Some Aspects of the Biology, Ecology and Control of slender thistle, *Carduus pycnocephalus* L. and *C. tenuiflorus* Curt. (*Compositae*) in Tasmania.

The biology, ecology and control of slender thistle.

by

Glenn Max
G. M. Bendall B.Agr.Sc.(Hons), Tas.

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HOBART

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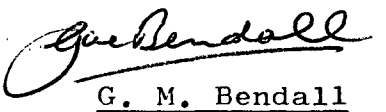
This thesis contains no material which has been accepted for the award of any other degree or diploma in any University, and to the best of my knowledge contains no copy or paraphrase of material previously published or written by any other person except where due reference is made in the text of the thesis.



G. M. Bendall

Department of Agriculture,
New Town Research Laboratories,
New Town,
Tasmania.

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CONTENTS

Summary

The germination, dormancy and nutritional requirements of slender thistle, and the effects of grazing management on the ecology of slender thistles in improved pasture were studied.

Heterocarpy was found to be well developed in slender thistles. Approximately 85% of the seed produced contained a soluble germination inhibitor which required leaching from the seed to facilitate germination. The remainder of the seed did not possess an inhibitor and would germinate without leaching. Seedlings arising from seeds without an inhibitor had greater root growth at low soil moisture than seedlings arising from seeds containing an inhibitor, thus conveying to the former seedlings a greater tolerance of moisture stress. The survival value of heterocarpy to slender thistles is discussed.

Following leaching, seed germinated over a range of well defined temperatures ($10^{\circ}C$-$30^{\circ}C$) and this was related to the germination pattern of slender thistles in the field.

Effect of burial of seed at varying depths on germination, dormancy, and longevity was observed. Seed buried at a depth of 1.3cm gave the highest percentage emergence. Twenty to 25% of seed buried at 5cm and 10cm remained dormant and formed the source for germination in following seasons. Five percent of seed buried at 10cm remained dormant for more than two years.

Slender thistles responded more to applications of nitrogen than to applications of phosphorus or potassium when grown in an infertile soil. Nitrogen greatly stimulated

vegetative growth and also directly increased the reproductive capacity of the plants by enhancing branching and hence the number of flower heads produced. High pH (pH6.5) also favoured thistle growth.

The effects of grazing management on slender thistle populations and botanical composition of improved pasture were investigated in two field trials. Deferred autumn grazing in winter and spring significantly reduced thistle population densities. Thistle control was obtained by two different ecological mechanisms:

1. Deferred autumn grazing caused pasture/thistle competition for light which resulted in etiolation of the thistles to the extent that they were readily eaten during subsequent grazing. The increase in acceptability of the thistles to the sheep appeared to be mainly due to morphological changes. An increase in nitrate (N) and total reducing sugars with etiolation may have also favoured acceptability.

2. Deferred autumn grazing apparently reduced the availability of moisture to thistle seeds and germination was partially inhibited.

Grazing management, especially spring grazing, favourably altered pasture botanical composition by reducing the proportion of weed grasses. These changes are discussed in relation to thistle control.

It is suggested that deferred autumn grazing may be an alternative to herbicides for slender thistle control in pastures and that control would be expected to be mainly by the first mechanism. It is also suggested that deferred autumn grazing and herbicides may be combined to give

effective control, as etiolated thistles were more easily killed with MCPA than normal rosette thistles.

I Literature Review

a) Introduction

Thistles are probably the earliest known plants recognised as being weeds and as a group they include many different species of varied importance. The most important thistle species occurring in Tasmania are listed in Table 1.

Table 1

Important Thistles of Tasmania

Carduus pycnocephalus L.	slender thistle	annual
C. tenuiflorus Curt.	winged slender thistle	annual
C. nutans L.	nodding thistle	biennial
Cirsium vulgare (Savi.) Ten.	spear thistle	biennial
C. arvense L. (Scop.)	Californian thistle	perennial
Onopordum acanthium L.	cotton thistle	biennial
Silybum marianum (L.) Gaertn.	variegated thistle	annual
Carthamus lanatus L.	saffron thistle	annual

With the exception of *C. nutans*, which is probably a post Second World War introduction, the species listed were introduced during the last century and have been of changing importance since that time. For example, *C. arvense* was the subject of the first weeds legislation in Tasmania, viz., the Californian Thistle Prevention Act, 1870. Tenison-Woods (1880) described *C. arvense* as "most pernicious in Tasmania". Today, the perennial thistle is only of localised importance. Tenison-Woods (1880) also drew attention to *S. marianum* and *C. vulgare*, and the latter species is now the cause of increasing concern to land-holders. *S. marianum* is readily controlled with herbicides and is no longer the problem that it apparently was in the past. *O. acanthium*, although well established at least 60 years ago (Hyde-Wyatt 1970) has only

been intensively controlled through an eradication campaign since 1968 (Hague and Kennedy 1969). The limited distribution of this species and also C. nutans make them amenable to eradication by a co-operative campaign.

Carduus pycnocephalus and C. tenuiflorus have been recognised as weeds of economic significance since the early part of this Century (Black 1913), and have replaced Californian thistle as the weeds of most concern. Slender thistles are the most troublesome of the pasture weeds because of their widespread occurrence, their propensity to form dense populations to the virtual exclusion of all other species and the prohibitive expense of satisfactory control measures. All these characteristics are not common to the other important thistle species in Tasmania.

However, as previously mentioned, the relative importance of these species as weeds is constantly in a state of flux and it is possible that with seasonal variation and adequate control measures, slender thistles may be replaced as the weeds of greatest importance by other species such as spear or Californian thistle.

b) Occurrence of Slender Thistles

C. pycnocephalus occurs as a native of Western Europe and has been introduced into Great Britain, whereas C. tenuiflorus is indigenous to both areas. (Clapham et al. 1957). According to Black (1913), C. pycnocephalus, at least, is also indigenous to Middle and Southern Europe, Northern Africa and S.W. Asia. Balock et al. (1971) have identified C. pycnocephalus from a group of 5 possible Carduus species occurring in West Pakistan. Both species have been introduced and have become well established in North America

(Bellue 1940; Robbins et al. 1951), where they are referred to as Italian thistles, New Zealand (Saxby 1948), the Australian Mainland, especially Victoria where C. pycnocephalus was recorded as being naturalised by 1887 (Ewart 1913), and Tasmania.

C. tenuiflorus is the more common species occurring in Tasmania (Curtis 1963) with C. pycnocephalus being the dominant species in the south-eastern area of the State.

Slender thistles commonly occur on roadsides, bush-runs, and wasteland and as serious weeds of crops (especially cereal crops) and pastures. They have also been observed to grow in coastal areas, and even on beaches which earned the species the common name of "shore" thistle (Black 1913).

c) Legislation as a Noxious Weed

In 1913, C. pycnocephalus was proclaimed a noxious weed for the Clarence Municipality in Tasmania (Black 1913) and for the whole of the State following the passing of the Noxious Weeds Act, 1938 by Parliament.

C. tenuiflorus was added to the list of noxious weeds in the Noxious Weeds Act, 1964.

Both species of slender thistle are also Prohibited Seeds under the Seeds Act, 1950.

d) Biology of Slender Thistles

(i) Taxonomy and Phylogeny

It is now generally recognised that there are two species of slender thistle - Carduus pycnocephalus L. and C. tenuiflorus Curt. as described by Curtis (1963), but there has in the past been considerable uncertainty as to the validity of this distinction. On the mainland of Australia, the two species were synonymised by Ewart (1930), although Clark (1949) distinguished between the two types but added

that they may not be specifically different. In Tasmania, C. pycnocephalus only was listed as a noxious weed until 1964, and it is most probable that both species were present and included under the one name especially after 1938 when the proclamation covered the whole state.

In California, Howell (1939) compared material with European specimens and concluded that two distinct species existed.

More recently, Michael (1966) used achene length to distinguish between the two species and agreed with Kazmi (1964) who gave the lengths of achenes of C.pycnocephalus as 4-5mm and C. tenuiflorus 3-4mm. Similar groupings of achene lengths have been observed in Tasmania.

There is considerable morphological variability within the two species, but work by Michael (1966) suggests that hybridisation between the two thistles is uncommon, which is in agreement with earlier European work described by Howell (1939).

Little is known of the phylogeny of slender thistles, although it is recorded that they once regularly occurred on beaches (Black 1913). Today, they appear to have evolved away from the shoreline habitats and become adapted to the high fertility areas of modern agriculture (Michael 1968(a), Moore 1971).

(ii) Morphology and Anatomy

The morphology of slender thistles has been adequately described by a number of authors (Cock 1951; Robbins et al. 1951; Clapham et al. 1957; Curtis 1963). It would be pertinent, however, to discuss those morphological and anatomical features which help them to be successful weeds.

Plate 1. Carduus pycnocephalus at flowering.

