*	*	ns	ns
Row Sp Quadratic	ns	ns	ns	ns	ns	ns
			Ox-eye Daisy Flower Number (no. m^{-2})			
30	0.0	0.0	23.8	7.0	2.0	0.0
22.5	0.0	0.0	15.3	0.3	1.0	0.0
15	0.0	0.0	0.0	1.5	0.0	0.0
Average	0.0	0.0	13.0	2.9	1.0	0.0
Bluegrass vs Brome	ns		**		*	
Row Sp Linear	ns	ns	**	ns	ns	ns
Row Sp Quadratic	ns	ns	ns	ns	ns	ns
			Grass Dry Weight (g m^{-2})			
30	373	630	227	584	240	460
22.5	273	728	153	691	216	483
15	408	763	224	578	375	688
Average	351	707	201	618	277	544
Bluegrass vs Brome	***		***		***	
Row Sp Linear	ns	ns	ns	ns	*	*
Row Sp Quadratic	*	ns	ns	ns	ns	ns

ns: Comparisons not sign different, different for *0.01 < P < 0.05, **0.001 < P < 0.01, ***P < 0.001.

Table III-7: Effect and contrasts of seedling Kentucky bluegrass and meadow bromegrass at three row spacings on ox-eye daisy growth. Experiment seeded in 1996.

Row Spacing	09/96		06/97		09/97	
(cm)	Bluegrass	Brome	Bluegrass	Brome	Bluegrass	Brome
			Ox-eye Daisy Dry Weight ($g\ m^{-2}$)			
30	11.5	4.4	320.9	14.1	129.2	1.7
22.5	11.6	2.0	308.9	6.0	97.8	1.7
15	12.1	1.7	274.7	3.5	67.7	0.7
Average	11.7	2.7	301.5	7.9	98.2	1.4
Bluegrass vs Brome	***		***		***	
Row Sp Linear	ns	ns	ns	ns	**	ns
Row Sp Quadratic	ns	ns	ns	ns	ns	ns
			Ox-eye Daisy Plant Number (no. m^{-2})			
30	10.5	16.5	24.0	18.5	23.3	13.5
22.5	13.3	11.0	31.0	18.0	21.0	4.3
15	12.8	10.5	28.0	12.5	16.8	5.0
Average	12.2	12.7	27.7	16.3	20.4	7.6
Bluegrass vs Brome	ns		*		**	
Row Sp Linear	ns	ns	ns	ns	ns	ns
Row Sp Quadratic	ns	ns	ns	ns	ns	ns
			Ox-eye Daisy Dry Weight per Plant (g)			
30	1.1	0.22	14.2	0.81	6.4	0.07
22.5	0.8	0.17	12.3	0.23	4.6	0.35
15	1.2	0.17	11.3	0.26	4.2	0.21
Average	1.0	0.19	12.6	0.43	5.1	0.21
Bluegrass vs Brome	***		***		***	
Row Sp Linear	ns	ns	ns	ns	ns	ns
Row Sp Quadratic	ns	ns	ns	ns	ns	ns
			Ox-eye Daisy Flower Number (no. m^{-2})			
30	0.0	0.0	610.0	23.5	80.0	0.5
22.5	0.0	0.0	762.0	19.0	61.3	1.0
15	0.0	0.0	661.0	10.0	56.3	0.0
Average	0.0	0.0	677.7	17.5	65.9	0.5
Bluegrass vs Brome	ns		***		***	
Row Sp Linear	ns	ns	ns	ns	ns	ns
Row Sp Quadratic	ns	ns	ns	ns	ns	ns
			Grass Dry Weight ($g\ m^{-2}$)			
30	51	327	215	747	195	488
22.5	68	401	257	892	214	645
15	72	455	281	1018	263	696
Average	64	394	251	886	224	610
Bluegrass vs Brome	***		***		***	
Row Sp Linear	ns	*	ns	ns	ns	*
Row Sp Quadratic	ns	ns	ns	ns	ns	ns

ns: Comparisons not sign different, different for *0.01 $< P <$ 0.05, **0.001 $< P <$ 0.01, ***$P <$ 0.001.

Table III-8: Effect of seedling grass crop on ox-eye daisy average height, stem number per plant and dry weight per plant (averaged over the grass seeding rates and row spacings) in September, 1996 (seeded in 1996).

	Grass	Ox-eye Daisy		
Grass Crop	Av.Ht(cm)	Average Height (cm)	No. of Stems per Plant	Dry Wt. per Plant (g)
No crop	0.0 c	17.9	23.9 a	8.8 a
Kentucky bluegrass	19.6 b	15.2	16.6 a	4.2 ab
Meadow brome	77.0 a	15.9	3.1 b	0.5 b

Means within the same column with the same letter are not significantly different (Student-Newman-Keuls test, $p<0.05$).

Table III-9: Effect of established grass crop on ox-eye daisy average height, stem number per plant and dry weight per plant (averaged over the grass seeding rates and row spacings) in September, 1996 (seeded in 1995).

	Grass	Ox-eye Daisy		
Grass Crop	Av.Ht(cm)	Average Height (cm)	No. of Stems per Plant	Dry Wt. per Plant (g)
No crop	0.0 c	26.7 a	79.8 a	55.4 a
Kentucky bluegrass	37.0 b	9.1 b	2.0 b	0.4 b
Meadow brome	91.2 a	5.8 b	1.0 b	0.1 b

Means within the same column with the same letter are not significantly different (Student-Newman-Keuls test, $p<0.05$).

Table III-10: Relative Yield Total (RYT_{bd}) of meadow bromegrass and ox-eye daisy, relative crowding coefficient of meadow bromegrass growing with ox-eye daisy (K_{bd}), Plant Relative Yield of meadow bromegrass (PRY_b) and Plant Relative Yield of ox-eye daisy (PRY_d) at varying proportions of meadow bromegrass and ox-eye daisy. Values derived from total (shoot + root) biomass harvested 74 days after transplanting as seedlings in a replacement series greenhouse experiment with 5 kg ha^{-1} N.

Brome:Daisy Proportion	RYT_{bd}	K_{bd}	PRY_b	PRY_d
75:25	1.01	1.24	1.05	0.83
50:50	1.10	1.67	1.39	0.83
25:75	1.14	2.38	2.00	0.86

Table III-11: Effect of species proportion and nitrogen rate on meadow bromegrass and ox-eye daisy growth parameters in replacement series greenhouse experiment.

	Meadow Bromegrass:Ox-eye Daisy Proportions							
	Pure Brome	75:25 Brome:Daisy		50:50 Brome:Daisy		25:75 Brome:Daisy		Pure Daisy
			Total (Shoot + Root) Dry Weight (g) per Plant					
5 kg N ha-1	4.8	5.1	0.95	6.7	0.95	9.7	0.99	1.15
100 kg N ha-1	7.6	9.1	0.86	10.3	0.91	14.2	0.74	0.95
% Increase	58%	78%	-9%	54%	-4%	46%	-25%	-17%
N Rate	*	**	ns	**	ns	***	ns	ns
			Shoot Dry Weight (g) per Plant					
5 kg N ha-1	2.5	2.7	0.80	3.2	0.78	4.9	0.79	0.92
100 kg N ha-1	4.1	5.2	0.81	5.7	0.85	9.4	0.67	0.77
% Increase	64%	93%	1%	78%	9%	92%	-15%	-16%
N Rate	**	***	ns	***	ns	***	ns	ns
			Root Dry Weight (g) per Plant					
5 kg N ha-1	2.4	2.4	0.16	3.5	0.17	4.8	0.20	0.23
100 kg N ha-1	3.5	3.9	0.05	4.1	0.06	4.8	0.07	0.18
% Increase	46%	63%	-69%	17%	-65%	0%	-65%	-22%
N Rate	ns	*	**	ns	***	ns	***	ns
			Root:Shoot Ratio (g/g)					
5 kg N ha-1	0.95	0.85	0.24	1.08	0.22	0.98	0.26	0.24
100 kg N ha-1	0.85	0.76	0.07	0.73	0.06	0.51	0.10	0.23
% Increase	-11%	-11%	-71%	-32%	-73%	-48%	-62%	-4%
N Rate	ns	ns	***	*	***	***	***	ns
			Apical Meristem No. per Plant					
5 kg N ha-1	5.6	6.7	6.7	8.3	5.4	9.7	5.4	5.4
100 kg N ha-1	8.9	9.6	6.7	11.7	6.0	13.7	5.7	5.7
% Increase	59%	43%	0%	41%	11%	41%	6%	6%
N Rate	**	*	ns	**	ns	**	ns	ns

*** .01 < P < .05, ** .001 < P .01, *** P < .001**

Table III-12: Effect of species proportion and nitrogen rate on meadow bromegrass and ox-eye daisy leaf parameters and average height in replacement series greenhouse experiment.

	Meadow Bromegrass:Ox-eye Daisy Proportions							
	Pure Brome	75:25 Brome	75:25 Daisy	50:50 Brome	50:50 Daisy	25:75 Brome	25:75 Daisy	Pure Daisy
				Leaf Number per Plant				
5 kg N ha-1	20.2	22.2	53	27.4	48	29.7	44	50
100 kg N ha-1	31.9	38.7	62	44.7	54	56.2	49	51
% Increase	58%	74%	17%	63%	13%	89%	11%	2%
N Rate	**	***	ns	***	ns	***	ns	ns
				Leaf Area per Plant (cm^2)				
5 kg N ha-1	224	252	161	312	148	415	139	179
100 kg N ha-1	466	555	143	630	165	1102	135	159
% Increase	108%	120%	-11%	102%	11%	166%	-3%	-11%
N Rate	***	***	ns	***	ns	***	ns	ns
				Leaf Area Ratio (cm^2 g^{-1})				
5 kg N ha-1	92	96	204	96	190	87	177	196
100 kg N ha-1	114	108	184	109	197	118	199	204
% Increase	24%	13%	-10%	14%	4%	36%	12%	4%
N Rate	**	ns	ns	ns	ns	***	ns	ns
				Leaf Area per Leaf (cm^2)				
5 kg N ha-1	11.2	12.0	3.0	11.6	3.1	14.5	3.2	3.6
100 kg N ha-1	14.8	14.6	2.3	14.1	3.1	19.8	2.8	3.1
% Increase	32%	22%	-23%	22%	0%	37%	-13%	-14%
N Rate	*	ns	*	ns	ns	**	ns	ns
				Average Height (cm)				
5 kg N ha-1	94	99	13.8	99	14.2	99	16.0	20.5
100 kg N ha-1	108	114	12.7	110	15.5	120	15.8	18.7
% Increase	15%	15%	-8%	13%	9%	21%	-1%	-9%
N Rate	**	**	ns	*	ns	***	ns	ns

*** .01 < P < .05, ** .001 < P .01, *** P < .001**

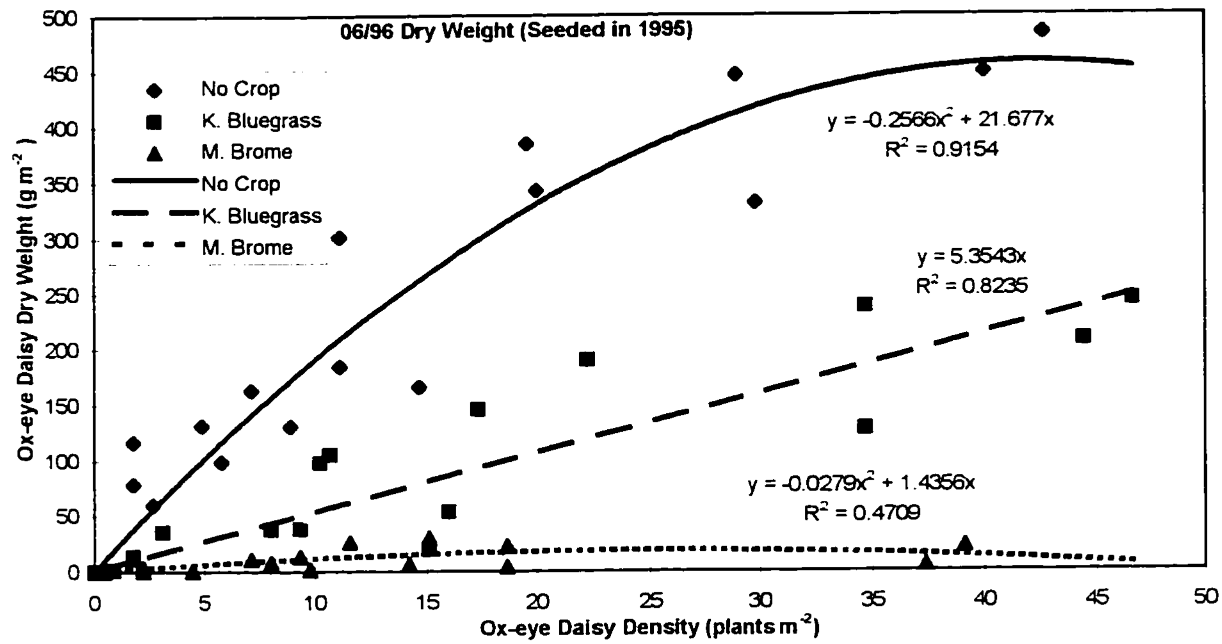


Figure III-1: Regression curves for effect of ox-eye daisy density on ox-eye daisy dry weight m^{-2} for 3 cropping regimes in June, 1996. The grass crops and ox-eye daisy were seeded in June, 1995.

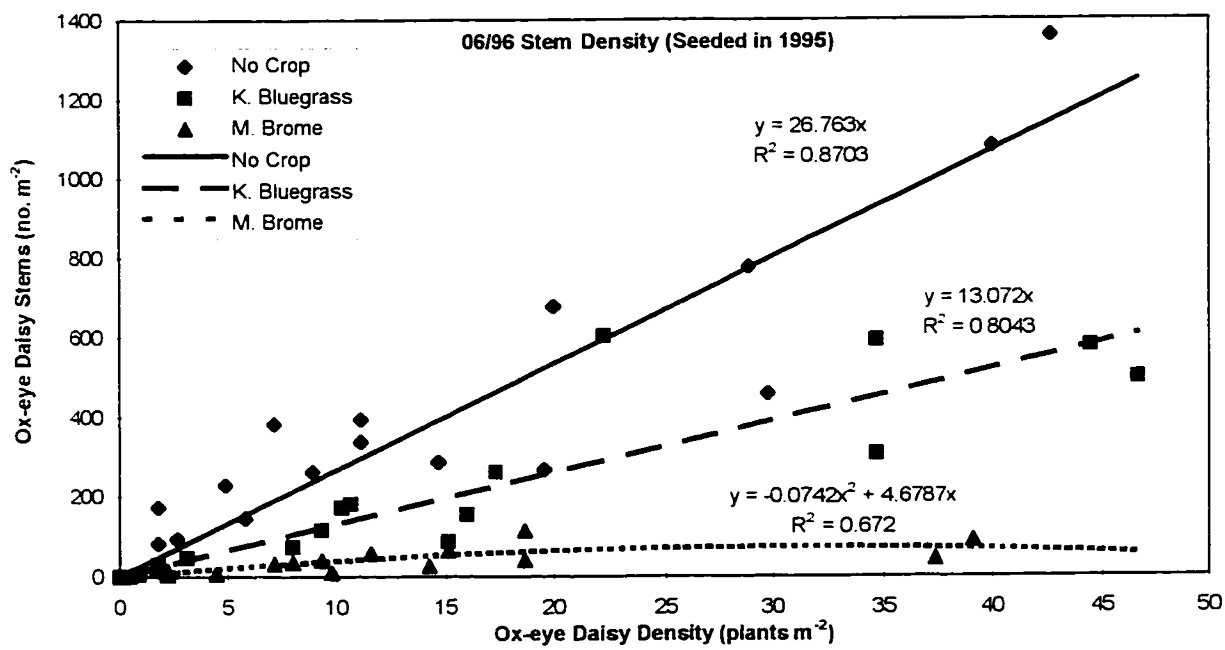


Figure III-2: Regression curves for effect of ox-eye daisy density on ox-eye daisy stem number m^{-2} for 3 cropping regimes in June, 1996. The grass crops and ox-eye daisy were seeded in June, 1995.

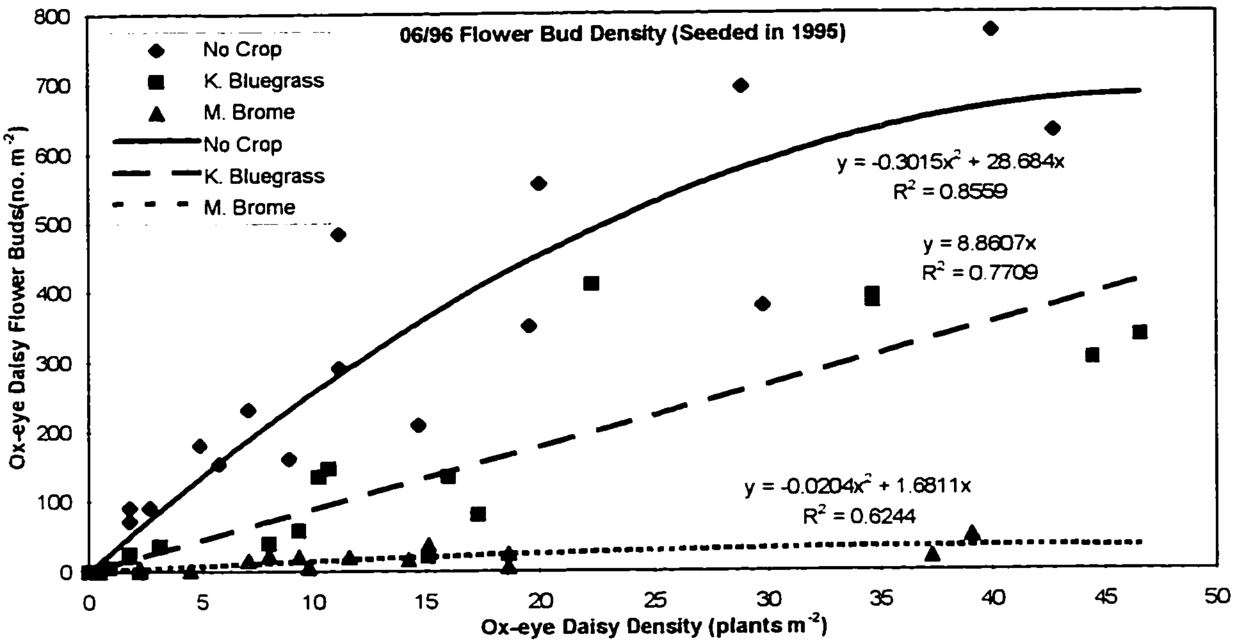


Figure III-3: Regression curves for effect of ox-eye daisy density on ox-eye daisy flower bud number m^{-2} for 3 cropping regimes in June, 1996. The grass crops and ox-eye daisy were seeded in June, 1995.

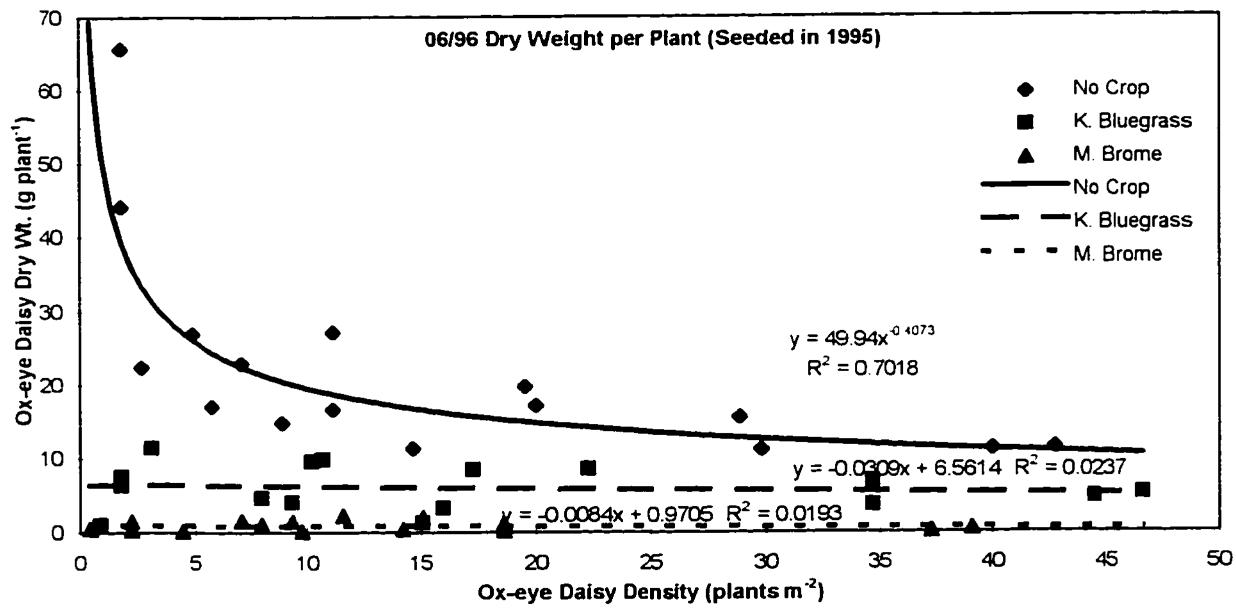


Figure III-4: Regression curves for effect of ox-eye daisy density on ox-eye daisy dry weight $plant^{-1}$ for 3 cropping regimes in June, 1996. The grass crops and ox-eye daisy were seeded in June, 1995.

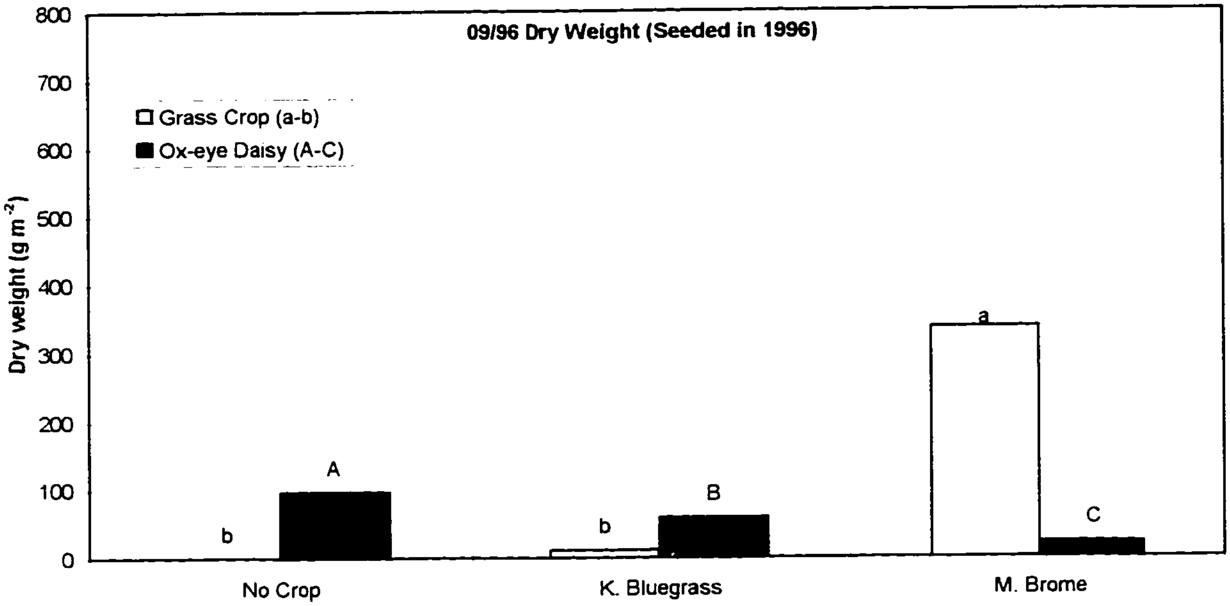


Figure III-5: Effect of grass crop on ox-eye daisy growth September, 1996 (averaged over the four ox-eye daisy seeding rates). The grass crops and ox-eye daisy were seeded in June, 1996. Means within the grass crop (a - b) or ox-eye daisy (A - C) with the same letter above are not significantly different (Student-Newman-Keuls test, $p<0.05$).

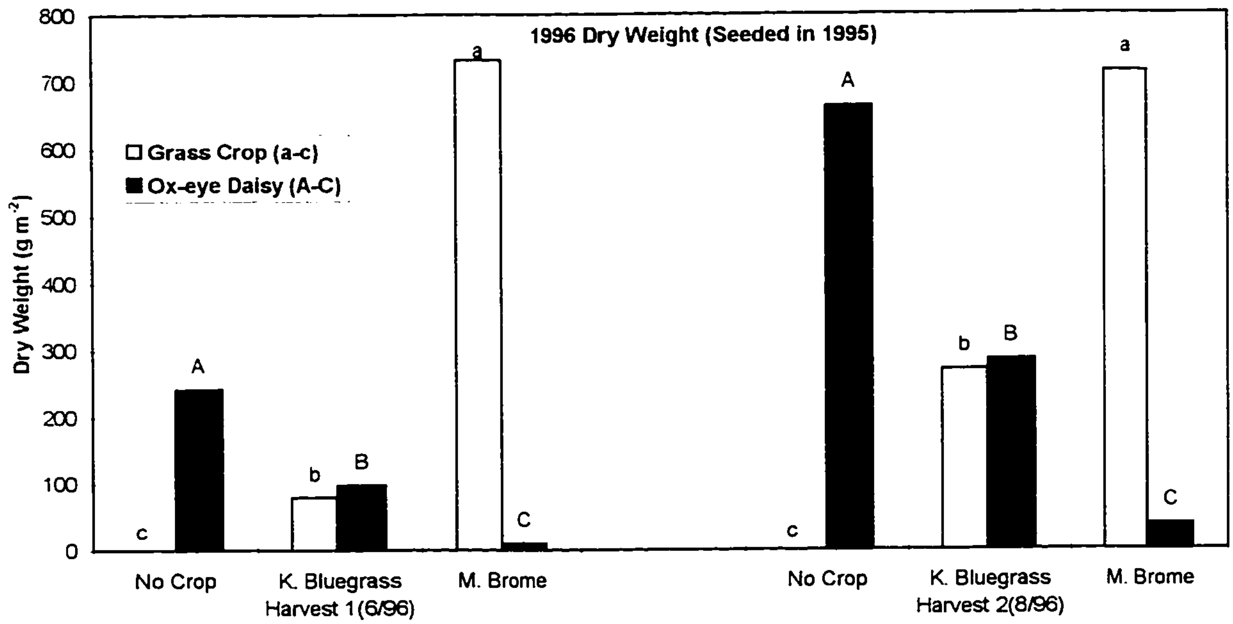


Figure III-6: Effect of grass crop on ox-eye daisy growth at two harvest times (June, 1996 and August, 1996) (averaged over the four ox-eye daisy seeding rates). The grass crops and ox-eye daisy were seeded in June, 1995. Within each harvest, grass crop (a - c) or ox-eye daisy (A - C) means with the same letter above are not significantly different (Student-Newman-Keuls test, $p<0.05$).

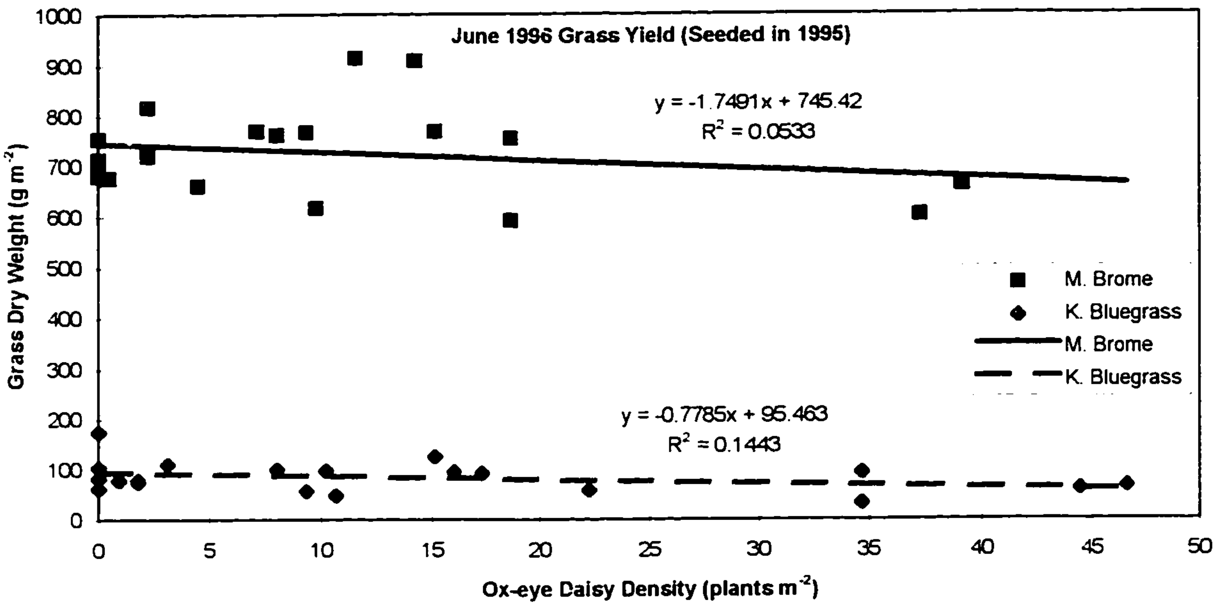


Figure III-7: Regression curves for effect of ox-eye daisy density on grass dry weight m^{-2} for the 2 grass crops in June, 1996. The grass crops and ox-eye daisy were seeded in June, 1995.

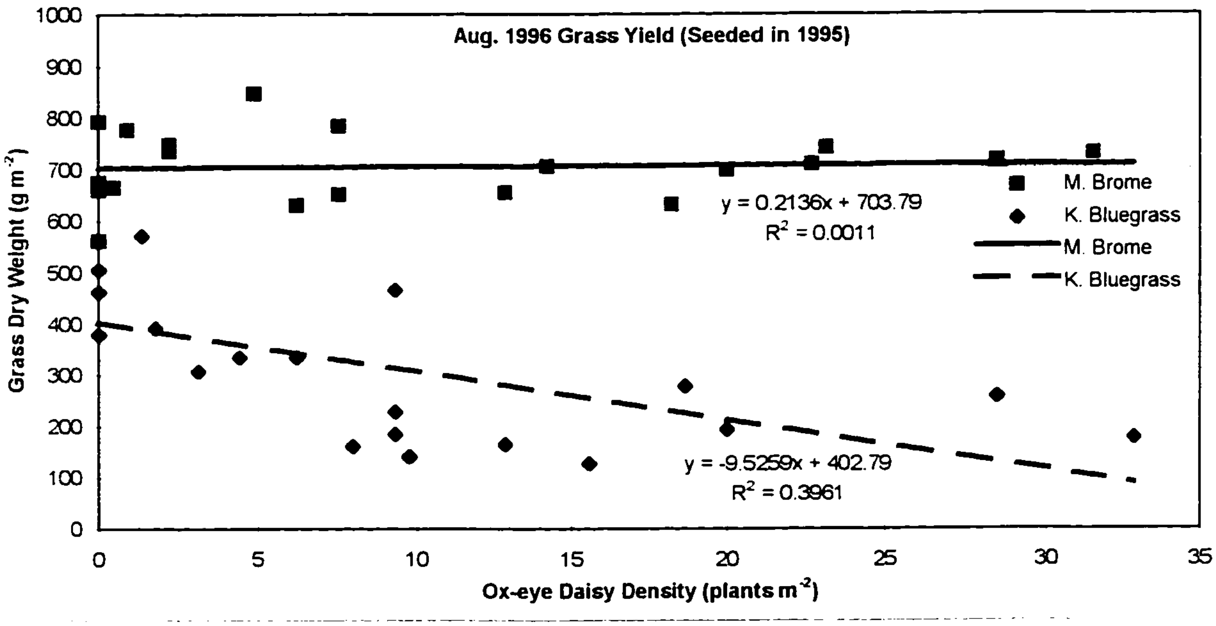


Figure III-8: Regression curves for effect of ox-eye daisy density on grass dry weight m^{-2} for the 2 grass crops in August, 1996 (harvest of regrowth from June, 1996 harvest). The grass crops and ox-eye daisy were seeded in June, 1995.