Plate 2. Carduus tenuiflorus at flowering.

The most significant morphological features are the spinous nature of the leaves and the spinous-winged stems (Plate 1, Plate 2) which make the species unattractive to stock at all stages of growth (Eastoe 1967), and aids their persistence as weeds of pasture.

The involucral bracts are very stiff and tend to be spinous with small hooks. This allows the flower heads, which readily dehisce as they dry, to adhere to wool causing vegetable fault (Salisbury 1961). This may also be a dispersal mechanism (Zohary 1950). Finally, most of the seed produced is sticky which would also aid dispersal of the species.

The significant anatomical feature of slender thistles is the location of the primary meristem in the centre of the rosette and below ground-level. In this position, the site of regrowth is protected from all but the most severe grazing, cutting or slashing which may be attempted for control.

(iii) The Seed Characteristics and Phenology

Little information has been documented on the characteristics of the seed of slender thistles. However, Cock (1951) observed that C. pycnocephalus was a "terrific seeder" although C. tenuiflorus actually produces more but smaller seeds per flower head (Michael 1966). The seed size/seed number difference between the species may be an adaptive compromise as suggested by Harper et al. (1970).

The seed is only blown small distances, rarely more than 2 or 3m from the parent plant (Cock 1951). Pappi seen blowing in the wind are seedless. Spread of seed by ingestion by birds and grazing animals, by adherence to animals and farm machinery and in hay and grain, are probably the major dissemination mechanisms.

Bellue (1940) and Robbins et al. (1951) mentioned

the occurrence of diaspory in slender thistles. Neither described the dimorphic seeds in detail or attempted to explain their significance.

The viability of new thistle seed is in general very high, but falls off rapidly in some species (Michael 1970). Sufficient seed may remain viable for long periods to allow for the reappearance of significant populations in future years. According to reports from old farm hands in Tasmania, slender thistle seed may remain viable for many years and will germinate readily following cultivation.

Slender thistles have the ability to complete maturation of seed when cut down during flowering but following fertilisation. Many species in the family Compositae possess this ability, but some common species such as C. vulgare and C. arvense do not (Gill 1938).

Germination of slender thistle seed appears to be mostly seasonal similar to other annual thistles. This is in contrast to the biennial thistles which show no seasonality in germination behaviour (Michael 1970).

The life-cycle of slender thistle may be divided in to three broad periods, viz. germination to rosette, over-wintering rosette, and overwintering rosette to flowering and seedfall. In Tasmania these periods are approximately correlated to the following months and seasons of the year respectively - March, April, May, and June (autumn), July and August (winter), and September, October, and November (spring).

Occasionally, germination may occur during spring or early summer. These plants act as biennials by over-summering as rosettes rather than as dormant achenes and flower the following spring.

(iv) Soil Fertility Relationship

Thistles commonly occur on areas of high fertility such as stock camps and around homesteads and rabbit warrens. With cultivation and the development of improved pastures, coupled with a general increase in fertility with the use of superphosphate and clovers, slender thistles, as with other thistle species have become more widespread (Michael 1970).

The annual and biennial thistles are commonly associated with high soil nitrogen (Moore 1971). However, Michael (1968(a), 1970) states that it is unwise to ascribe their preponderance just to nitrogen, and shows that in the case of slender thistles, calcium may be of special importance.

This would be in agreement with Moore (1967(b)) who suggested that the invasion of subterranean clover pastures by C. pycnocephalus after several applications of superphosphate can be explained by the greater aggressiveness of the thistle at high levels of calcium, with clover being more aggressive at low levels of calcium. Also, New Zealand work (Metson et al. 1971) has indicated that the accumulation of soluble salts associated with the rise in soil fertility in pastures may be a factor in the increase in frequency of Carduus spp.

(v) Associated Pathogens and Insects of Slender Thistles

The only known disease of slender thistle is Puccinia cardui-pycnocephali Syd. recorded on C.pycnocephalus in 1964 in southern Tasmania (Anon. 1968). The same rust also occurs on C. tenuiflorus.

Two aphid species which may adversely affect slender thistles are Brachycaudus helichrysi (Kalt.) and Capitophorous elaeagni (del. Guer.), originally recorded by

Plate 3. Effect of aphids on slender thistles in pasture.

Plate 4. Effect of soil cracking on slender thistle establishment in improved pasture.

Martyn and Miller (1963) and also recorded in West Pakistan by Balock et al. (1971). The aphids have been observed to kill thistles in the rosette stage (Plate 3) during weather conditions of prolonged high humidity.

A moth Choreutis bjerkandella Thun. has also been recorded on C. pycnocephalus and can be of ecological significance (Hardy pers. comm.).

The thistle seed weevil, Rhinocyllus conicus, although not recorded in Tasmania, is an important parasite of slender thistles in Eastern Europe and around the Mediterranean (Anon. 1973). The weevil has been introduced into California for the biological control of Silybum marianum and Carduus nutans (Anon. 1973) and could be a potential agent for the biological control of these species and slender thistles in Tasmania.

Many other thistle species may also be infested with rusts and insects, but Californian thistle appears to be the only other species adversely affected.

(vi) Ecology and Importance of Slender Thistles in Pasture

Weeds rarely invade natural undisturbed communities (Harper 1965) and similarly, thistles never invade pastures with a good, continual ground cover (Michael 1970). Those pastures which have been weakened by poor management or insect attack, or have opened up in dry seasons, form favourable sites for slender thistle establishment (Inch 1964). Plate 4 shows the effects of soil cracking on slender thistle establishment in southern Tasmania.

The irregular appearance of thistle populations from season to season has been discussed by Michael (1968(a), 1970) and related to periods of drought. Thistles may be worse after drought which may result in a good crop of viable seed for the following season. Good "thistle" years are often associated with good "clover" years which are related to seasonal rainfall (Michael 1970). Variations in thistle populations have been recognised for a long time and were first noted by Tenison-Woods (1881) with respect to the seasonal variation of variegated thistle.

Even during poor thistle years, some seed production in slender thistle still occurs. Well developed phenotypic plasticity allows the species to produce from one viable seed per thistle under harsh or highly competitive conditions to 700 or more (20 to 30 seeds/flower) under favourable conditions.

Once established, slender thistles may reduce pasture production by direct competition for moisture, nutrients and light during the rosette to flowering or "green-stage" of the thistles. Their domination may be greatest, however, at the mature dry stage when there may be a reluctance by sheep to enter dense stands, thus reducing the availability of fodder (Eastoe 1967). This would result in uneven grazing, and the subsequent deterioration of the pasture could increase the likelihood of corbie and cockchafer attack (Anon. 1966).

Salisbury (1961) placed slender thistle high on the list of species frequently occurring as wool aliens causing vegetable fault in wool, resulting in greatly suppressed wool prices (Webster and Whan 1967). In New Zealand, the thistle has been associated with nitrate poisoning of stock (Coup 1959), although recent work in Australia (McBarron 1972)

suggests that nitrate poisoning attributable to slender thistle would be unlikely.

Certain beneficial effects have also been attributed to slender thistles. Moore (1971) suggested that they may be beneficial in pasture by mopping up excess soil mineral nitrogen, thus preventing excessive nitrate uptake and accumulation by the improved pasture species and probable nitrate poisoning in the grazing animal. Ewart (1930) claimed that the seeds were of value as a source of nutrition to the grazing animal, and this is probably why Saxby (1948) claimed winged slender thistle to be excellent stock feed in depleted areas of Central Otago, New Zealand.

In general, slender thistle is a weed of sufficient nuisance value to warrant control.

(vii) Control Methods

a) Mechanical and Chemical

Prior to the discovery of the phenoxyacetic-type herbicides (e.g. MCPA and 2,4-D) in the 1940's, mechanical methods were used in the control of slender thistle. "..... the best way is to skim them off, big and little, at the surface of the ground before blossoming with a sharp, broad light hoe - not cutting the grass" (Black 1913). This statement also shows that the importance of maintaining a good grass cover was realised, although probably not the reason why!

From the time of the development of the phenoxyacetic compounds for weed control to the present day, MCPA and 2,4-D have been and are being recommended and used for the control of slender thistle in Tasmania (Cock 1951; Anon. 1966).

The use of chemicals for weed control has become an integral part of arable crop culture, but for broad acre pasture weed control, the value of herbicides has been overemphasised with a corresponding over-dependence on chemicals alone for maintaining improved pasture communities (Kennedy 1970).

Broad acre weed control using high rates of herbicides (e.g. up to 1.68 kg a.e. MCPA/ha are recommended for slender thistle control - Anon.(1966)) is unsatisfactory for a number of reasons:

1. It is expensive and requires annual repetition to deplete seed store in the soil (Thurston 1960).

2. It reduces pasture productivity by reducing pasture legumes and not favouring growth of improved grasses (Pearce 1972).