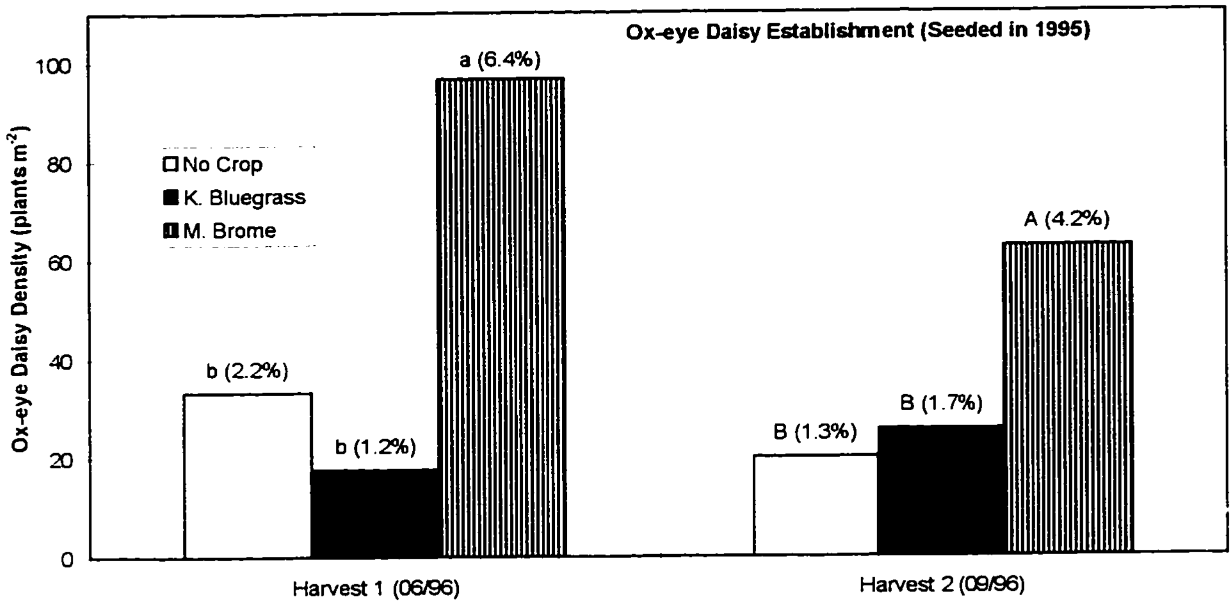
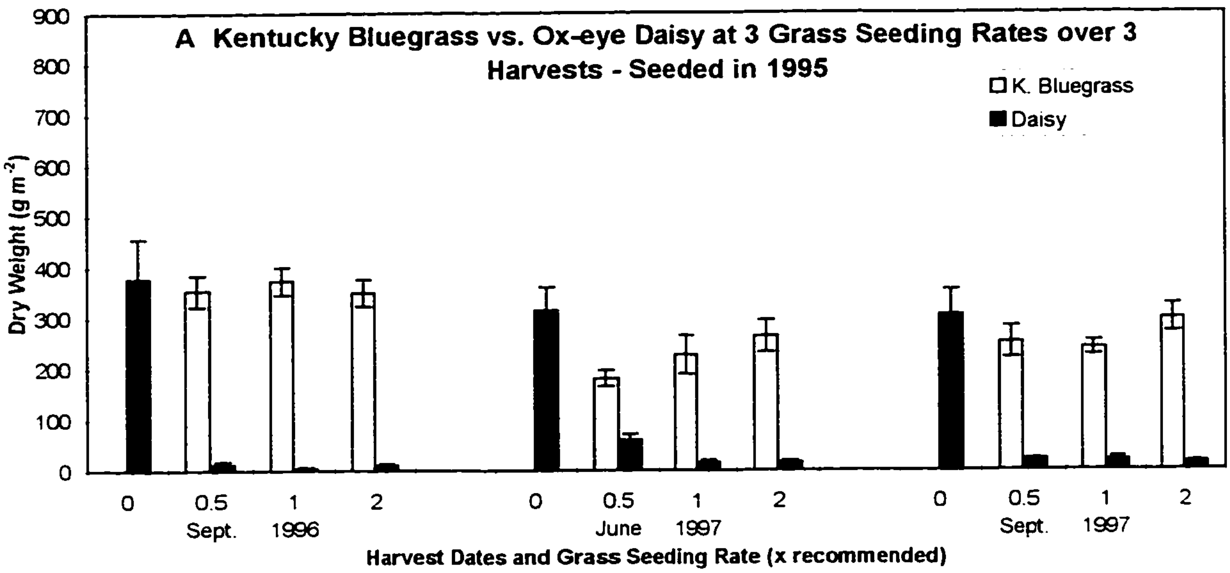


Figure III-9: Effect of grass crop on establishment and persistence of ox-eye daisy (averaged over the grass seeding rates and row spacings). Numbers in brackets are a percent of the number of ox-eye daisy seeds planted. Within each harvest, means with the same letter above are not significantly different (Student-Newman-Keuls test, $p<0.05$).



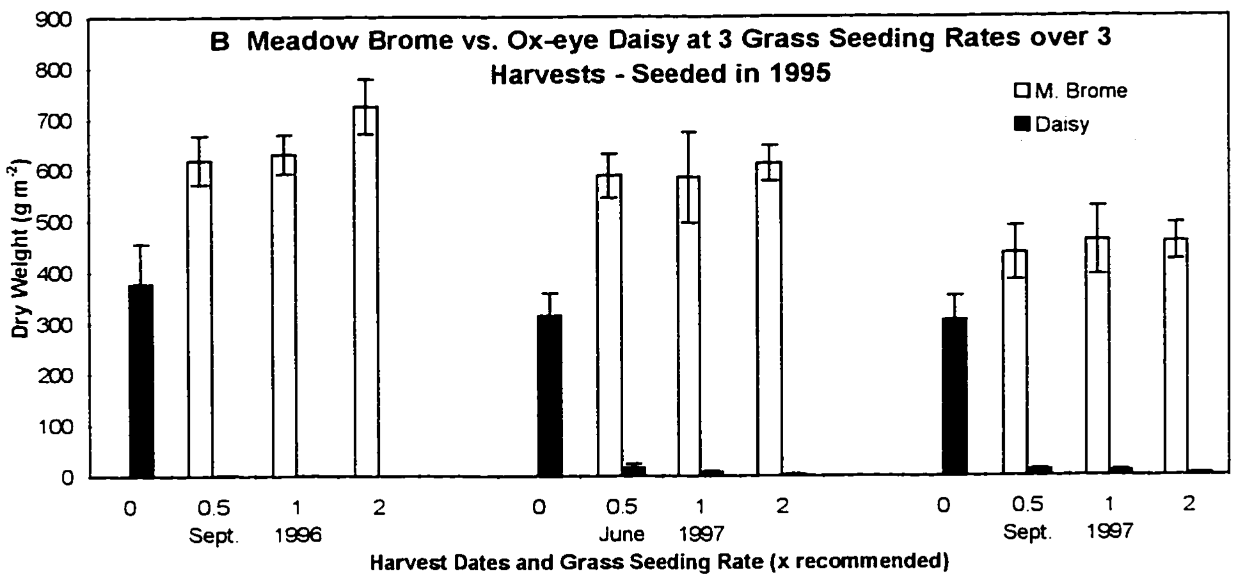
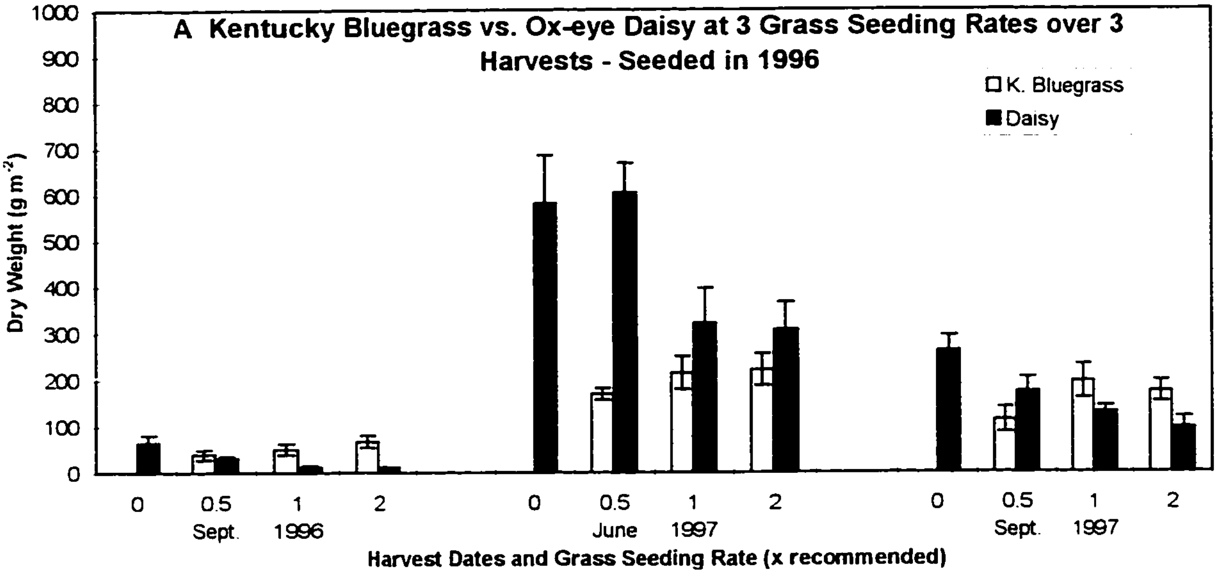


Figure III-10: Ox-eye daisy and grass dry weights with ox-eye daisy growing alone and with three seeding rates of Kentucky bluegrass (A) and three seeding rates of meadow brome grass (B). Experiment seeded in 1995 and three harvests conducted in 1996 and 1997. Bars represent standard error of the mean. See Table III-4 for significant linear and quadratic contrasts.



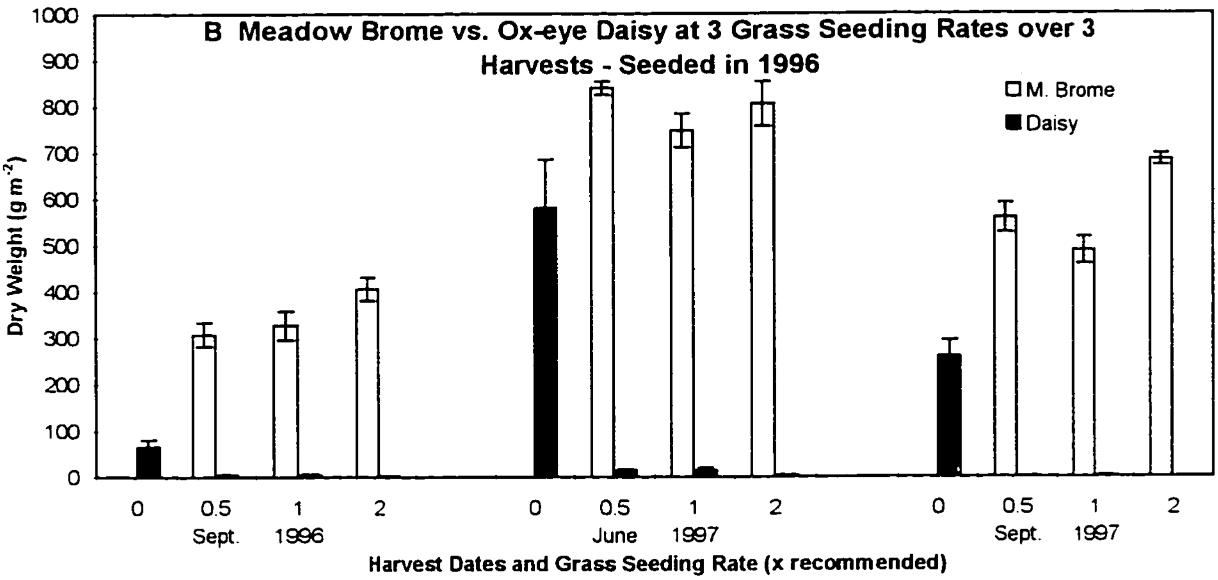
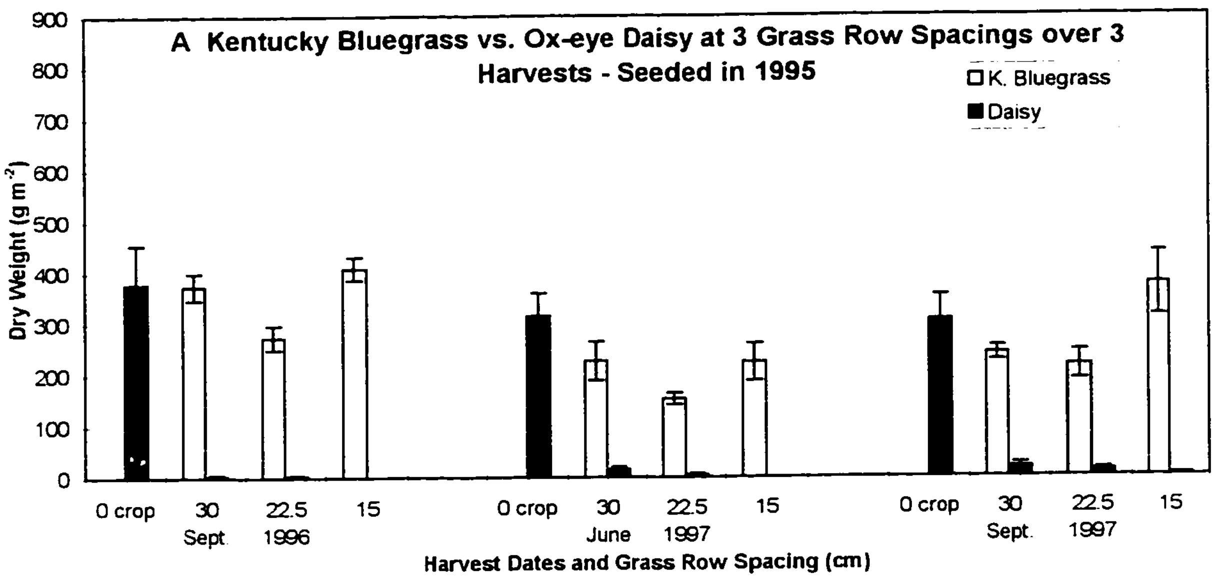


Figure III-11: Ox-eye daisy and grass dry weights with ox-eye daisy growing alone and with three seeding rates of Kentucky bluegrass (A) and three seeding rates of meadow brome grass (B). Experiment seeded in 1996 and three harvests conducted in 1996 and 1997. Bars represent standard error of the mean. See Table III-5 for significant linear and quadratic contrasts.



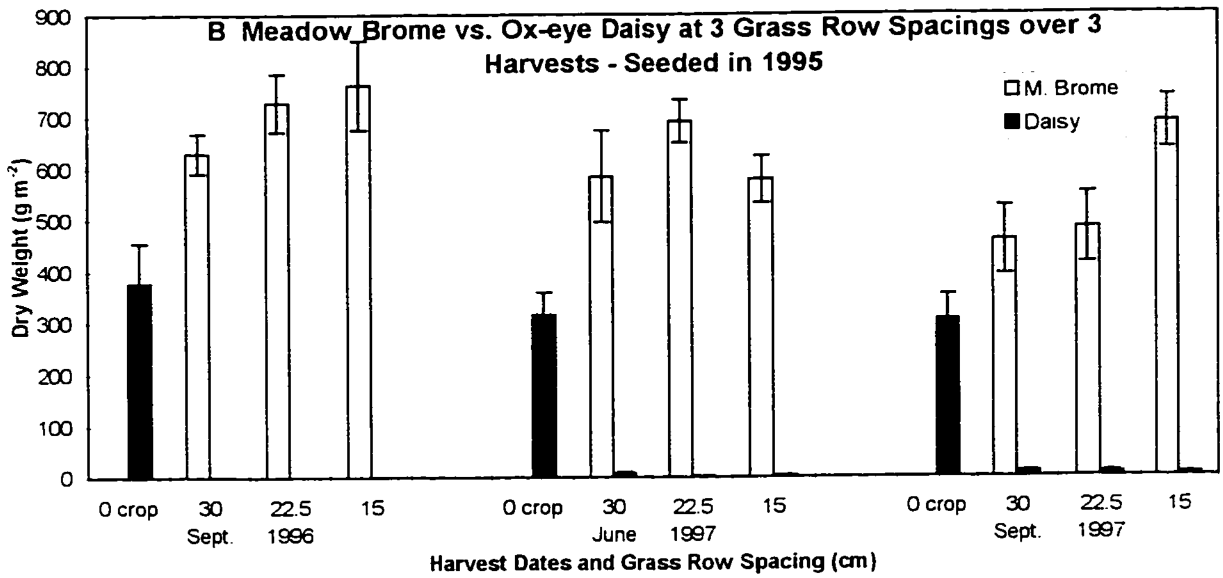


Figure III-12: Ox-eye daisy and grass dry weights with ox-eye daisy growing alone and with three row spacings of Kentucky bluegrass (A) and three row spacings of meadow brome grass (B). Experiment seeded in 1995 and three harvests conducted in 1996 and 1997. Bars represent standard error of the mean. See Table III-6 for significant linear and quadratic contrasts.

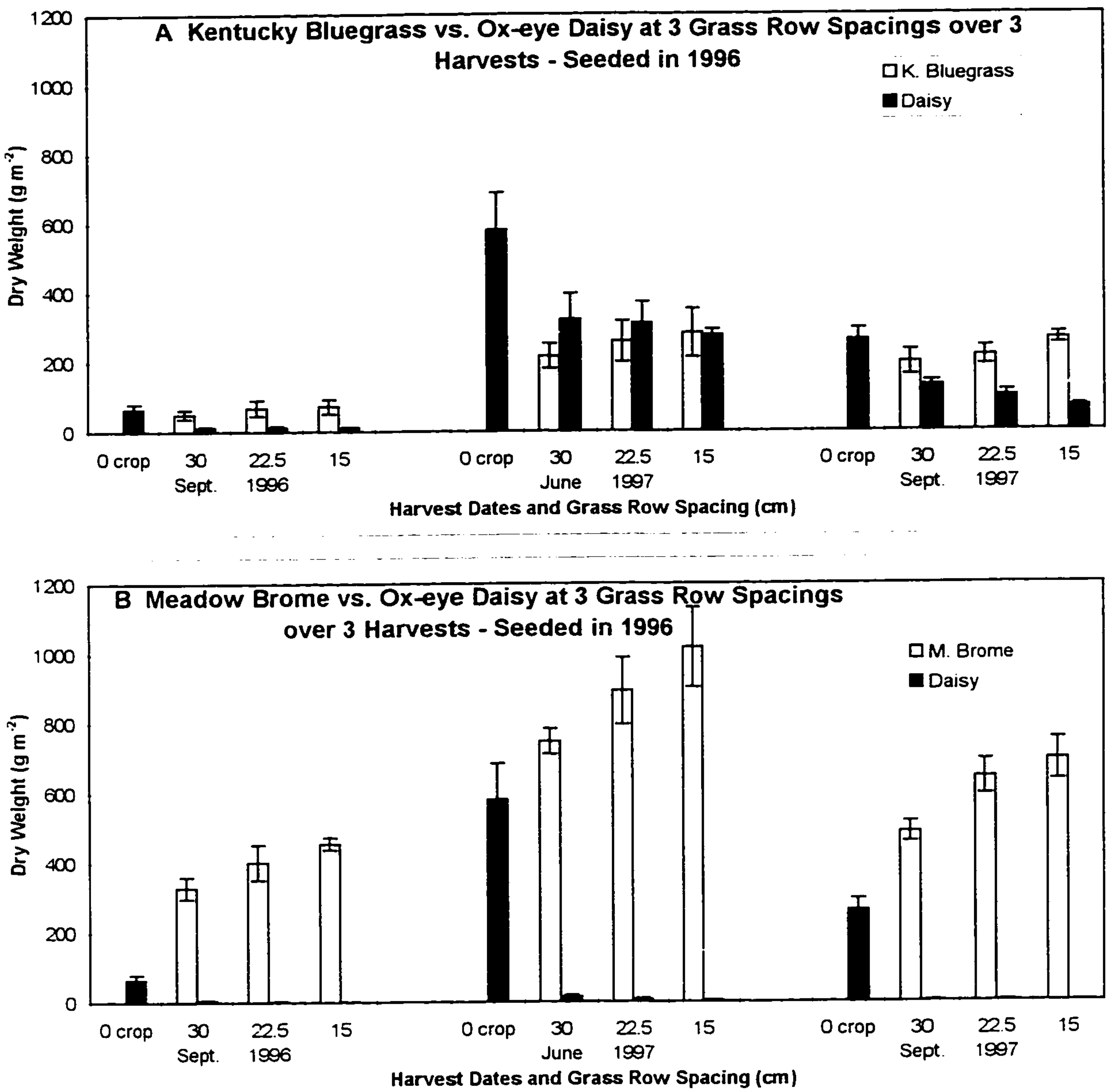


Figure III-13: Ox-eye daisy and grass dry weights with ox-eye daisy growing alone and with three row spacings of Kentucky bluegrass (A) and three row spacings of meadow brome grass (B). Experiment seeded in 1996 and three harvests conducted in 1996 and 1997. Bars represent standard error of the mean. See Table III-7 for significant linear and quadratic contrasts.

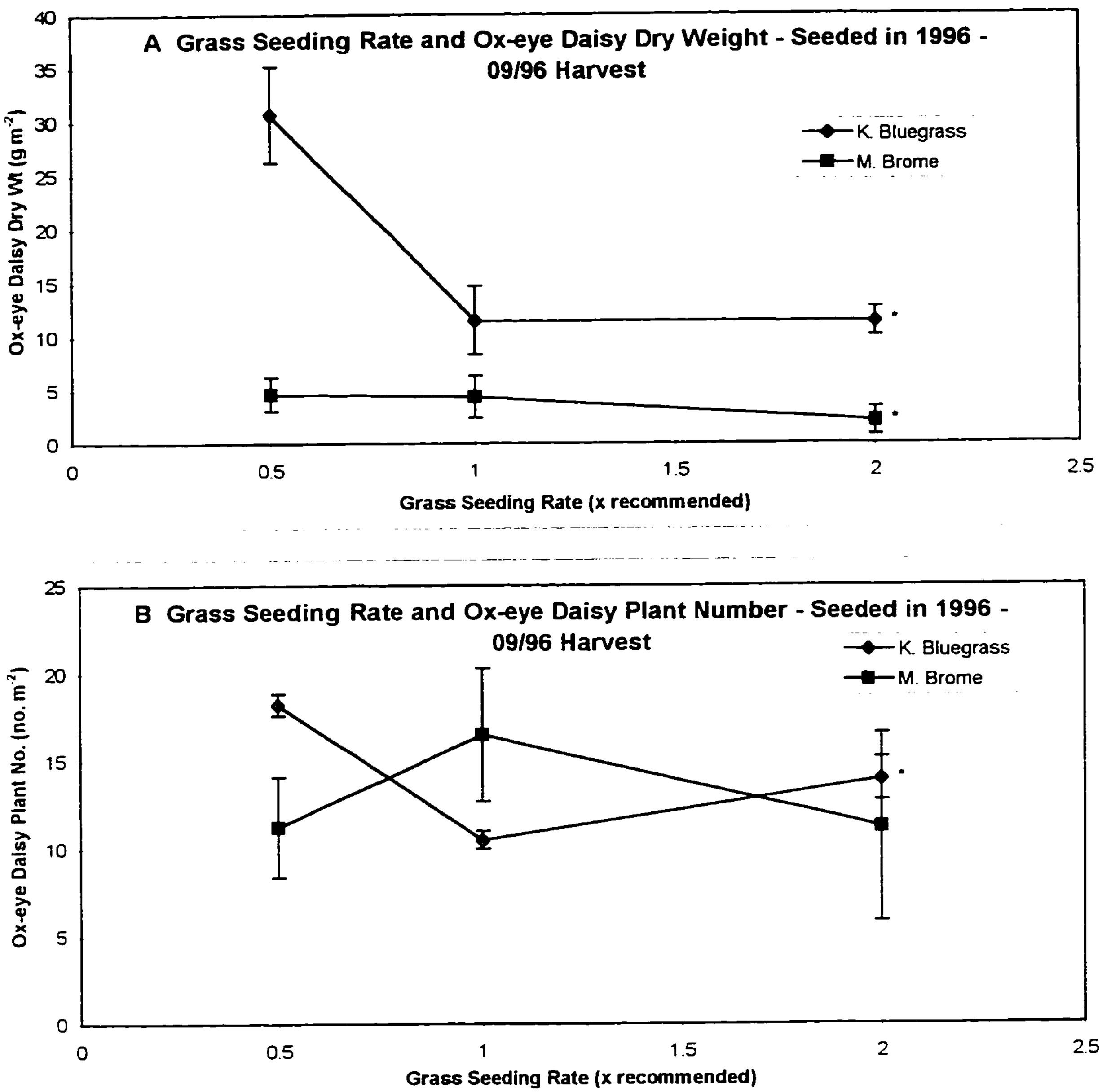
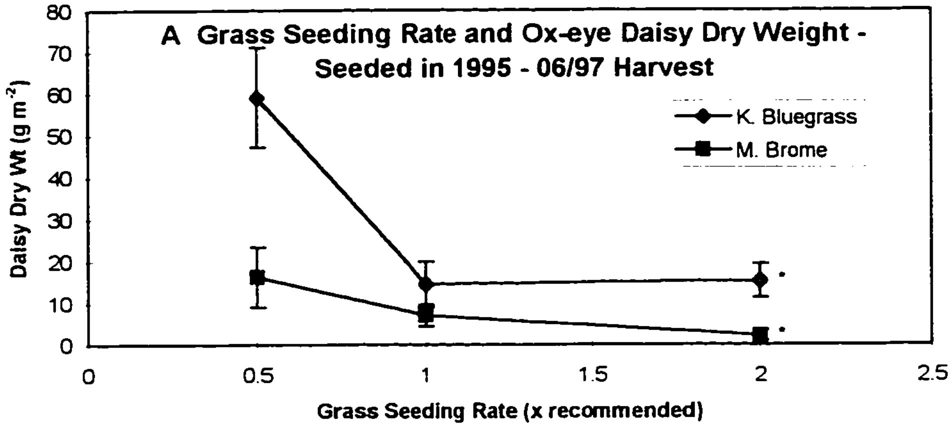
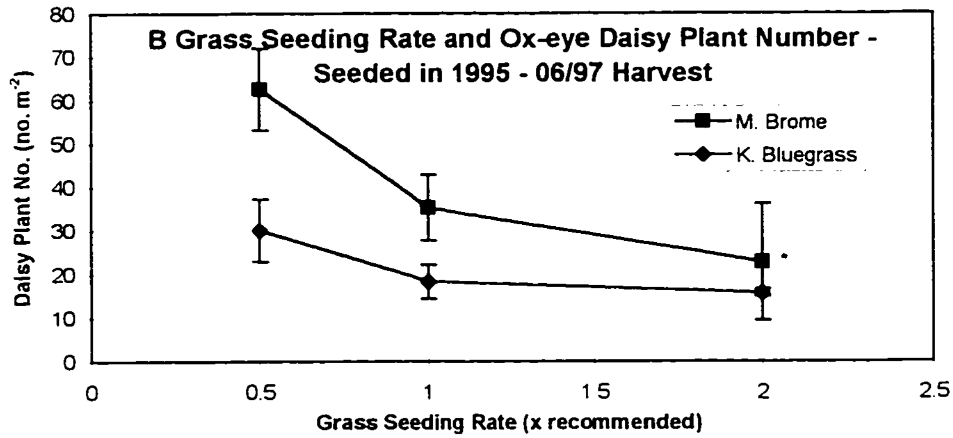


Figure III-14: Ox-eye daisy dry weight (A) and plant number (B) at three seeding rates of Kentucky bluegrass and meadow brome grass. Data collected 09/96 from experiment seeded in 1996. Bars represent standard error of the mean. Stars indicate significant linear contrasts ($p < 0.05$).





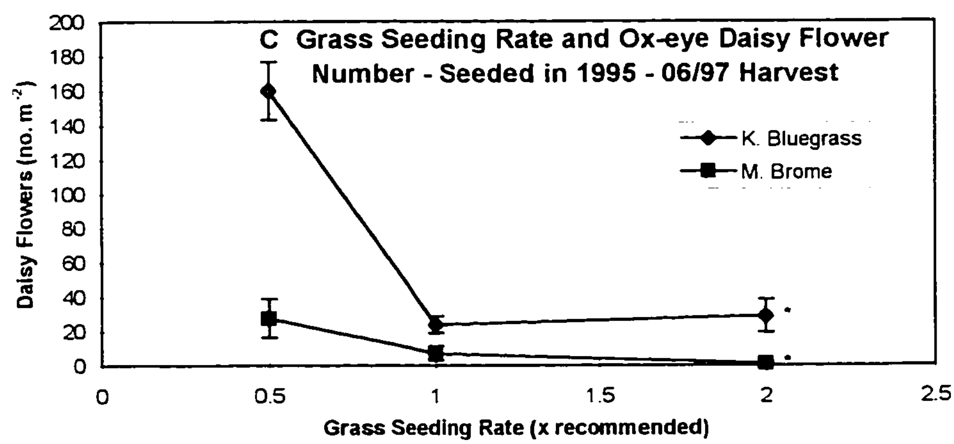


Figure III-15: Ox-eye daisy dry weight (A), plant number (B) and flower number (C) at three seeding rates of Kentucky bluegrass and meadow brome grass. Data collected 06/97 from experiment seeded in 1995. Bars represent standard error of the mean. Stars indicate significant linear contrasts ($P < 0.05$).

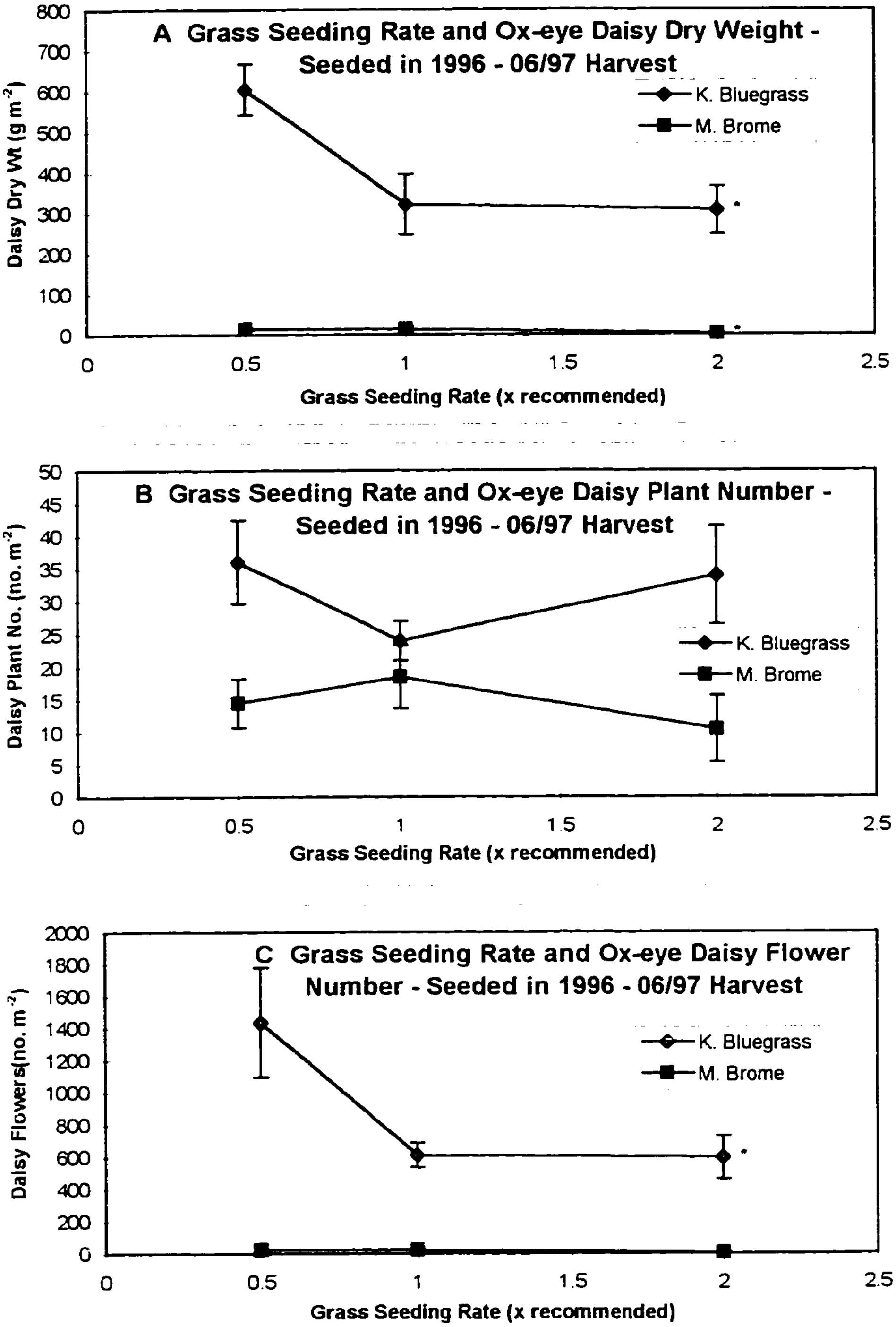


Figure III-16: Ox-eye daisy dry weight (A), plant number (B) and flower number (C) at three seeding rates of Kentucky bluegrass and meadow brome grass. Data collected 06/97 from experiment seeded in 1996. Bars represent standard error of the mean. Stars indicate significant linear contrasts.