3. It may have detrimental environmental effects.

4. It increases the input of non-solar energy for animal production, thus increasing the unfavourable dependence of modern agriculture on fossil fuels (McClymont 1973).

Satisfactory pasture weed control techniques must therefore overcome these deficiencies, and in addition, must be simple so that they can be applied over large areas.

b) Ecological Weed Control

Although there is no documented evidence of slender thistles in pasture being controlled by ecological methods, some other thistle species and pasture weeds have been controlled satisfactorily by such techniques.

It should be noted that ecological methods may be applied for the control of weeds in both crops and pastures, but the following discussion will be especially with respect to pastures.

Ecological weed control, that is, altering the environment to the detriment of the weeds, overcomes the disadvantages inherent in chemical weed control, and may take three general forms:-

1. Promoting the growth of pasture in competition with the weeds, thus reducing the growth of the weeds.

Davies (1968) suggested that pasture botanical composition was the resultant of soil fertility, moisture status, and imposed cutting or grazing treatments. He improved the competitive ability of a pasture, resulting in a reduced weed component, by altering these factors.

Moore and Cashmoore (1942) showed that the best method of controlling St. John's wort (Hypericum perforatum L. var. angustifolium DC) was to sow a mixture of Phalaris tuberosa and subterranean clover (Trifolium subterraneum) with adequate fertilizer. It is believed that the main factor in the control of this weed is the reduction in light intensity under the sward (Moore and Williams 1965).

Onopordum acanthium has been controlled successfully by lucerne (Medicago sativa) and cocksfoot (Dactylis glomerata)(Michael 1965) and by Festuca arundinacea or Phalaris tuberosa (Michael 1968(c)).

Similarly, lucerne and Phalaris tuberosa have been used to control Silybum marianum (Michael 1968(b)). Competition for moisture is believed to be the prime factor in the

control of these two thistles.

2. Altering growth form or controlling growth of the weed to increase palatability or acceptability to the grazing animal. That is, to "utilise" the weed as a pasture species.

Myers and Squires (1970) controlled the growth of barley grass (Hordeum leporinum) by deferring grazing for 20 days after the first autumn irrigation. The barley grass, being very palatable at this stage, was readily controlled when grazed.

Pearce (1969, 1972) used a sub-lethal rate of MCPA and 2,4-D to increase the palatability of weeds. This "spray/graze" technique could be useful for the control of a wide range of pasture weed species including slender thistles. Herbicide doses required were not detrimental to pasture legumes (Pearce 1972).

Also, the growth of some weeds may be changed to increase their susceptibility to herbicides, thus facilitating the use of low but lethal doses of chemical (Bendixen 1970).

3. Direct grazing using high stocking rates.

Whatman (1967) reported the satisfactory control of ring fern (Paesia scaberula) in New Zealand by sheep stocked at 20-25/ha. Also, Gunning (1966) has shown that the eradication of barley grass from small areas may be accomplished with sheep at high stocking rates.

These techniques either overcome or greatly reduce the dangers inherent in using high rates of herbicides over large areas.

It is important to recognise the ecological basis of

the grassland sward and the value of the ecological concept in pasture weed control (Moore 1957). It must also be remembered that, in applying ecological principles, we take cognisance of the biology of the species, its environment, and of man's use of that environment (Moore 1967(b)). Biological studies may help in making existing weed control methods more effective or determine possible new methods (Chancellor 1968).

Since slender thistles are primarily a major pasture weed it was decided to adopt a biological and ecological approach in this study of the species with the aim of formulating effective non-chemical control techniques.

II Some Aspects of the Seed of Slender Thistle

a) Introduction

Slender thistles, normally winter annuals, survive the adverse dry summer periods as dormant achenes. The key to the successful control of slender thistles, as with other annual weeds, lies in their seeds (Chancellor 1968). If seed production, or the physiological functions of the seed could be controlled then the species would no longer be a problem. A knowledge of the factors which regulate germination behaviour and seedling survival is, therefore, fundamental in the development of satisfactory control methods.

The seed used in the following series of experiments was harvested by collecting mature seed heads and drying in an incubator at 30°C for 48 hours. Seed heads were then shaken in a plastic bag and the seed separated from other plant material manually and with the aid of a small fan. The seed was stored in open containers under laboratory conditions until used.

In the initial phase of experimentation, it was found that leaching of the new seed was essential to facilitate germination. The leaching requirement was fulfilled by allowing tap water to drip over the seed placed on a strip of fine fly wire. Unless otherwise stated, C. pycnocephalus was used in all experiments.

b) Diaspory in Slender Thistle

(i) Morphological Aspects

Diaspory, which is not uncommon within the plant kingdom (Salisbury 1942; Koller 1957; Harper 1965; van der Pijl 1969), is exhibited by both species of slender thistle.

Figure 1 shows the dimorphic seeds of C. pycnocephalus. The seeds of C. tenuiflorus are similar to those illustrated both physically and physiologically.

The most common seed type (Fig.1A) is cream in colour, striated, and is coated with a sticky gum-like material. The testa contains a water-soluble germination inhibitor and the embryo will germinate only after leaching or dissection from the testa.

The less common seed type (Fig.1B) is dark-grey in colour, not striated and not sticky, and will germinate without any prior leaching. These seeds are slightly smaller than the more common type and occur as marginal or ray fruits in each flower head.

The proportions in which the diaspores occurred in southern Tasmania, and their average weights are given in Table 2. No difference was observed in the proportions of dimorphic seeds or their average weights at two harvests during the flowering season.

Figure 1

The Diaspores of Slender Thistle

A Striated and sticky

B Not striated and not sticky

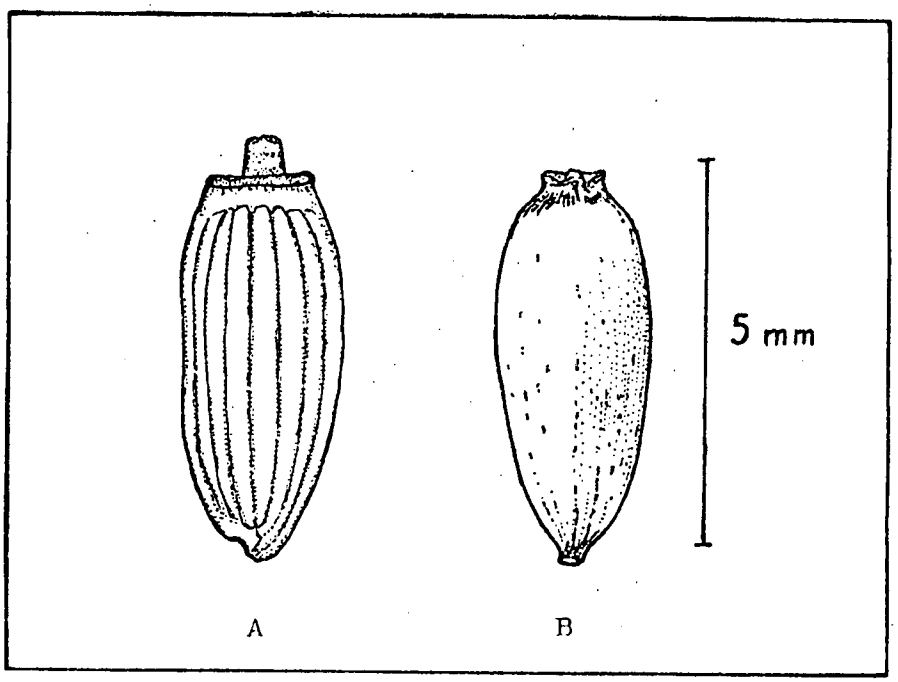

5 mm
A
B

TABLE 2

Seed Dimorphism in Slender Thistle (Harvested November 1970)

	C. tenuiflorus		C. pycnocephalus	
Seed Type	Proportion	Av. Weight (mg)	Proportion	Av.Weight (mg)
Non-sticky	14.4%	0.0029 ±0.0001	13.5%	0.0058 ±0.0002
Sticky	85.6%	0.0033 ±0.0003	86.5%	0.0064 ±0.0003

The dimorphic seeds occurred in all the flower heads examined at different times throughout the season. The most non-sticky seeds observed in any one seed head were six for a C. tenuiflorus head but generally the number varied from two to three for both species. In the occasional flower head, seminal trimorphism was observed. In this case, an intermediate seed type was found which was striated and sticky on one side, and dark grey, not striated and not sticky on the other. This type required leaching to facilitate germination and is probably an immature form of the common sticky seed type. It is unlikely, however, that the completely non-sticky seeds are simply immature stages of the sticky type because of the constant proportions in which they occurred throughout the flowering season.

The non-sticky seeds also have reduced pappus development and are not released from the mature flower head as are the sticky seeds. The marginal seeds remain enclosed by the involucre and fall with the mature head at abscission.