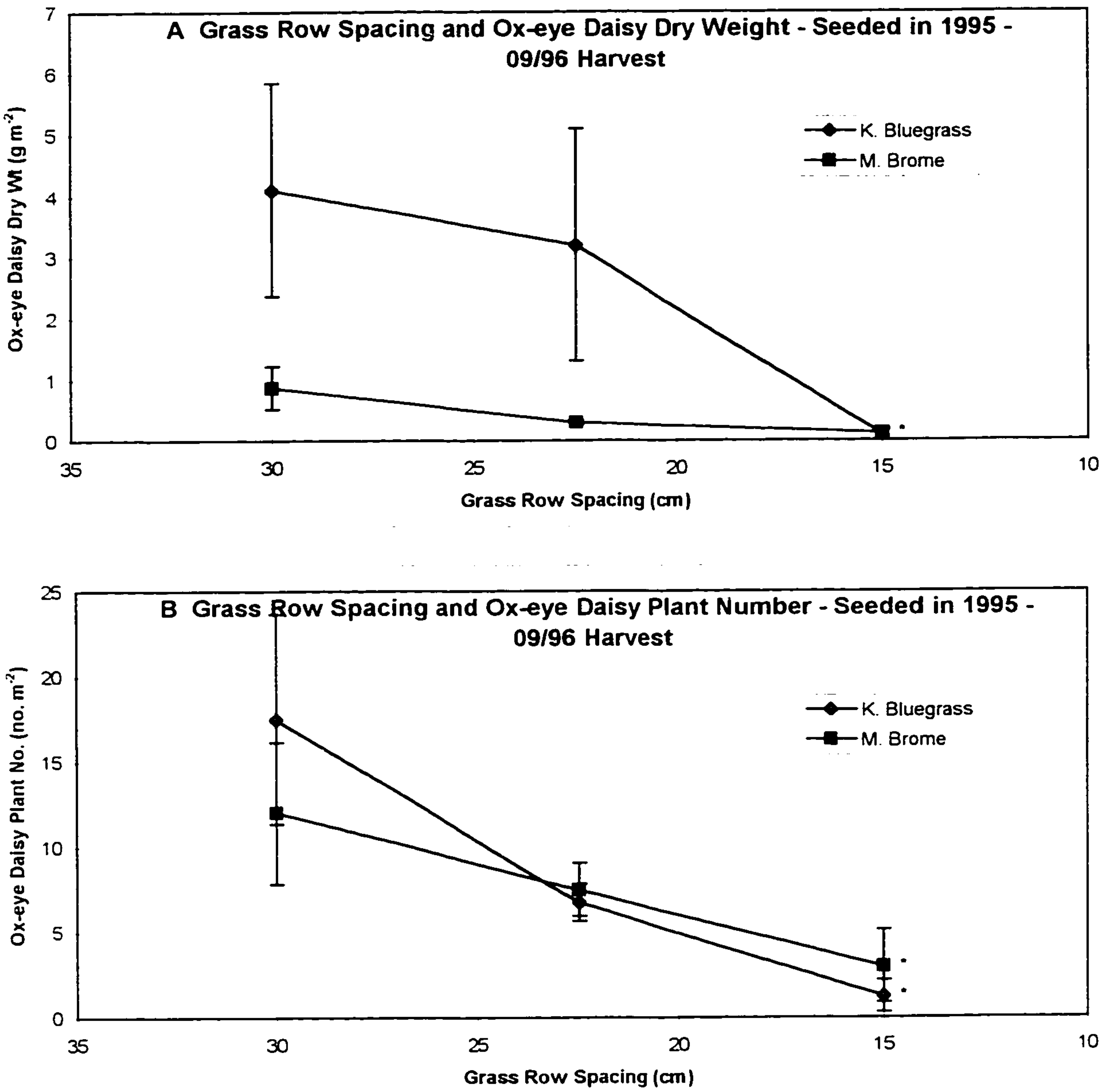


Figure III-17: Ox-eye daisy dry weight (A) and plant number (B) at three row spacings of Kentucky bluegrass and meadow brome grass. Data collected 09/96 from experiment seeded in 1995. Bars represent standard error of the mean. Stars indicate significant linear contrasts.

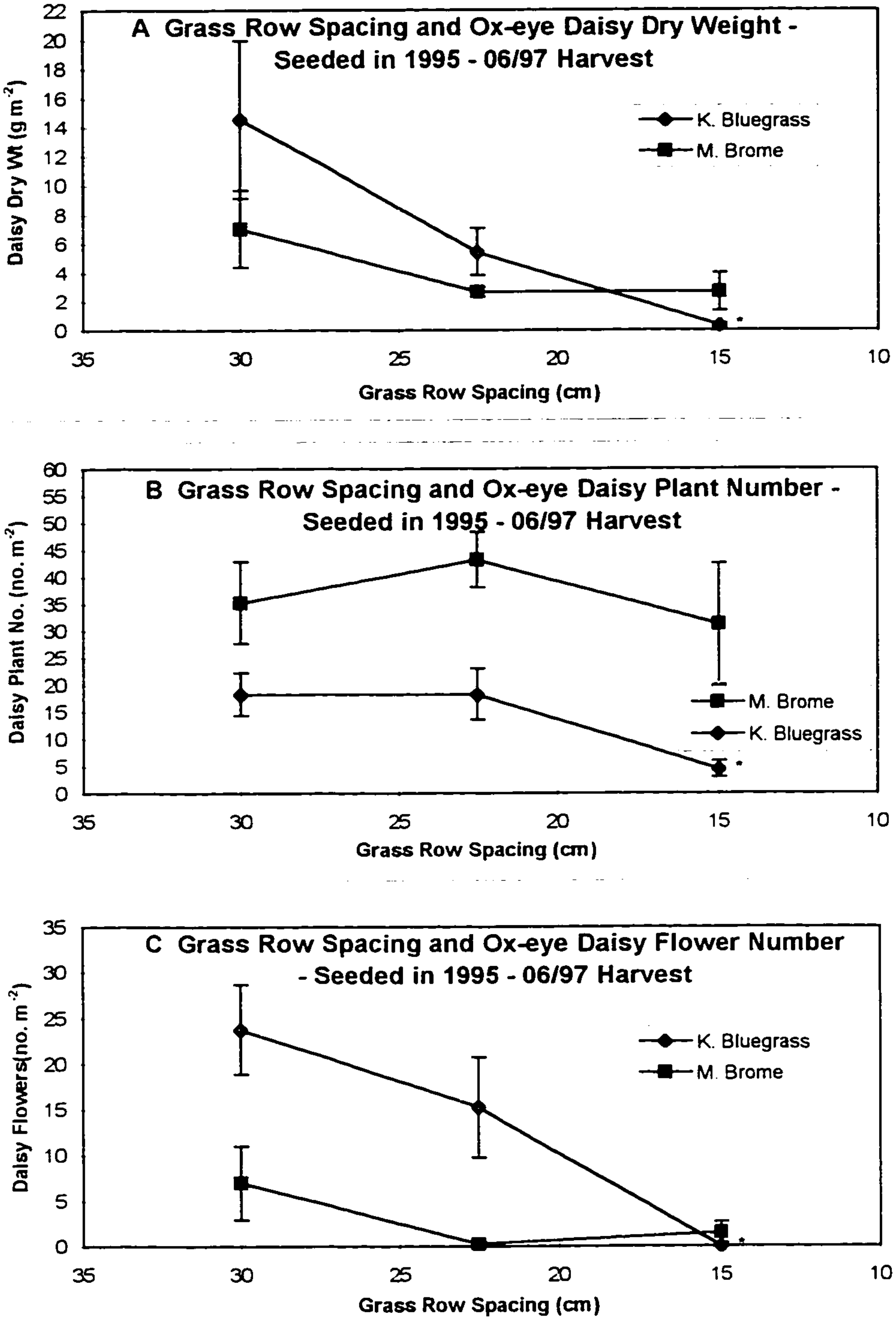


Figure III-18: Ox-eye daisy dry weight (A), plant number (B) and flower number (C) at three row spacings of Kentucky bluegrass and meadow brome grass. Data collected 06/97 from experiment seeded in 1995. Bars represent standard error of the mean. Stars indicate significant linear contrasts ($P < 0.05$).

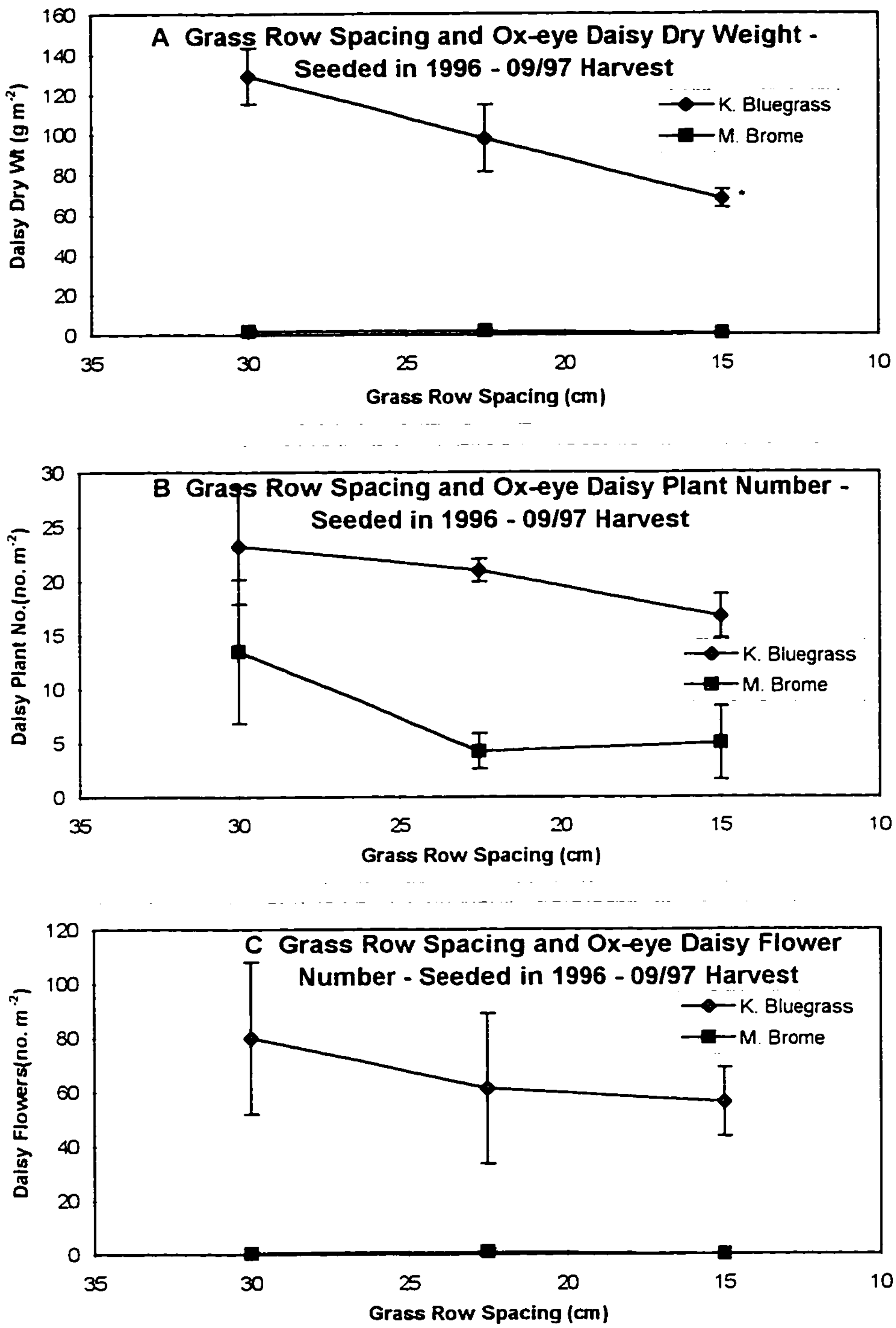


Figure III-19: Ox-eye daisy dry weight (A), plant number (B) and flower number (C) at three row spacings of Kentucky bluegrass and meadow brome grass. Data collected 09/97 from experiment seeded in 1996. Bars represent standard error of the mean. Stars indicate significant linear contrasts.

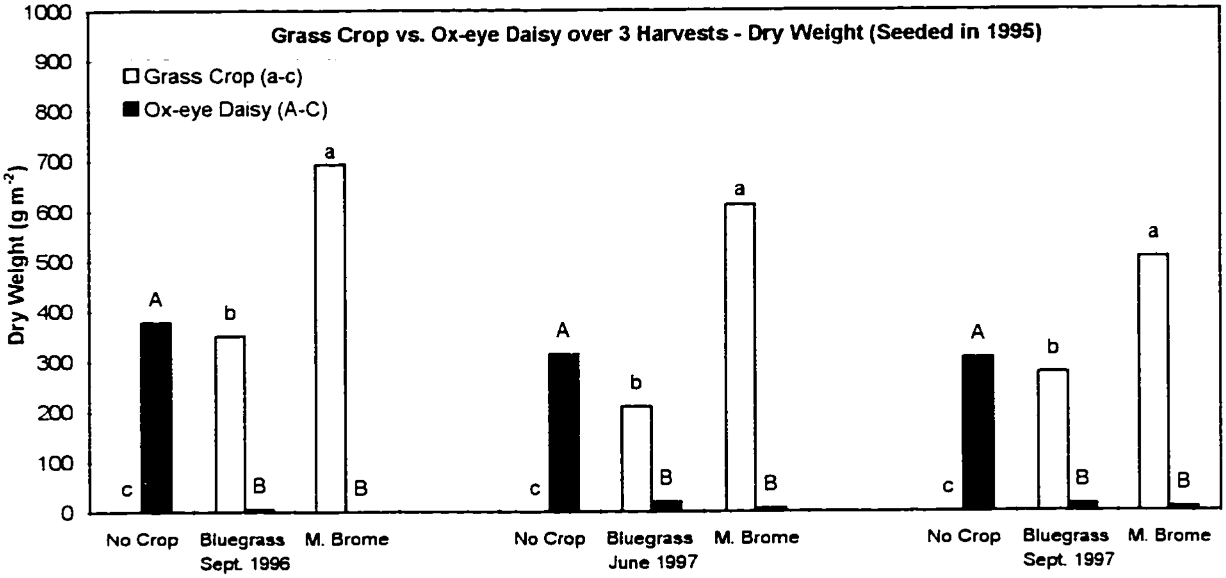


Figure III-20: Effect of grass crop on ox-eye daisy growth (averaged over the grass seeding rates and row spacings) over three harvests. The grass crops were seeded on July 28, 1995 and the ox-eye daisy was seeded on August 26, 1995 (the ox-eye daisy did not emerge until May, 1996). Within each harvest, grass crop (a - c) or ox-eye daisy (A - C) means with the same letter above are not significantly different (Student-Newman-Keuls test, p<0.05).

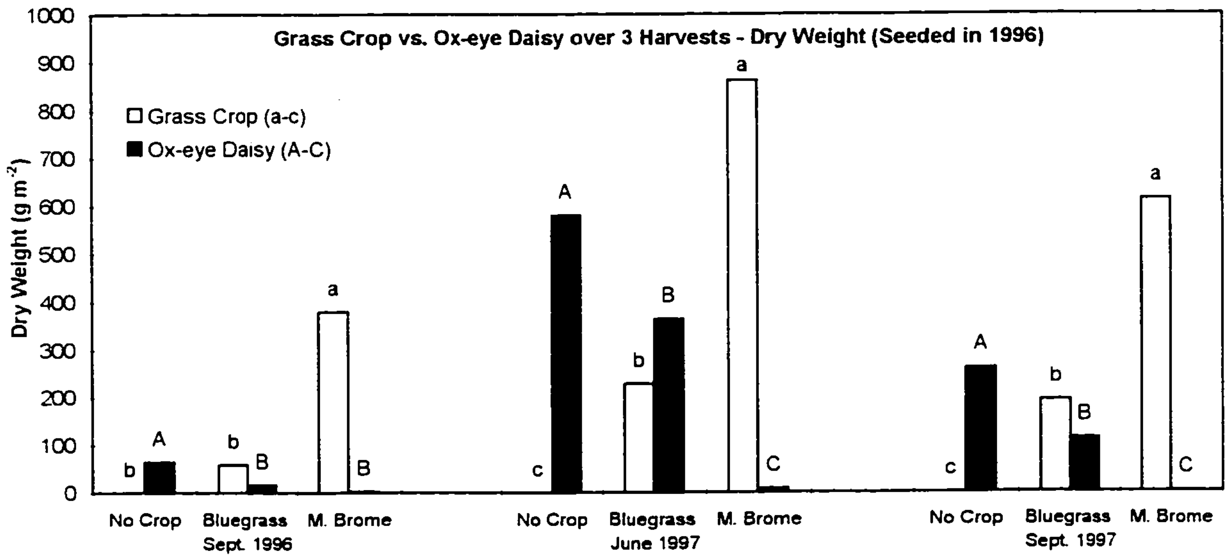


Figure III-21: Effect of grass crop on ox-eye daisy growth (averaged over the grass seeding rates and row spacings) over three harvests. The grass crops were seeded on June 10, 1996 and the ox-eye daisy was seeded on June 24, 1996. Within each harvest, grass crop (a - c) or ox-eye daisy (A - C) means with the same letter above are not significantly different (Student-Newman-Keuls test, p<0.05).

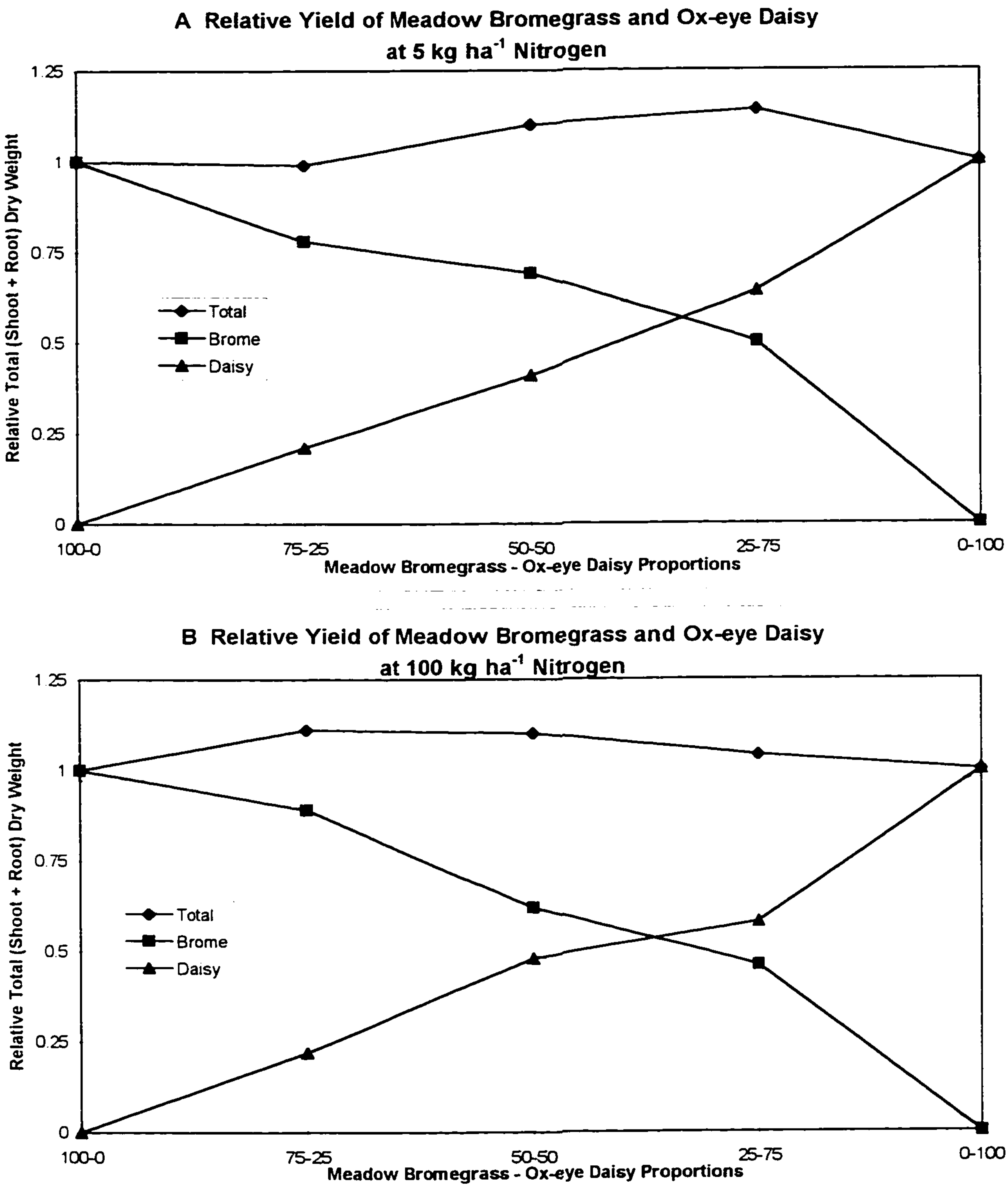


Figure III-22: Replacement diagrams for meadow brome grass vs ox-eye daisy replacement series greenhouse experiment with 5 (A) and 100 (B) kg ha^{-1} of N applied. Actual (—) and expected (- - -) relative yields of meadow bromegrass (■), ox-eye daisy (▲), and total (◆).

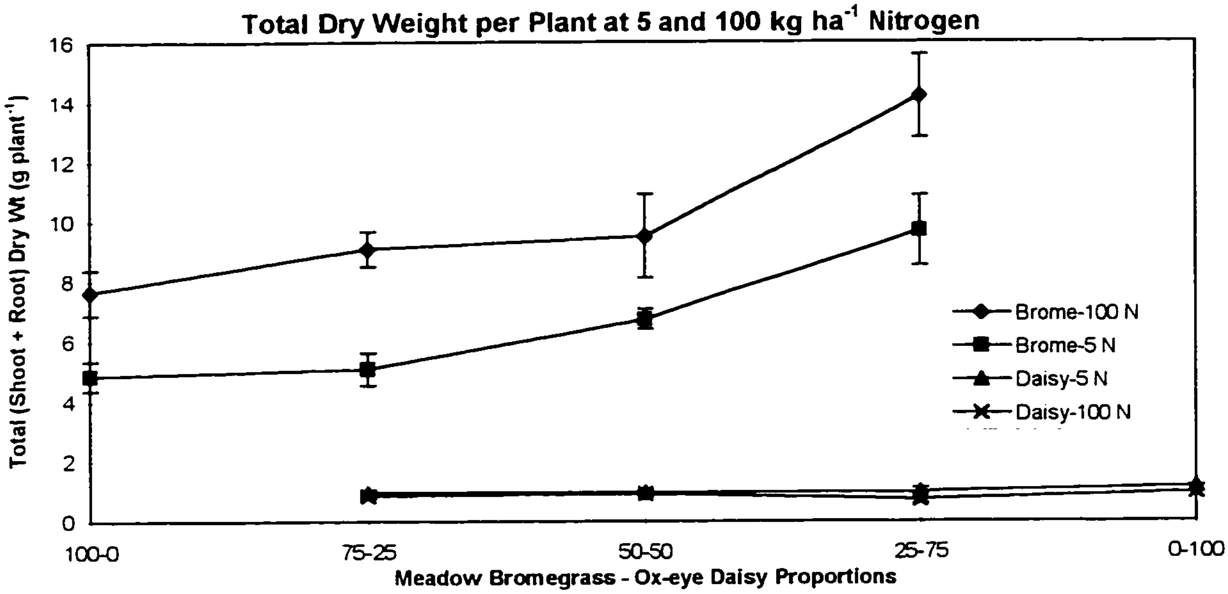


Figure III-23: Effect of nitrogen on total (shoot + root) dry weight per plant of meadow brome grass and ox-eye daisy growing at varying proportions in replacement series greenhouse experiment. Bars represent standard error of the mean.

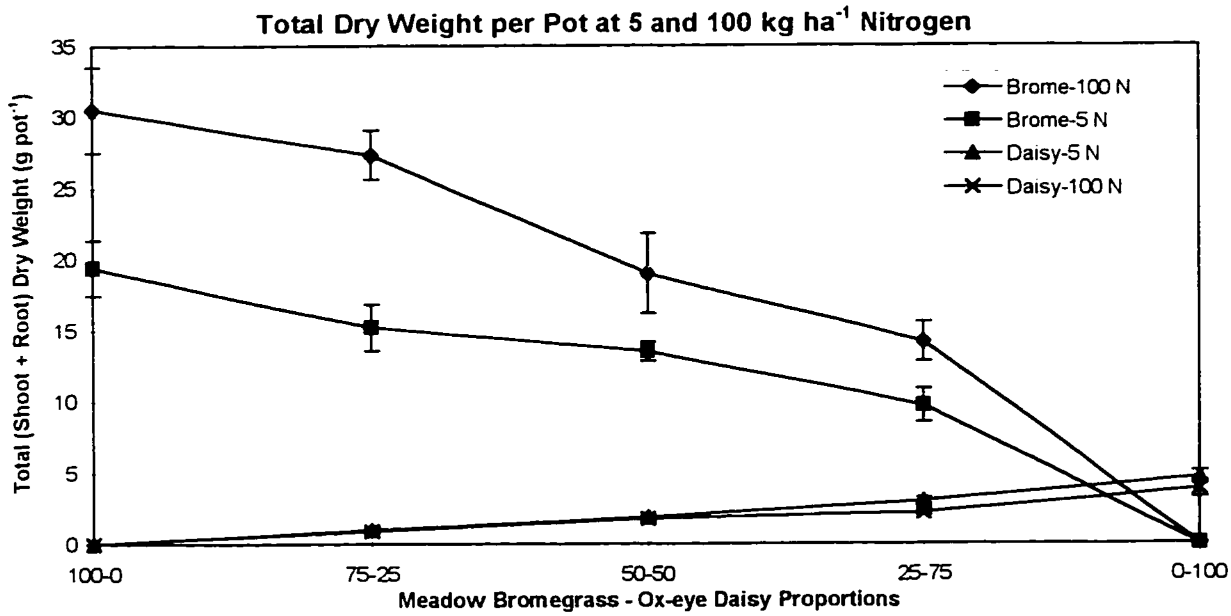


Figure III-24: Effect of nitrogen on total (shoot + root) dry weight per pot of meadow brome grass and ox-eye daisy growing at varying proportions in replacement series greenhouse experiment. Bars represent standard error of the mean.

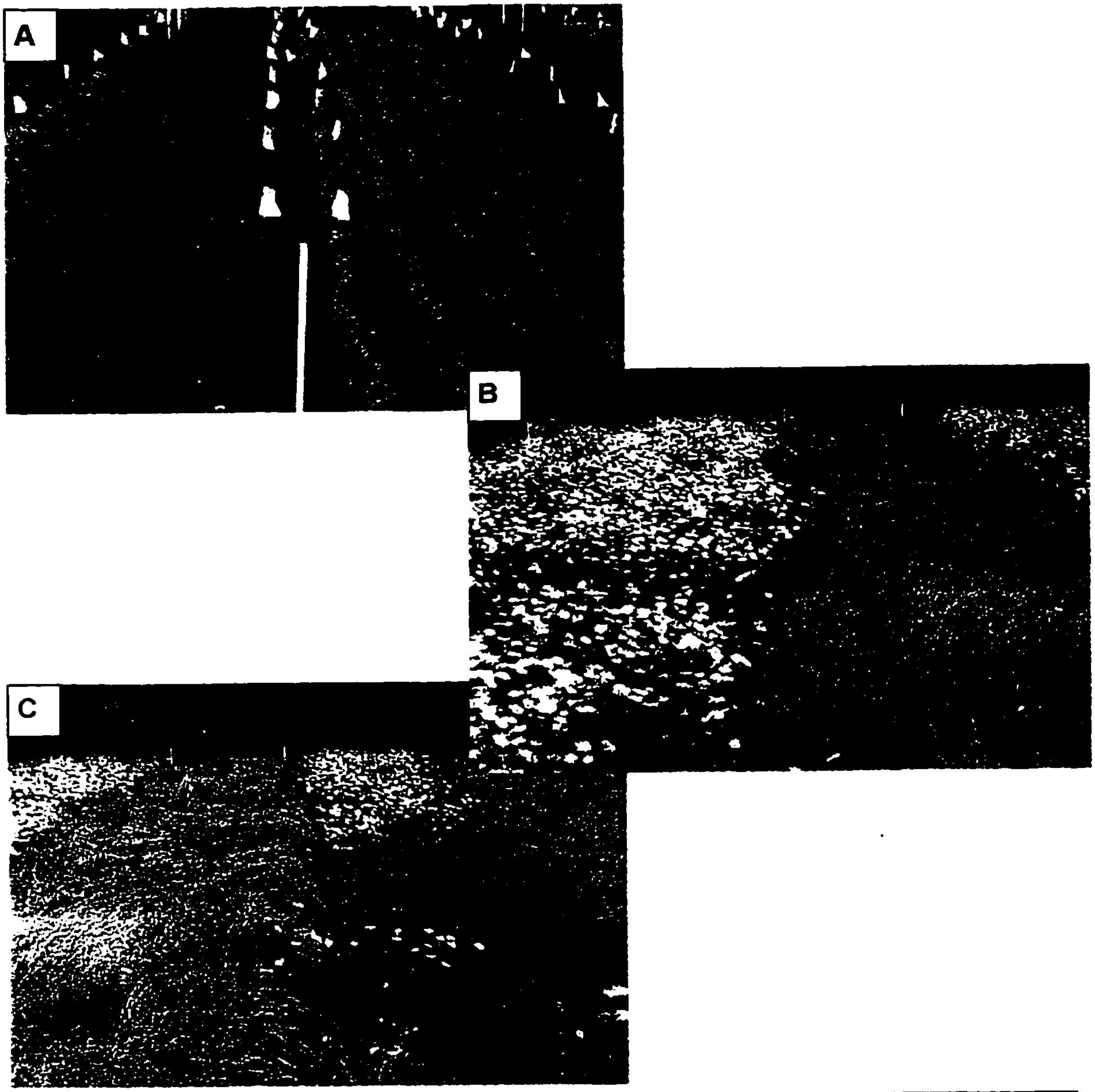


Plate III-1: Effect of grass species on ox-eye daisy at varying densities of ox-eye daisy at University of Alberta field research station, Edmonton. (A) Seedling stage of experiment seeded in 1995 with Kentucky bluegrass on the left and meadow bromegrass on the right. (B) Flowering stage of experiment seeded in 1996 with no crop on the left and meadow bromegrass on the right (picture in 09/1997). (C) Flowering stage of experiment seeded in 1996 with meadow bromegrass on the left and Kentucky bluegrass on the right (picture in 09/1997).