Heterocarpy in the Compositae is closely connected with differentiation in dispersal (Zohary 1950). The incomplete synaptospermy observed in slender thistles could be

such a differentiation. The sticky seeds which have well-developed pappi designed for wind transport, are released prior to abscission of the seed head. The non-sticky seeds however, have reduced pappi and use the prickly involucre as a transport vehicle following abscission.

(ii) Physiological Aspects

Although the two main seed types are quite different morphologically, physiologically they differ only in requirements for germination, with the water soluble germination inhibitor probably being contained in the sticky material covering the more common of the seed types. The inhibitor, however, breaks down 10-12 weeks following seed-fall thus facilitating germination without leaching.

Water soluble inhibitors are common in desert and semi-desert species where rainfall is of paramount importance (Koller 1964; van der Pijl 1969). Slender thistles are adapted to growing on shoreline areas and beaches (hence the common name "shore" thistle) and it is possible that during the species' adaptation to such areas, water soluble germination inhibitors have evolved as a survival mechanism.

Seed polymorphism, by enforcing differences in germination time enables a proportion of the population to avoid major hazards (Harper 1965). The presence of water soluble inhibitors would ensure that seed would not germinate until sufficient moisture was present for seedling establishment, thus avoiding drought. The concurrence of seeds without an inhibitor would allow a proportion of the population to germinate early or in seasons of prolonged low rainfall, thus

increasing the probability of successful perpetuation of the species during periods or in localities of low moisture. If this assumption is valid, it might be expected that seedlings arising from the latter seed types (no germination inhibitor) would have a greater tolerance to moisture stress than the former seed type, the germination of which is controlled by a soluble inhibitor.

A glasshouse experiment was set up to test the hypothesis that seedlings arising from seeds without a soluble germination inhibitor have a greater tolerance to moisture stress than seedlings arising from seeds containing a soluble germination inhibitor.

Materials and Methods

The experiment was commenced during October, 1972 in the glasshouse. The experimental design was a 2 x 3 factorial arranged in four randomised complete blocks.

The treatments comprised two seed types (sticky - with inhibitor; non-sticky - without inhibitor) and three soil moisture regimes - dry (20% moisture by weight), medium dry (25% moisture) and moist (30% moisture).

Plants were grown in a 50/50 sand/peat mix, which had previously been adjusted to the desired moisture status, in 500 ml conical flasks. Germinated seeds were placed in a plug of moist Krasnozem soil in the neck of the flask to facilitate early uniform seedling establishment. Black polythene was placed over the top of each flask to prevent moisture loss by evaporation, and the seedlings grew through a small hole in the polythene. Each was placed in a sand-

filled 1.7 litre bucket to prevent excessive heating and to allow the roots to grow in the dark.

Thistles were harvested 4 weeks after planting and dried for 24 hours at 100°C. Roots were washed free of sand and peat and also dried at 100°C for 24 hours.

Results and Discussion

The dry weights of the tops and roots for each seed type at the three moisture levels are tabulated in Appendix I. The mean dry weights are shown in Figure 2.

Both roots and shoots responded significantly to moisture status as would be expected. Shoots showed no difference in response between seed types as compared with the roots which showed a significant difference in response between seed types. The non-sticky seeds had greater root growth at low soil moisture than the sticky seeds, and about the same root growth at 25% soil moisture.

The greater root growth of seedlings arising from the non-sticky seeds would convey to these plants a greater tolerance of moisture stress than those plants arising from the sticky seeds with less root growth. At the time of harvest, the greater root growth was not reflected in higher foliage yields, thus it appears to be simply a mechanism to increase the chances of survival under dry conditions.

There is a greater evolutionary trend to heterocarpy in Compositae than in any other family (Zohary 1950). In the slender thistles, heterocarpy is well developed with both morphological and physiological differences between the diaspores apparent. Diaspory, resulting in differentiation in

Figure 2

Effect of soil moisture on the growth of seedlings arising from the diaspores of slender thistle.

(Dry weight of roots and foliage, gm)

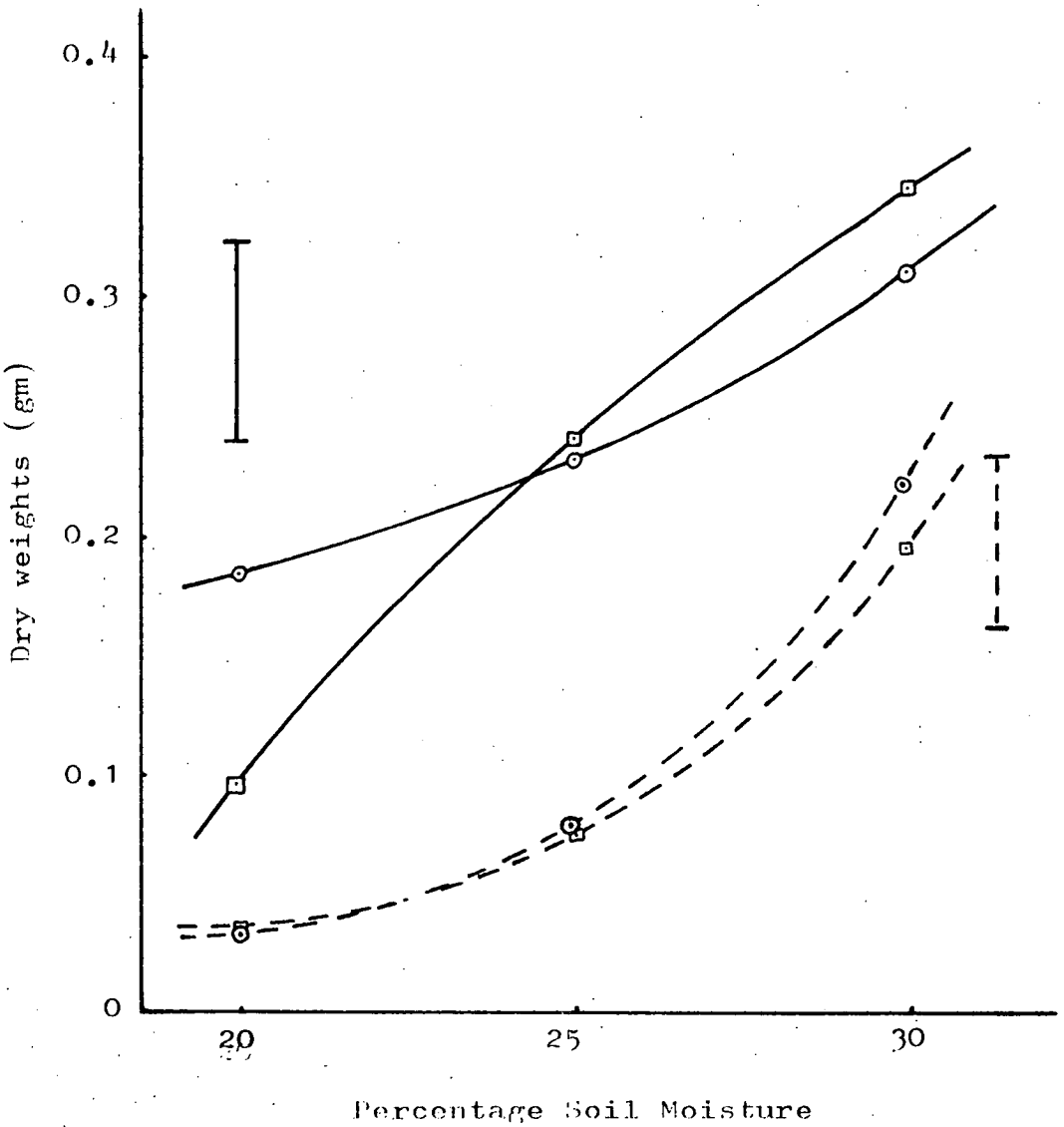
———— Roots

------ Foliage

⊙ Non-sticky seeds

⊡ Sticky seeds

LSD's P = 0.05 for roots at 20% moisture and P = 0.01 for foliage are shown.


0.4
0.3
0.2
0.1
0
Dry weights (gm)
20
25
30
Percentage Soil Moisture

dispersal, germination, and seedling survival mechanisms, appears to have strong survival value for the species. This would be emphasised in semi-arid regions e.g. sand-dunes and similar places which were common habitats of slender thistles (Black 1913), and in seasons of low rainfall.

c) Effect of Temperature on Germination

Method

The effect of temperature on the germination of slender thistle seed was examined in the laboratory.

Slender thistle (C. pycnocephalus) seed was leached for approximately one hour, and then samples of 50 seeds were placed on moist filter paper in petri dishes and incubated at the following temperature: 5°C, 10°C, 15°C, 20°C, 25°C, 30°C and 35°C. All treatments were replicated four times and germination counts were made after 3, 4 and 5 days.

The germination of C. tenuiflorus seed was also tested at each temperature but unreplicated. Similar temperature responses were observed to C. pycnocephalus.

Results and Discussion

The temperature range of seed germination is shown in Figure 3. At 15-25°C, approximately 100% germination was recorded. At 10°C and 30°C there were sharp reductions and at 5°C and 35°C no germination was recorded after 5 days.

In the field (southern Tasmania) slender thistle germinates from December to April with occasional germinations before and after this period. The reduction in germination after April may be associated with the mean soil temperatures shown in Table 3.

Figure 3

The effect of temperature on the germination of slender thistle.

(Percentage germination after five days)

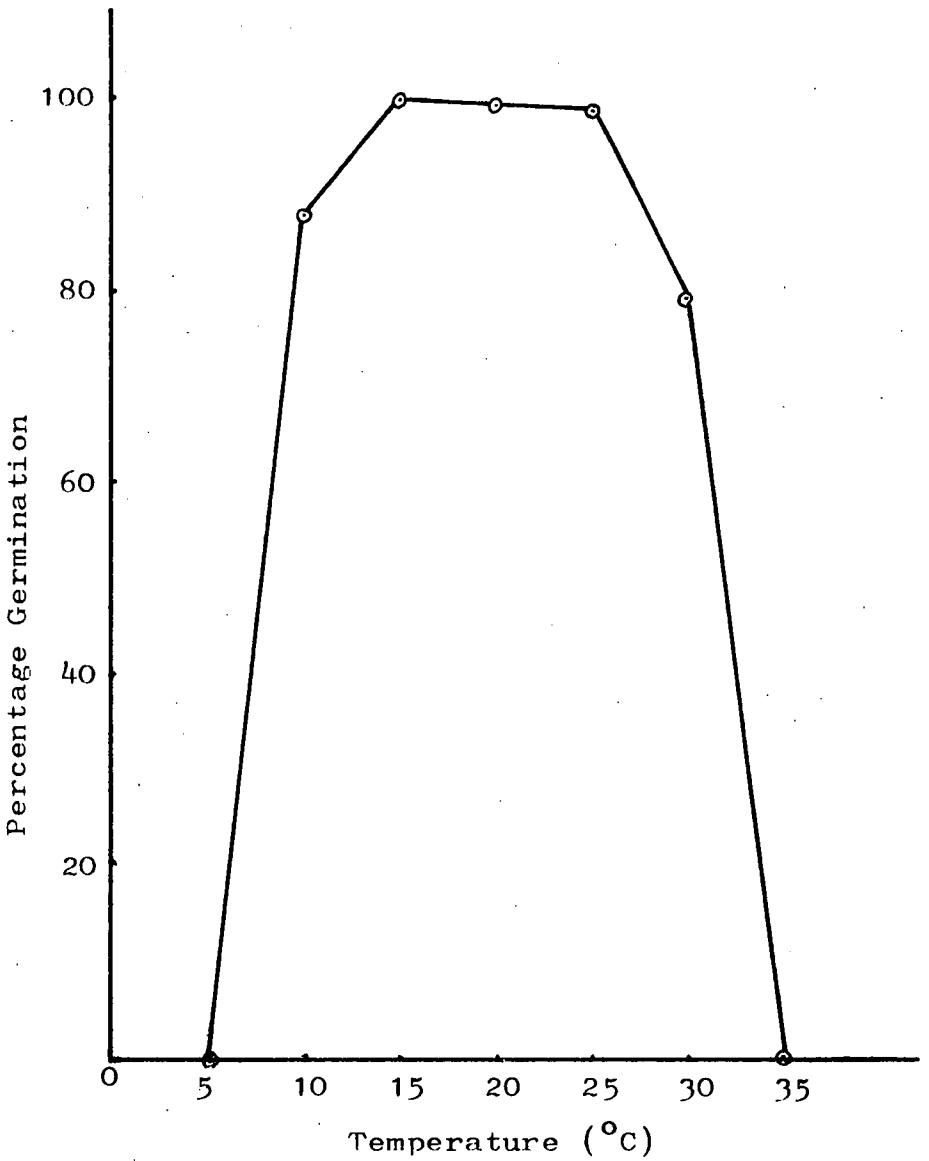

100
80
60
40
20
0
Percentage Germination
5
10
15
20
25
30
35
Temperature (°C)

TABLE 3

Soil Temperature (°C) at Hobart

4" (10.16 cm) Probe (Means 1961-67)

Month	Maximum	Minimum	Mean
January	25	12	17
February	21	10	16
March	20	9	15
April	16	4	11
May	13	2	8
June	10	1	6
July	8	1	5
August	9	1	6
September	13	3	8
October	17	6	11
November	19	6	14
December	23	10	16

From March to May the mean soil temperature drops from 15°C to 8°C. In the laboratory, percentage germination dropped rapidly from 100% to approaching nil between these temperatures. Although the soil temperature is suitable for germination for some time before December, it would be inhibited by lack of sufficient rainfall for pre-germination leaching.

The effect of fluctuating temperatures on germination in the field would need to be considered to define the limits of temperature on germination more precisely. However, the results do suggest a definite inhibition of germination by low temperatures during the winter months.

d) Effect of Depth of Seed Burial on Germination

Method

Two field experiments were set up to study the effects of four depths of burial on the emergence, dormancy and longevity of slender thistle seed. Fifteen centimetre lengths of 6 cm diameter irrigation pipe were partially filled with soil and placed in holes in the ground. The bottom of the pipes were left open to facilitate drainage and to simulate field conditions. The soil used was a medium textured Podzolic soil on dolerite obtained from a thistle infested area in southern Tasmania and steam sterilised to kill any viable seeds present. Groups of 21 seeds were each placed on fly-wire discs and buried at depths of 0, 1.3 cm, 5 cm, and 10 cm in the pipes and covered with soil. All seed was sown on the 10th and 11th January, 1969. The technique allows the ungerminated seeds to be readily retrieved at regular intervals for testing of viability.

In one experiment, depths of burial were replicated six times and emergence only was recorded during the first year. Emergence was recorded with the appearance of the cotyledons at the soil surface, and observations were carried out daily during the germination season (January to April) and at regular intervals throughout the year.

In a second experiment, depths of burial were replicated 16 times and two replications were retrieved each March and November over four years (1969-1972) to study seed longevity. For each plot, the ungerminated seeds were removed and their viability recorded in the laboratory by placing on moist filter paper in petri-dishes and incubating at 25°C for

10 days. An estimate of the percentage viable seed remaining at each retrieval was obtained.

Table 4 shows the monthly rainfall recorded at the site of the experiments from 1969 to 1972.

TABLE 4

Monthly Rainfall (mm) at New Town Research Laboratories 1969-1972

Month	1969	1970	1971	1972
January	21	101	53	51
February	111	30	94	43
March	33	36	29	14
April	72	25	41	62
May	68	19	96	9
June	41	38	37	17
July	27	57	19	91
August	47	110	56	40
September	20	28	75	39
October	16	91	80	27
November	92	48	55	28
December	81	54	64	53
TOTAL	629	637	699	474

Results and Discussion

The mean percentage emergence in the first year of slender thistle seed buried in soil at four depths are given in Table 5.

TABLE 5

First year Emergence of Slender Thistle Seed Buried in Soil at Four Depths

	Depth of Burial			
	Surface	1.3 cm	5 cm	10 cm
Mean Percentage Emergence	36.5	62.7	38.9	0

LSD=21.9, P=0.01

Highest emergence occurred from a depth of 1.3 cm and nil from 10 cm. No significant difference was observed between emergence of surface seed and seed at 5 cm.

Figure 4 shows the percentage viable seed remaining at each retrieval from March, 1969 to November, 1972.

The percentage viable seed remaining at the surface was nil at all retrievals. At 1.3 cm depth, 14% viable seed was retrieved in November, 1969, but no viable seed remained at subsequent retrievals. Thus, curves for surface seed and 1.3 cm depth do not appear on the graph.

After the initial germination, 20 to 25% of viable seed remained at 5 and 10 cm depth. By the end of the first year, less than 5% of the initial seed population remained viable at 5 cm depth, compared with 24% at 10 cm depth. By March, 1972 no viable seed remained at either depth. In this experiment, virtually all germination occurred in the first year in similar proportions to that shown in Table 5. Only an occasional emergence was observed in later seasons.

Low germination at the surface (Table 5) was in part due to irregular rainfall and rapid drying of the surface soil following rain. The seeds imbibed water, but rapidly dried out as the surface soil dried before germination was

initiated. That is under the experimental conditions of the trial, few microsites (Harper 1960) were suitable for satisfactory germination, as compared with the heterogenous field situation where many suitable microsites would be expected to be available.