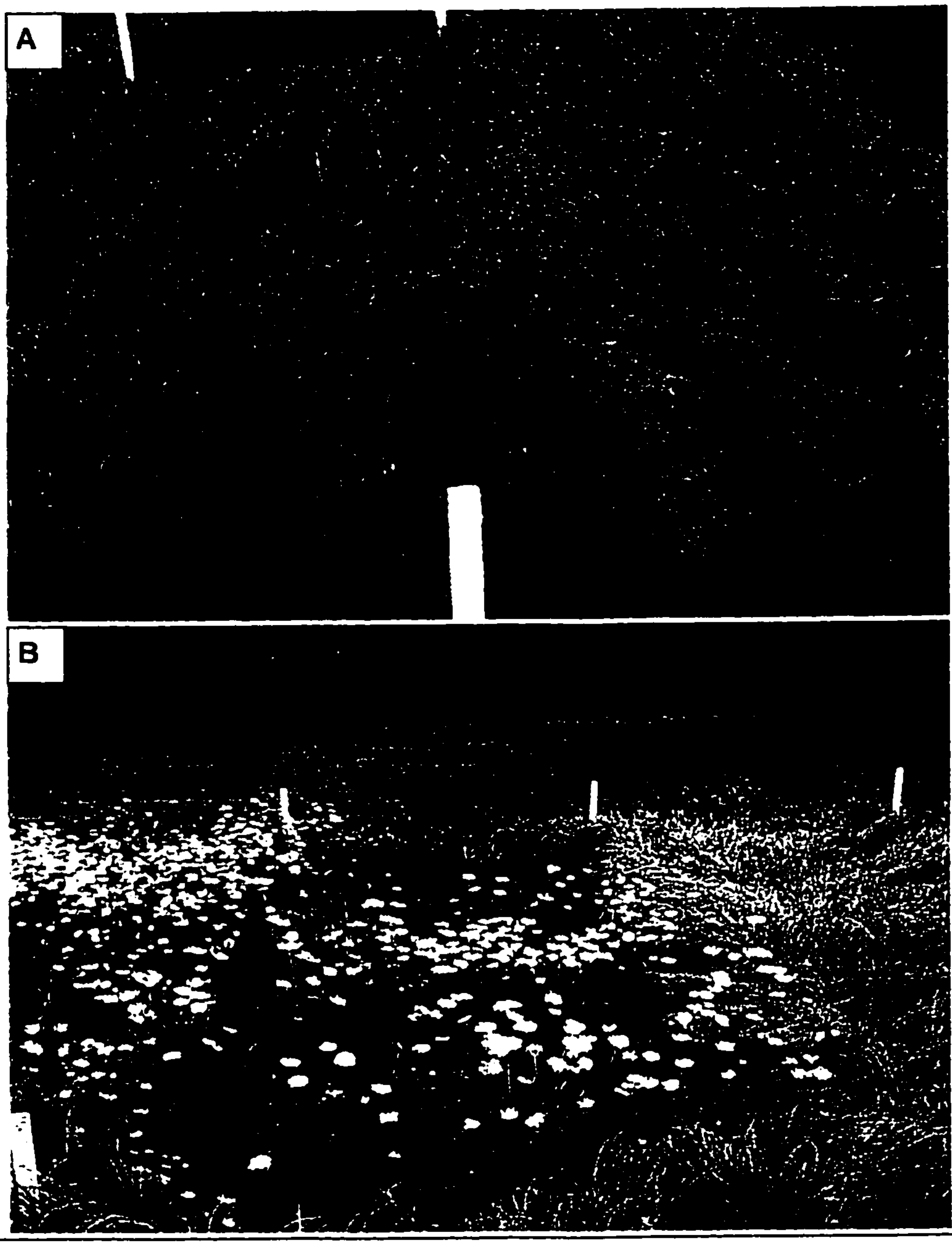


Plate III-2: Effect of grass species at varying seeding rates and row spacings on ox-eye daisy at the University of Alberta field research station, Edmonton. (A) Ox-eye daisy vegetative stage of experiment seeded in 1995 with Kentucky bluegrass at 2x recommended seeding rate and 30 cm row spacing on the left and meadow bromegrass at 0.5x recommended seeding rate and 30 cm row spacing on the right (picture in 08/96). (B) Ox-eye daisy flowering stage of experiment seeded in 1996 with no crop on the left, Kentucky bluegrass at 1x recommended seeding rate and 15 cm row spacing in the middle and meadow bromegrass at 2x recommended seeding rate and 30 cm row spacing on the right (picture in 09/97).

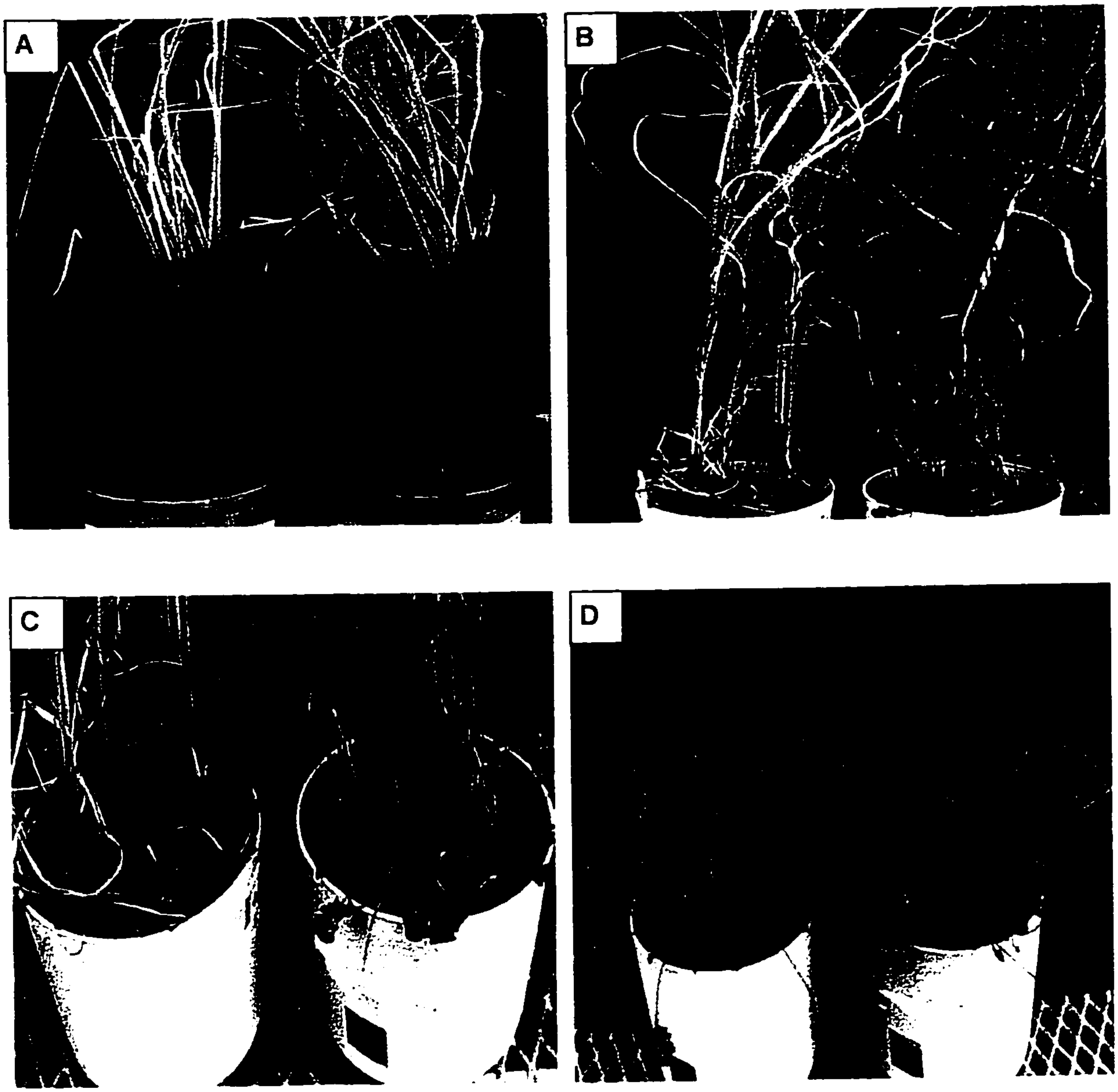


Plate III-3: Replacement series experiment conducted in the greenhouse to determine the relative competitiveness of ox-eye daisy and meadow bromegrass. (A) 52% light reduction shade cloth used the duration of the experiment. (B) and (C) Three meadow bromegrass plants and one ox-eye daisy plant per pot 74 days after transplanting with 5 kg N ha^{-1} on the left and 100 kg N ha^{-1} on the right. (D) Four ox-eye daisy plants 74 days after transplanting with 5 kg N ha^{-1} on the left and 100 kg N ha^{-1} on the right.

Chapter IV

Ox-eye Daisy and Competition

GENERAL DISCUSSION AND CONCLUSIONS

Ox-eye daisy frequently invades less well managed pastures or hay land, or land where there has been disturbance (Howarth and Williams 1968, Olson et al. 1997). In pastures, the situation may be exacerbated as the livestock selectively graze the competitive forage allowing the ox-eye daisy to mature, produce more seed and spread further (Gilkey 1957).

A strategy for the control or suppression of ox-eye daisy needs to be economical as well as effective. Enhancing crop competition may provide a cost effective approach to weed control, where producers wish to minimize costs on land that is not highly productive, or on land which producers perceive to be of lower value than cultivated or "cropped" land.

The purpose of this research was to determine a cost effective means of providing long term control of ox-eye daisy in pasture and hay land. A series of field and greenhouse experiments were established to address this objective. The experiments focused primarily on competition as a mechanism to control, and prevent the spread of, ox-eye daisy.

The first series of field and greenhouse experiments indicated that competition was a valid approach to the control of ox-eye daisy in pastures and hay lands. Maintaining a competitive forage stand not only assisted in preventing ox-eye daisy from establishing, but it also reduced or eliminated an existing ox-eye daisy infestation. Two years of fertilizer application in the spring to a fenced-off area of pasture, increased forage production and resulted in the forage out-competing the ox-eye daisy.

Spring surface-applied fertilizer also increased grass growth to assist a herbicide in providing longer term control of ox-eye daisy. When 2,4-D, applied to a grass-legume stand for ox-eye daisy control, also suppressed the legume, there was an increase in ox-eye daisy growth and number the following year as a result of the more open canopy and reduced competition. Fertilizer application counteracted this negative effect of the herbicide by stimulating the grass growth and this prevented the further spread of ox-eye daisy.

Fertilizer application stimulated the forage growth and reduced the amount of light reaching the ox-eye daisy located lower in the canopy. Greenhouse studies showed that a reduction in light intensity was probably the main reason for the observed reduction in ox-eye daisy growth in the field following the addition of fertilizer. The ox-eye daisy seedlings were affected more by the light reduction than the ox-eye daisy rosettes as the majority of the seedlings died under a 96% light reduction. The ox-eye daisy root biomass weight was reduced more than the shoot biomass when grown under low light intensities.

The addition of fertilizer to ox-eye daisy growing alone under reduced light conditions in the greenhouse did not enhance its growth. This was similar to the response in the field when fertilizer enhanced the forage growth, resulting in a reduction in the quantity of light reaching the ox-eye daisy.

The second series of field and greenhouse experiments indicated that, when seeded at approximately the same time, grass growth suppressed ox-eye daisy growth, with meadow bromegrass being a more effective competitor than Kentucky bluegrass. Neither grass affected the rate of germination or establishment of ox-eye daisy.

Increasing the seeding rate or decreasing the row spacing of the grass species did not consistently reduce ox-eye daisy emergence, biomass or flower production. A higher seeding rate and narrower row spacing was more critical when seeding a less competitive grass like Kentucky bluegrass into a field with a known ox-eye daisy seed reservoir.

Meadow bromegrass competed successfully with ox-eye daisy when both were seeded at the same time in a replacement series experiment in the greenhouse. Meadow bromegrass also responded to nitrogen application with a large increase in biomass while ox-eye daisy did not respond to nitrogen application.

In summary, applying plant competition principles with the use of vigorous forage species and/or fertilizer application to stimulate grass growth was an effective means of providing suppression of ox-eye daisy. Long term suppression can be obtained by maintaining a competitive forage stand.

RECOMMENDATIONS

The most appropriate strategy for addressing ox-eye daisy infestations in pasture and hay land will vary with the forage species and land use.

The herbicide 2,4-D ester, applied at 1.7 kg ha^{-1} early in the growing season (May) when the ox-eye daisy is small and before it produces flowering stems, will suppress ox-eye daisy in grass hay land or pasture. An integrated approach, with fertilizer applied at 100 kg N ha^{-1} and P, K and S to soil test recommendation as a surface application in April or May, will increase the level of control. The early spring fertilizer application can be repeated, as needed, to maintain suppression of the existing ox-eye daisy plants and prevent the establishment of new plants from seed. The increased forage production may cover the cost of the fertilizer.

To address an ox-eye daisy infestation in pasture, the sward should be managed properly and not grazed until there is good forage growth in the spring. Late fall grazing should be discouraged and rotational grazing used if possible.

It is important to ensure that the pasture is not overgrazed, especially under dry conditions.

An ox-eye daisy infestation in a legume, or legume-grass, sward may be more difficult to control as, currently, there are no herbicides that will control ox-eye daisy without killing or suppressing the legume. Fertilizer application in April or May for two or more years can effectively reduce the ox-eye daisy problem but may also suppress the legume component of the sward.

If a pasture or hay land has sparse forage growth and is infested with high levels of ox-eye daisy and other perennial weeds, the stand may need to be removed with tillage and the land rotated into an annual cereal crop using tillage and/or herbicides to address the ox-eye daisy problem over several years.

When rotating back into a forage crop on land with a known ox-eye daisy seed bank, choose forage species that establish quickly, fill in open spaces quickly, grow tall and produce a large amount of biomass (i.e., are more competitive), such as meadow bromegrass. The forage should be seeded into a "clean", well prepared seedbed at a narrow row spacing and a seeding rate that will quickly provide a competitive forage stand. If there is a flush of ox-eye daisy seedlings, 2,4-D ester can be applied when the ox-eye daisy seedlings are still small (2 to 4 leaf stage). If a companion crop (which may delay establishment of the forage) is used when seeding a grass species, a crop that can be sprayed with 2,4-D ester, such as wheat or barley, should be used. When seeding, and possibly on an annual basis, fertilizer should be applied to soil test recommendation. Pasture should be well established before grazing and not overgrazed.

Plant competition is the key to managing or preventing an ox-eye daisy problem in pasture or hay land. Maintaining a healthy, competitive forage stand with the use of fertilizer and proper management will not only produce more forage but will also help restrict the invasion and growth of weeds like ox-eye daisy.

LITERATURE CITED

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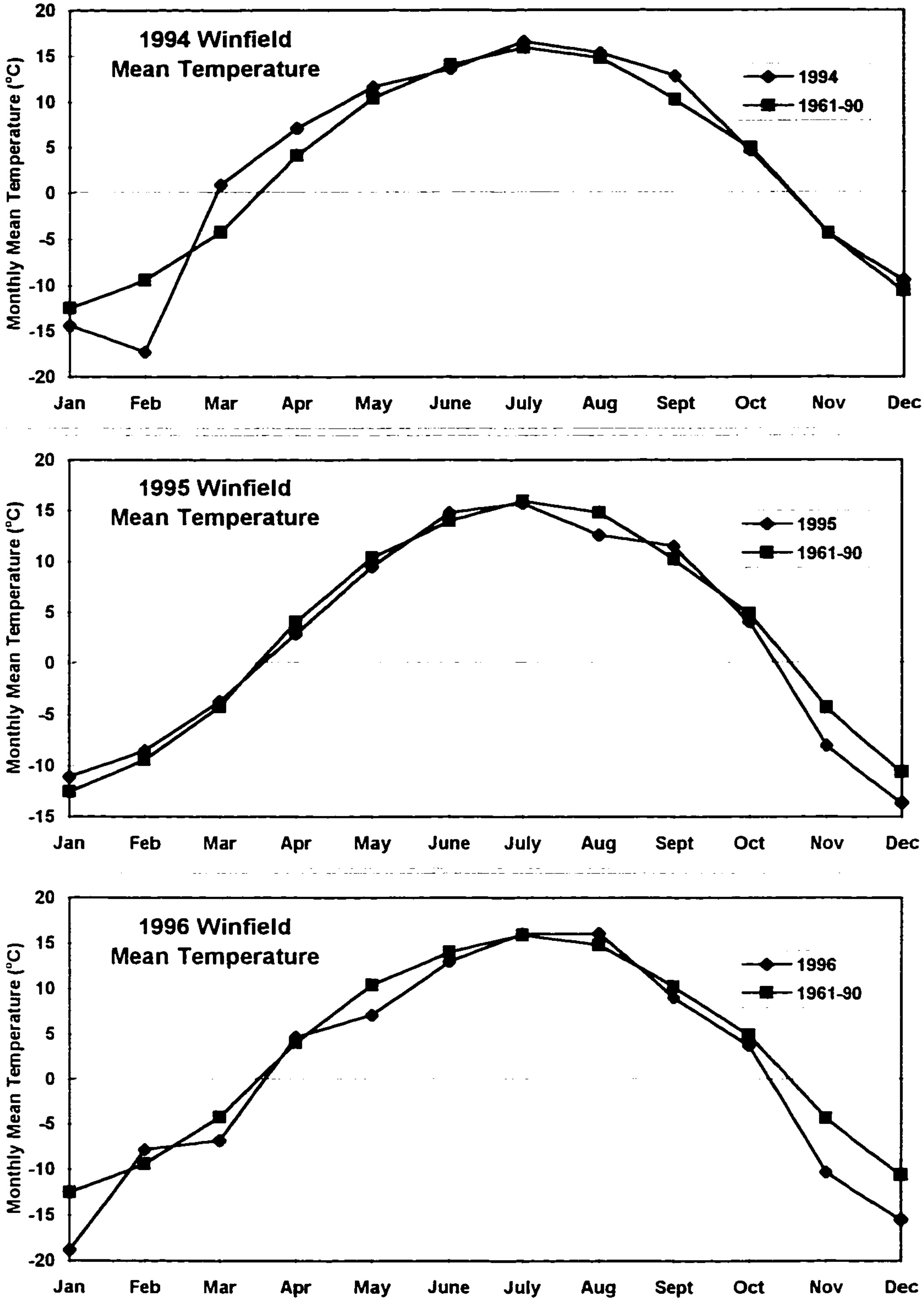
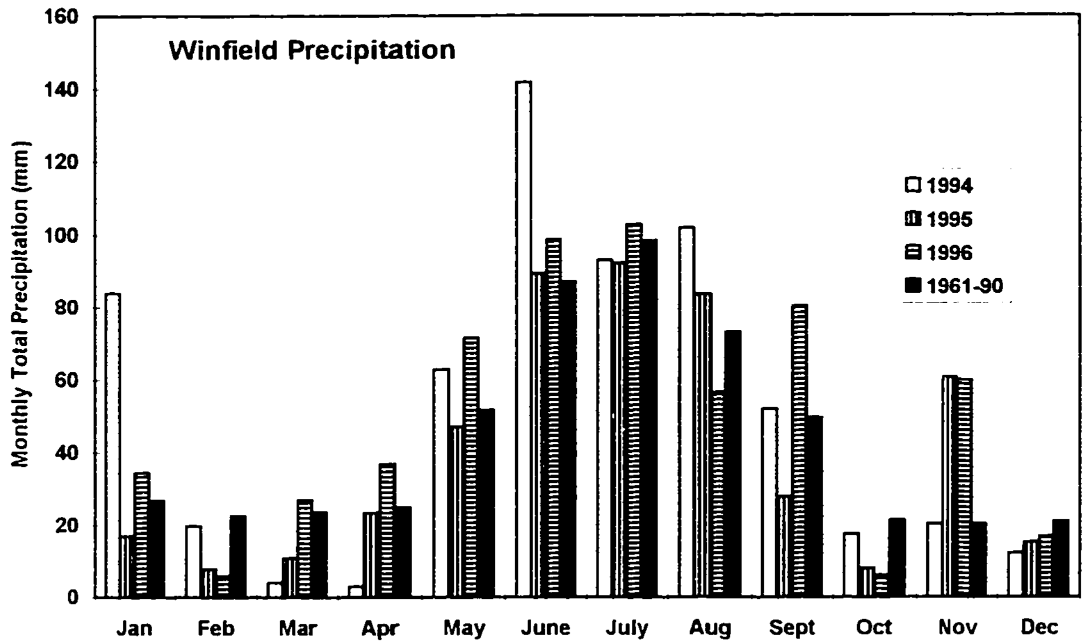
Olson, B. E., R. T. Wallander and P. K. Fay. 1997. Intensive cattle grazing of oxeye daisy (*Chrysanthemum leucanthemum*). Weed Technol. 11:176-181.