Retrievals in the second experiment showed that much of the seed which had not emerged had either been removed, probably by birds or soil fauna e.g. ants and millipedes, or decomposed. In the first retrieval, many seeds appeared to have germinated, but the seedlings had perished before emergence. This was observed at all depths, especially at 5 cm and 10 cm., where in a number of instances, the remains of the hypocotyl of the germinating seed was found. At the surface, 1.3 cm, and 5 cm., mortality was probably due to infection by soil-borne micro-organisms. No seedlings were observed to reach the soil surface from 10 cm depth, probably because of a lack of sufficient food reserves in the seed. Similar reasons for low seedling emergence have been suggested by Harper (1955) and Roberts and Feast (1972). Chancellor (1964) studied the germination of 18 weed species and found that 95% of all seedlings measured came from less than 5 cm depth. It was not surprising then that no seedlings emerged from 10 cm depth in the present experiment.

Seed longevity increased with depth of burial (Fig. 4) This agrees with the conclusions from the "Duvel buried seed" experiment (Toole and Brown 1946) and with the work of Roberts and Feast (1972), that weed seeds live longer when buried more deeply in undisturbed soil. The greater longevity of the seed at 10 cm depth probably reflects a decreasing influence of weather and temperature fluctuations,

Figure 4

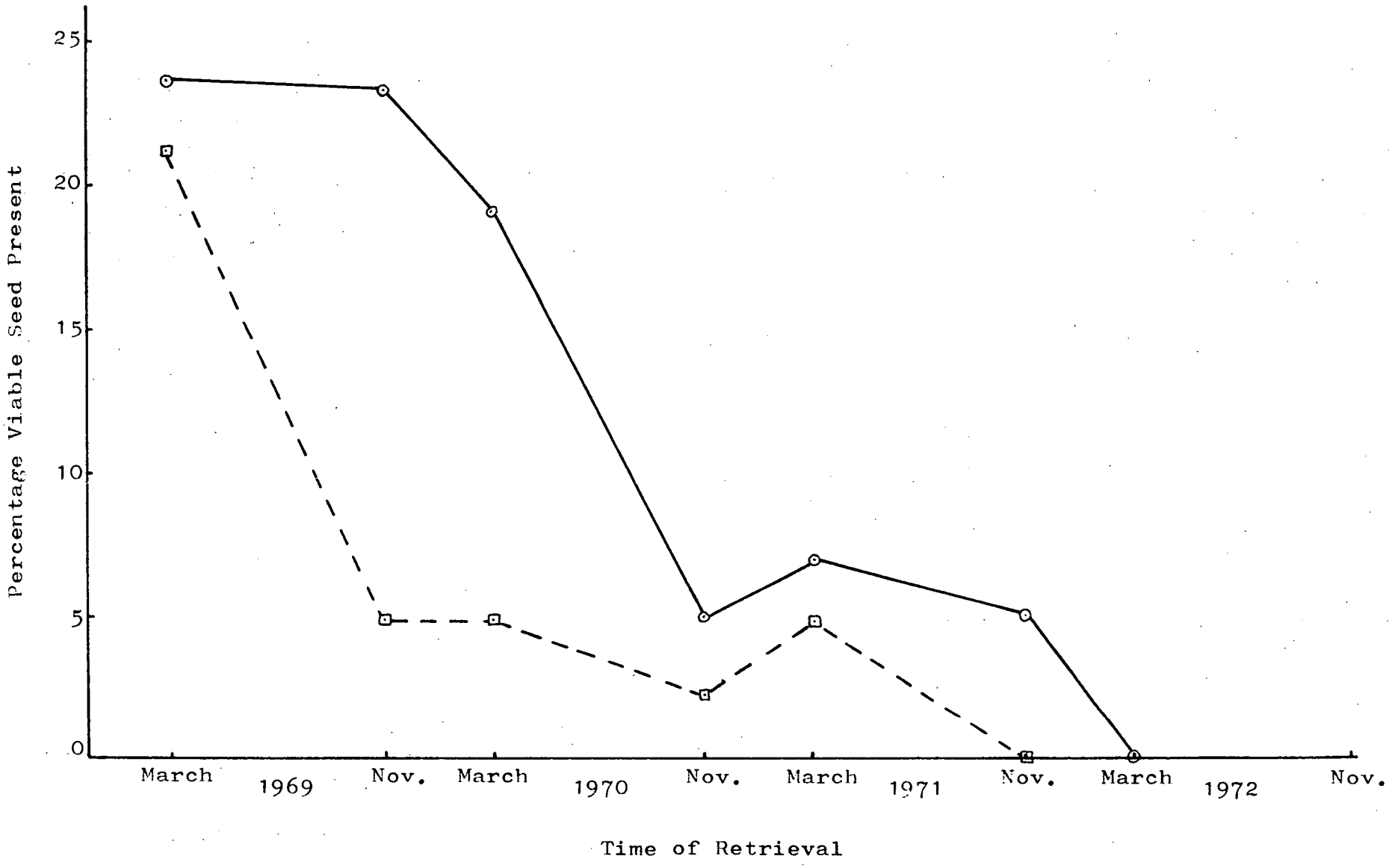
The effect of depth of burial on the longevity of slender thistle seed - Percentage viable seed present March 1969 - November 1972.

___ 10 cm depth

--- 5 cm depth

LSD = 15.5, P = 0.01

LSD = 11.15, P = 0.05


Percentage Viable Seed Present
25
20
15
10
5
0
March
1969
Nov.
March
1970
Nov.
March
1971
Nov.
March
1972
Nov.
Time of Retrieval

lower decomposition activity, and lower soil-fauna populations at the greater depths.

It is suggested that the artificial conditions created in the experiment may have been favourable for the development of soil-fauna populations which would reduce seed longevity. Also, the experimental area was kept free of vegetation by hand-weeding thus exposing the seeds to climatic conditions to a greater extent than would occur under field conditions. This would tend to reduce seed longevity. Under the conditions of this experiment seed longevity extended to nearly 3 years, whereas Goss (1924) observed 4.5% viability of Carduus seed after 20 years. However, in his experiment the seeds were placed in sterile soil in closed porous containers and buried. Exposed to climatic and soil factors under natural field conditions, it would not be expected that seed would remain viable for 20 years, but field observations suggest that longevity may be in excess of 3 years.

The results show that seed buried at 5 cm and 10 cm forms the main seed reserve from season to season. The carry-over of ungerminated seed in the experiment was small because of the abovementioned factors, but at least 5% of the original seed source will remain viable for more than 2 years when buried at a depth of 10 cm, and if brought to the surface will germinate under favourable conditions.

e) Conclusion

Many factors govern germination and dormancy in slender thistles. In most of the newly produced seed there is a soluble germination inhibitor in the testa which requires leaching out to facilitate germination. In a small proportion

of the seed, the inhibitor is absent and such seed will germinate readily without any prior leaching. Diaspory, resulting in differentiation in dispersal, germination and seedling moisture requirements appears to be important in the survival of the species by increasing the range of environmental conditions suitable for plant growth.

If sufficient leaching of the seed does occur and the soil temperature is greater than 10°C, then most seed will germinate but with approximately 20% of the buried seed remaining dormant until the following season. 5% of the original buried seed remains dormant for at least three years and will germinate under suitable conditions. The reserve of seeds in the soil aids survival by preventing eradication by one year's control (Thurston 1960).

Satisfactory control of established populations in pasture may only be achieved by annual repetition of existing control measures (cutting or spraying with herbicides) to prevent further seed production, until the seed store in the soil has been depleted by germination or lost to biotic causes.

III Nutritional Aspects of Slender Thistle

a) Introduction

Slender thistles are commonly called weeds of high-fertility or nitrophilous weeds. Observations in Tasmania suggest that they never invade native pastures, but will readily invade "run-country" following the introduction of legumes and fertilizer applications. Their response to fertility is also evident in their invasion of stock camps, and around homesteads and in established pastures.

To observe the response of slender thistles to changing fertility, an experiment was set up to study the effect on growth and seed production of nitrogen, phosphorous, and potassium applications to a low fertility soil. A second experiment was also carried out to observe the effect of changing pH on thistle growth.

b) Effect of N, P, K on Growth and Seed Production

Materials and Methods

The experiment was set up in 91 buckets in the glass-house using a Podzolic Soil on Sandstone (Dimmock 1957) obtained near Campania, in S.E. Tasmania, from a run-down pasture. The pasture had received no fertilizer applications for a number of years, plants were sparse with few improved species and a few very stunted slender thistles. Three levels of each of nitrogen, phosphorus and potassium were arranged in a 3^3 factorial design with two replications. Nitrogen was applied as urea at the equivalent of nil (n_o), 250.8 (n_1) and 501.6 (n_2) kg urea/ha; phosphorus as superphosphate at nil (p_o), 250.8 (p_1), and 501.6 (p_2) kg superphosphate/ha; and potassium as muriate of potash at nil (k_o), 124.4 (k_1), and 250.8 (k_2) kg potash/ha.

Leached thistle seeds were sown singly in each bucket during May, 1969 and regularly hand-watered during the experiment.

Plant diameters were measured after 5 months of growth prior to bolting, and the number of basal branches and the number of flowers per thistle were counted during the period of maximum flowering.

Results and Discussion

Table 6 indicates the growth response of slender thistles to applications of nitrogen, phosphorus and potassium.

TABLE 6

Response of slender thistles to nitrogen, phosphorus and potassium

(Mean rosette diameters, cm)

n_o	n_1	n_2
28.33	44.83	47.33
p_o	p_1	p_2
38.56	40.11	41.83
k_o	k_1	k_2
41.33	40.56	38.61

LSD = 10.48 P = 0.01

Nitrogen significantly (P = 0.01) increased thistle growth while phosphorus and potassium had no significant effects. No significant interactions were observed (Appendix IV).

With respect to basal branching, a significant (P = 0.05) interaction between nitrogen and potassium occurred (Table 7).

TABLE 7

Interaction of nitrogen and potassium fertilizers on basal branching in slender thistles

(Mean number basal branches/thistle)

	k_o	k_1	k_2
n_o	0	0	0
n_1	0.17	1.33	1.50
n_2	3.00	3.00	4.00

LSD = 0.71, P = 0.05

Nitrogen greatly increased basal branching at all levels of potassium, and no branching occurred at nil nitrogen applications. Potassium increased branching only in the presence of nitrogen. At low nitrogen levels, a low application of potash significantly increased branching, but at high nitrogen, only high rates of potash had a significant effect. Maximum branching occurred at high rates of application of both fertilizers.

The flowering response of slender thistles to soil fertility is shown in Table 8.

TABLE 8

Response of flowering in slender thistles to nitrogen, phosphorus and potassium

(Mean number of flowers/thistle)

n_o	n_1	n_2
8.67	28.22	34.56
p_o	p_1	p_2
21.78	24.50	25.17

(cont'd)

TABLE 8 (cont'd)

k_o	k_1	k_2
23.11	25.78	22.56

LSD = 17.24 P = 0.05

LSD = 23.24 P = 0.01

Nitrogen greatly stimulated flower production, but phosphorus and potassium had no significant effects. No interactions were observed.

Nitrogen increased the reproductive capacity of the thistles by greatly increasing the number of basal branches produced per plant and hence the number of flower heads per plant. Although potassium in the presence of nitrogen increased branching (Table 7), there was not a corresponding increase in the number of flowers produced. It appears that nitrogen also stimulated flowering in the leaf axils, which potassium did not.

There were no observed differences between the number of seeds per flower between treatments.

By analyzing soil samples from thistle infested areas and ajacent areas with no thistles, Michael (1968(a)) has shown that thistles, in general, are weeds of fertile soils. He also suggests that one should avoid generalisations relating thistles to nitrogen alone. The present results with slender thistle indicate that nitrogen is of greater importance than either phosphorus or potassium in promoting growth and maintaining seed production capacity.

It follows then that slender thistles would be expected to be more prolific on soils of high nitrogen status than in areas of low soil nitrogen. Field observations have

shown that slender thistles will, in general, invade clover dominant pastures of good ground cover more readily than grass dominant pastures. This may be due more to a greater nitrogen availability in the clover dominant pastures than in the grass sward rather than merely a reaction to reduced competition for light.

c) Effect of pH on Slender Thistle Growth

Materials and Methods

Thistles were grown in the glasshouse at three pH regimes, viz. pH4, 5.2 and 6.5, in a randomised complete block design with four replications. pH 5.2 was the normal pH of the sandy-loam (Podzolic soil on Sandstone) used. The pH of this soil was increased or decreased by the additions of calcium carbonate or sulphur respectively, and three weeks elapsed before planting to allow equilibration of the oxidation of sulphur to H_2SO_4. pH's were measured using a Metrohm pH meter with combination electrode in a slurry of a soil sample.

Individual plants were grown in 2.3l. (0.5 gal.) buckets and regularly hand-watered during the experiment.

The thistles were harvested after 6 weeks of growth and dried at 100°C for 24 hours prior to weighing.

Results and Discussion

The effect of pH on the growth of slender thistle is indicated in Figure 5.

Higher pH favoured thistle growth, with a suppression of virtually all growth at the lowest pH used. Growth increased rapidly from pH4 to pH 5.2, the natural pH of the sandy loam, and less rapidly from pH 5.2 to 6.5.

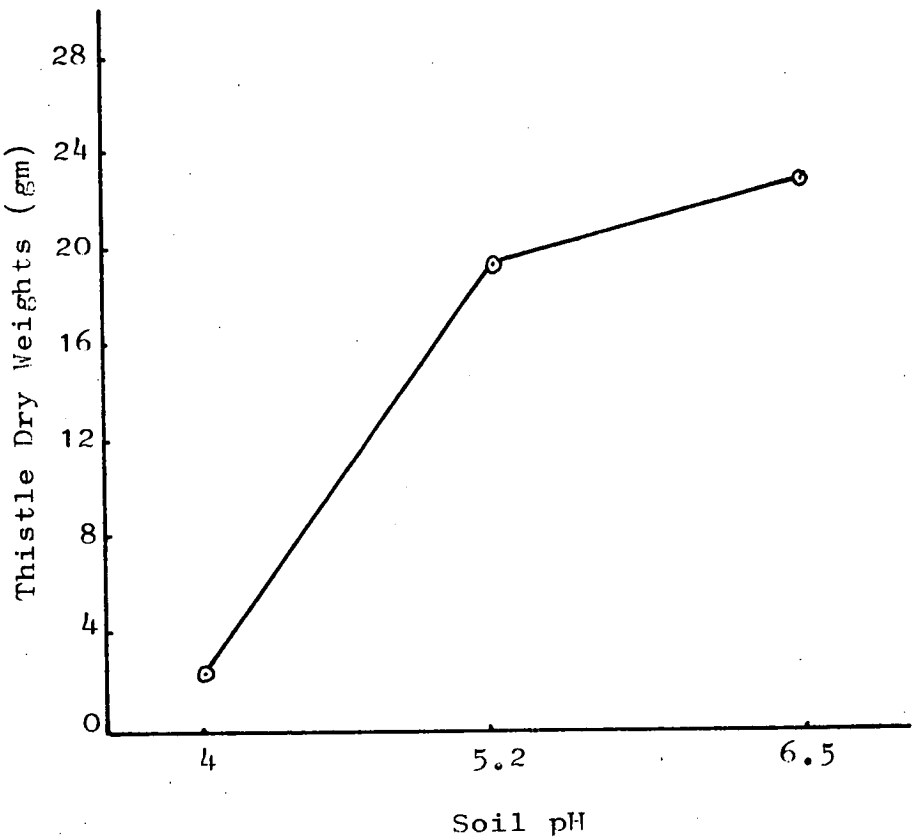
Figure 5

Effect of pH on the growth

of slender thistles

(Thistle dry weight after six weeks growth)

LSD= 3.02 P= 0.01


Thistle Dry Weights (gm)
28
24
20
16
12
8
4
0
4
5.2
6.5
Soil pH

This result is in accord with that observed by Michael (1968(a)) where high soil calcium appeared to be especially favourable to slender thistle (Carduus tenuiflorus).

In Tasmania it appears that C. pycnocephalus and C. tenuiflorus have similar nutritional requirements as they often occur in mixed populations. Moore (1967(a)), however, working in Canberra, has shown in glasshouse experiments that levels of nitrogen and calcium determine the outcome of competition between the two species, but does not state their critical requirements.

d) Conclusion

High soil nitrogen is important for maximum growth and seed production in slender thistles, although it appears not to be an absolute pre-requisite for their persistence.

It is an inference from Metson et al. (1971) that the accumulation of soluble salts, associated with the increase in fertility in pastures and stock-camps, may be a factor in the increase in frequency of Carduus spp. with increased fertility. Slender thistles may be especially adapted to high soluble salt (saline) conditions from their shore-line habitats and this would probably explain their response to increasing pH.

Allen and Meeklah (1973) suggested that fertility control may be a possible thistle control method under certain circumstances - for example, fencing to control stock "camping". However, adequate fertilizers are necessary for satisfactory pasture establishment and growth, and the results suggest that fertilizer requirements which may be necessary

for satisfactory pasture growth also favour thistles. This may be especially pronounced on "run-country" following fertilizer applications and the introduction of legumes, and where the development of good continuous pasture ground cover is difficult.

In some areas of Tasmania the lack of satisfactory slender thistle control measures is preventing the maximum development of "run-country" which would otherwise, give a profitable return with the introduction of legumes and fertilizers.