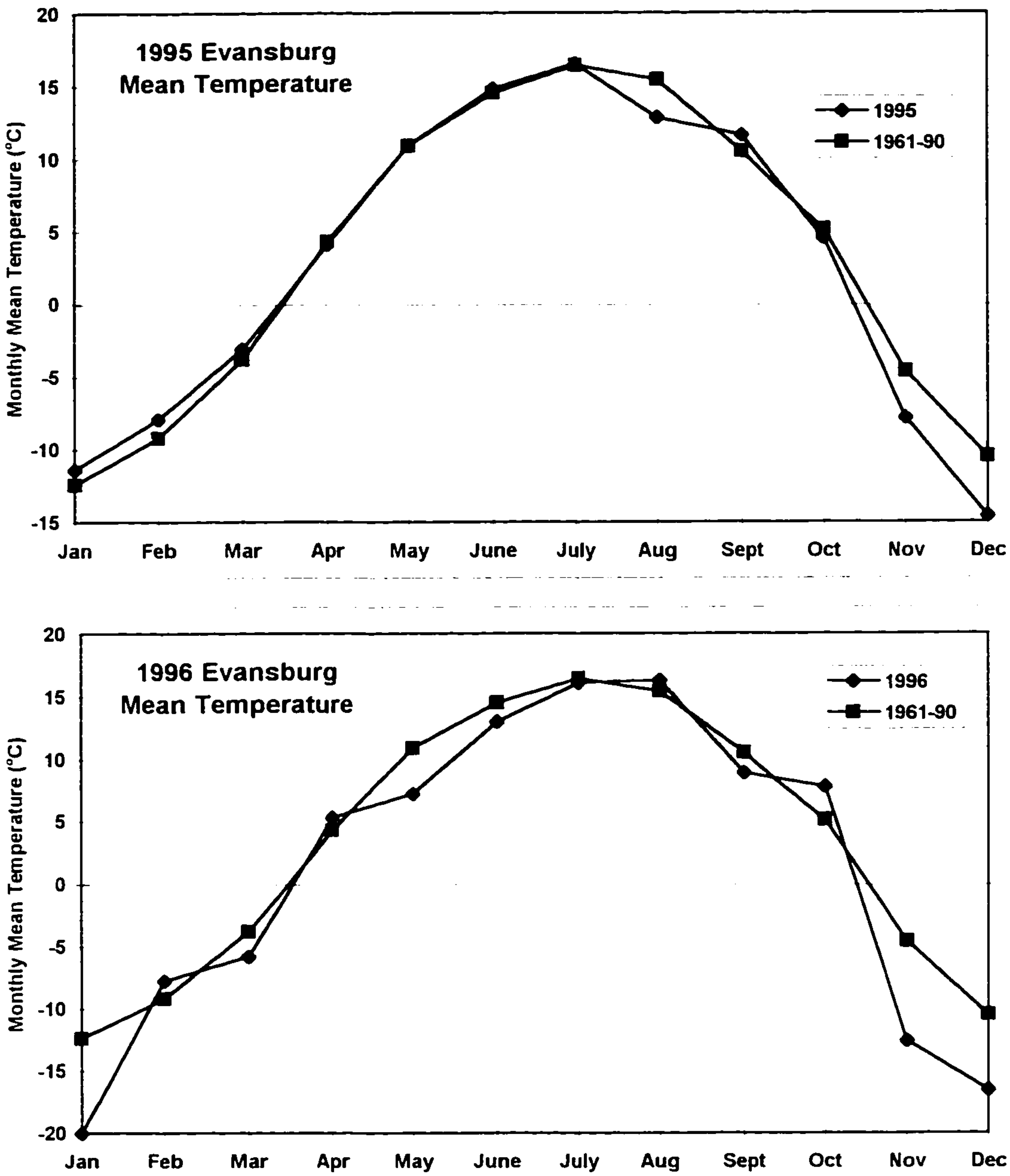
Appendix: Weather Data



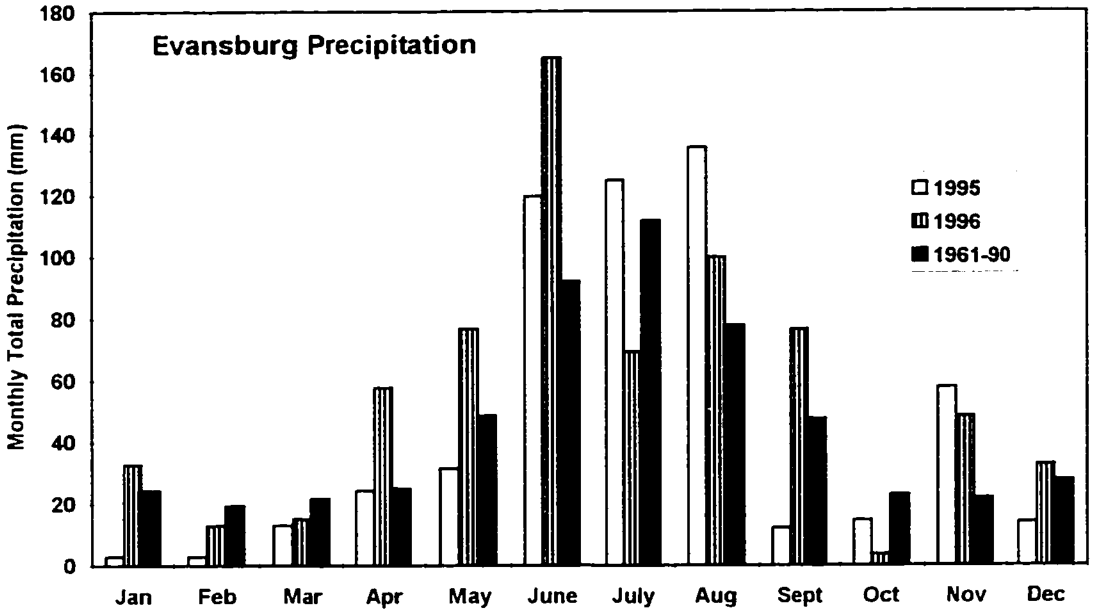
II-A: Mean monthly temperature (°C) at Winfield (20 km from the fertilizer experiment) in 1994, 1995, 1996 and 1961-90 average.



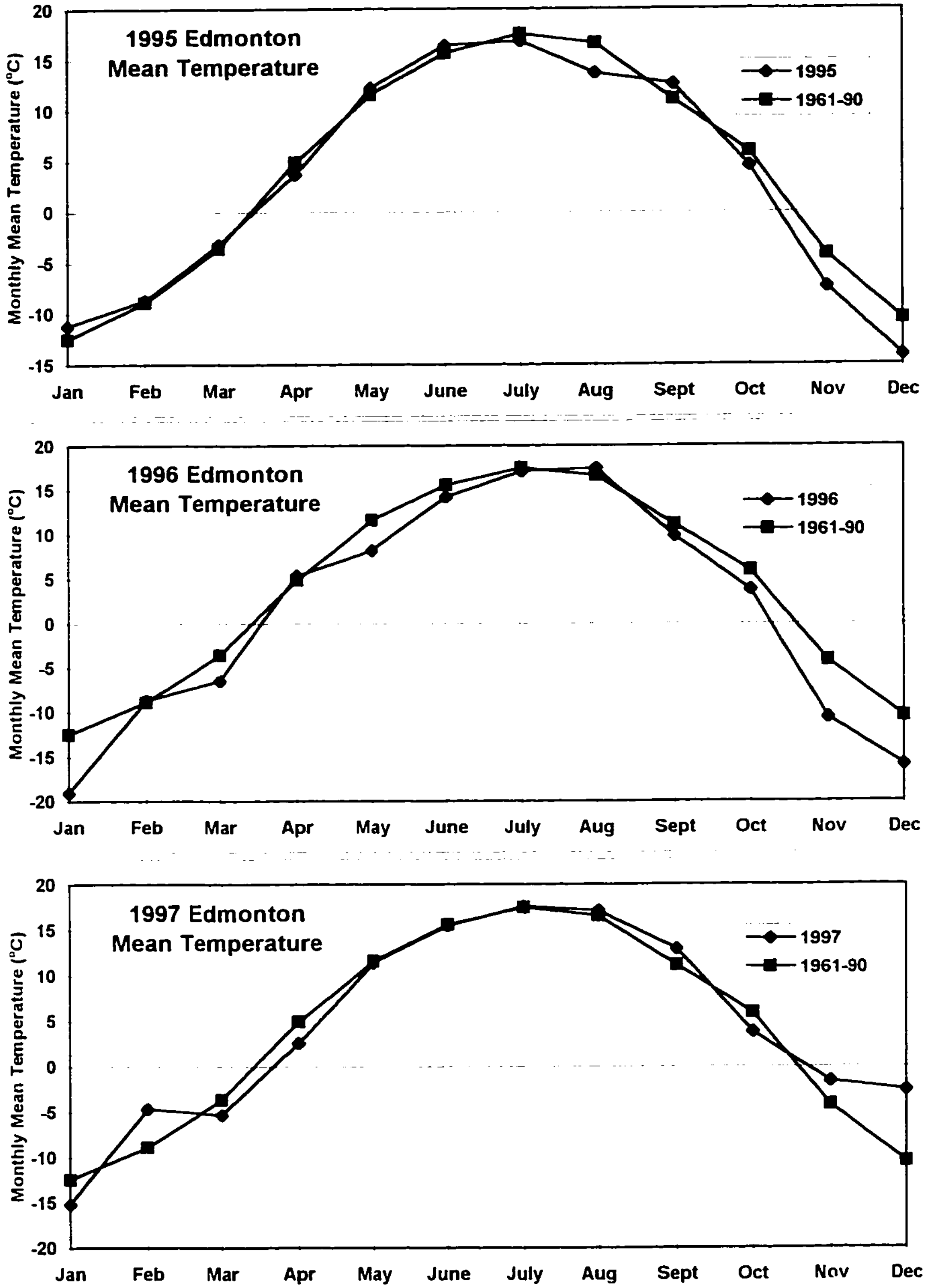
II-B: Total monthly precipitation (mm) at Winfield (20 km from the fertilizer experiment) in 1994, 1995, 1996 and 1961-90 average.



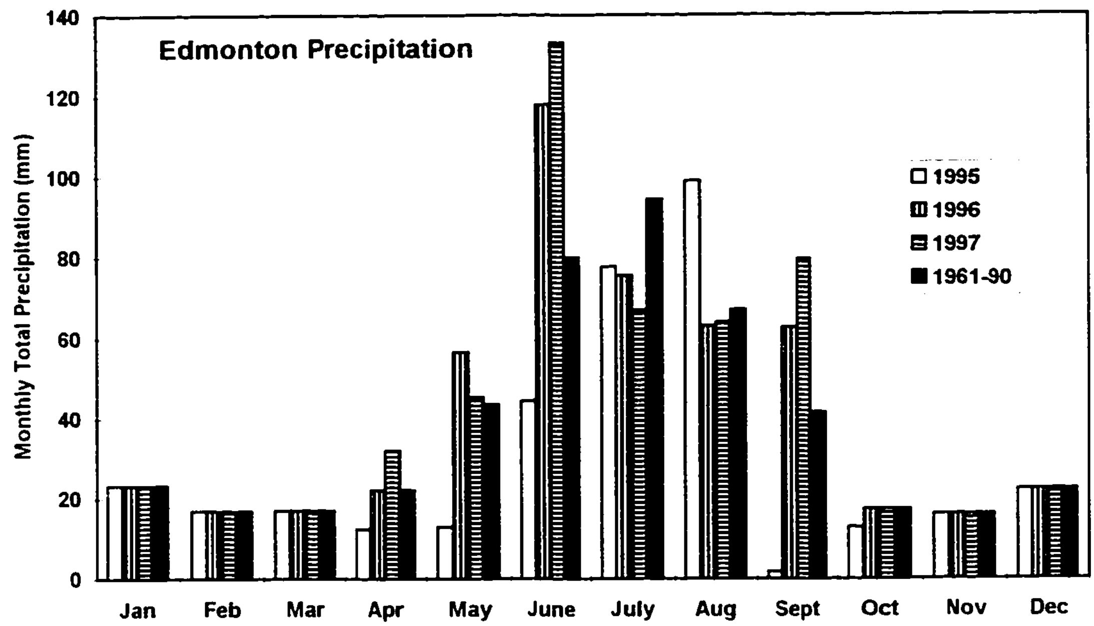
II-C: Mean monthly temperature (°C) at Evansburg (5 km from the fertilizer and herbicide experiment) in 1995, 1996 and 1961-90 average.



II-D: Total monthly precipitation (mm) at Evansburg (5 km from the fertilizer and herbicide experiment) in 1995, 1996 and 1961-90 average.

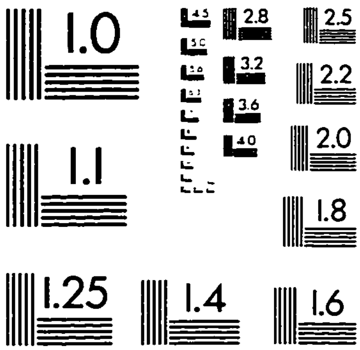


III-A: Mean monthly temperature (°C) at Edmonton University of Alberta Research Farm in 1995, 1996, 1997 and 1961-90 average.



III-B: Total monthly precipitation (mm) at Edmonton University of Alberta Research Farm in 1995, 1996, 1997 and 1961-90 average.

IMAGE EVALUATION TEST TARGET (QA-3)



150mm

6"

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