IV The Effect of Grazing Management on the Ecology of Slender Thistles in Improved Pasture

a) Introduction

Slender thistles are probably the most common and detrimental pasture weeds in Tasmania. At present, herbicides are used to control the thistles, but this method is frequently inefficient and uneconomical and may suppress pasture legumes. Since slender thistles occur predominantly in sheep grazing areas, it was decided to consider the effects of grazing management on the ecology of the species with the possibility of using grazing management for slender thistle control. If seeding could be prevented for three years, it would appear that a slender thistle population could virtually be eliminated from a pasture in this time. With this in mind, two grazing trials were established to study the effects of various grazing management systems on slender thistle populations in improved pasture.

In considering the effects of grazing management on the ecology of a particular species, it is also necessary to know what effects the treatments have on all the other pasture components. This is especially true if a particular management system proves effective in the control of a weed - the system would be satisfactory only if it had no detrimental effects on the improved pasture species. Furthermore, the improvement and maintenance of pasture ground-cover may be of considerable importance in the suppression of a pasture weed. In the following two experiments, observations were made on the effects of grazing management on all pasture components.

b) Materials and Methods

(i) Sorell Grazing Trial

The first experiment was commenced in March, 1970 in the Sorell district of southern Tasmania on a six years old pasture with the dominant species being Lolium perenne (perennial ryegrass), Bromus spp., Cynosurus echinatus and Trifolium subterraneum (subterranean clover). The soil type is a Black Soil on Basalt (Loveday 1957) and the area has an average annual rainfall of 575 mm (Table 10).

Grazing and no grazing treatments were applied in the three life-cycle periods (autumn, winter and spring) in the form of a 2^3 factorial design arranged in four randomised complete blocks (Table 11).

Plots of size 20 m x 10 m were arranged within a 1.7 ha area in two ranks of 16 plots each (Plate 5). Plots were not stocked individually, but Corriedale x Merino wethers stocked at 17/ha grazed the area around the plots. Those plots which required grazing had the short end fences removed so that the boundary area and the plots were grazed at the same intensity.

Thistle populations were sampled in March, August (at the end of the winter treatment) and November (at the end of spring treatment), 1970, by (a) 24 random counts per plot using 929 cm^2 (1 ft^2) quadrats and (b) four larger quadrats (1 m^2) per plot selected so as to sample high and low density populations of thistles.

Pasture botanical composition determinations were carried out in October of the second year. During this year, all plots were opened and the whole trial area was continuously

Plate 5. Sorell Grazing Trial

May, 1970.

Plate 6. Richmond Grazing Trial

July, 1971.

grazed, so that any pasture composition differences between plots were due to the grazing treatments of the previous year.

A number of sampling methods or techniques could have been used to estimate botanical composition. The most quantitative method, that of cutting samples for hand separation and dry-weight analysis was ruled out as being too time consuming. Of the other methods for estimating botanical composition either by area or by weight, the use of the point quadrat for estimation by area is considered to be the most objective (Drew 1944; Brown 1954), especially in short pastures. Botanical estimations were carried out using an inclined (32.5^{o}) point quadrat rather than a vertical quadrat as the latter tends to underestimate the grass component (Warren Wilson 1959). Twenty frames of 10 points each were taken at random in each plot with all hits being recorded to the point of reaching ground level. The pasture height at the time of sampling was 5-8 cm which was suitable for point quadrat analysis.

(ii) Richmond Grazing Trial

The second experiment was established in the Richmond district of southern Tasmania, to study in further detail those grazing management systems which were effective in controlling slender thistle in the Sorell trial. The experiment was commenced in March 1971 on a three years old pasture with the dominant species being Lolium perenne, Trifolium subterraneum, and Bromus spp. Other species present were Vulpia spp. and broadleafed weeds: Rumex spp., Cirsium vulgare, and Plantago spp. The soil type is a Podzolic

Soil on Dolerite (Loveday 1957) and the mean annual rainfall for the area is 525 mm (Table 10). Grazing and no grazing treatments were applied in autumn and spring in a 2 x 2 factorial design in six randomised complete blocks (Table 14). All treatments were grazed during the winter. The layout of the experiment (Plate 6) was similar to that at Sorell, but with a plot size of 20m x 8 m and stocked with Polwarth wethers at 15/ha.

Because of some variability in the thistle density at Sorell, a more rigorous sampling technique was adopted at Richmond. Thistle populations were sampled in March and at the end of each grazing period in the first year using eight permanent m^2 quadrats selected at random in each plot. Botanical composition determinations were carried out at the same time as the thistle counts. In March and June, 1971, botanical compositions were determined by eye-estimate of the relative weights of species in situ in the field using a 929 cm^2 quadrat at 16 random sites in each plot. In August and November, 1971, pasture composition was determined by sampling in grazing exclosures and composition determined from hand separations. Two quadrats of 1m x 0.25 m were sampled in each plot. All plots were grazed over the summer period - December to March.

During the second year of the experiment (1972), abnormally dry conditions were experienced (Table 10). The grazing treatments were continued, but sampling was necessarily limited. Thistle counts, however, were carried out in March, early July and late October. Because of lack of pasture growth, it was only possible (or worthwhile) to carry out

botanical composition determinations in August. The inclined point quadrat method was used as all plots were grazed to equal heights during the winter grazing period.

(iii) Rainfall at Trial Sites, 1970-72

Table 10 tabulates the rainfall at meteorological stations close to the two experimental sites for 1970 at Sorell and from October 1970 to December 1972 at Richmond.

(iv) Statistical Analyses

Where necessary, raw data were transformed to a suitable scale for analysis on the basis of Tukey's test for non-additivity and an examination of residuals plotted against expected values. Percentage thistle survival was the variable analysed at Sorell, the number of thistles counted at each time being expressed as a percentage of the initial population estimate. The initial thistle populations at Richmond were sufficiently uniform to allow the actual number of thistles to be analysed. Randomised complete block analyses of variance were performed on the measures of thistle survival and botanical composition at each site. The treatment sums of squares were partitioned into single degrees of freedom orthogonal contrasts to test the observation that a period of pasture competition followed by a grazing period reduced thistle populations.

Raw and transformed data and the analyses of variance are given in Appendix V.

c) Results

(i) Sorell Grazing Trial

The actual thistle counts for March, August and November are given in Appendix V.

TABLE 10

Rainfall at Sorell, 1970: Richmond Oct. 1970-Dec. 1972

Month	Rainfall (mm) - Sorell		Rainfall (mm) - Richmond			
	1970	28-year average	1970	1971	1972	52-year average
January	85	38		97	55	44
February	37	46		54	36	44
March	39	39		36	10	39
April	21	54		14	55	45
May	52	53		73	5	41
June	26	42		28	13	43
July	29	48		8	78	40
August	77	45		55	33	39
September	23	43		76	19	37
October	76	60	58	59	25	54
November	61	50	42	83	29	43
December	160	57	158	49	27	56
Total	686	575		632	385	525

The mean percentage slender thistle survivals at the August and November counts are tabulated in Tables 11 and 12.

TABLE 11

Mean Percentage Thistle Survival, Sorell - August, 1970

Treatments *A	W	S	Random Quadrats	High Density Quadrats	Low Density Quadrats
† 1	1	1) ‡	§		
1	1	0)	22.46(8.90)	20.55(8.60)	24.07(9.62)
1	0	1)			
1	0	0)	37.30(11.79)	21.89(9.41)	43.8 (13.05)
0	1	1)			
0	1	0)	5.91(4.46)	0.22(1.66)	4.76(4.05)
0	0	1)			
0	0	0)	26.01(9.87)	62.58(15.84)	32.81(10.66)
LSD (P=0.05)			(2.07)	(1.01)	(2.28)

*A = Autumn

W = Winter

S = Spring

† 1 = Grazing

0 = No grazing

‡ Essentially only four treatments at the August count.

§ Transformed means in brackets

- Transformation $\sqrt{x+0.5}$ where

x = percentage thistle survival.

The results indicate that grazing after no grazing period consistently reduced slender thistle populations. At

the August count (Table 11), the treatments involving winter grazing after autumn deferment (010 and 011) were the most effective in thistle control. By November (Table 12) spring grazing only (001) and no winter grazing (101) were also proving effective.

TABLE 12

Mean Percentage Thistle Survival, Sorell - November, 1970

Treatments *A	W	S	Random Quadrats	High Density Quadrats	Low Density Quadrats
† 1	1	1	12.15(2.92)‡	4.13(1.89)	0.83(1.02)
1	1	0	37.28(5.56)	6.55(2.52)	6.63(2.85)
1	0	1	3.25(1.74)	2.75(1.68)	3.73(2.82)
1	0	0	23.95(4.87)	5.78(2.49)	18.20(4.10)
0	1	1	2.38(1.57)	0.20(0.82)	0 (0.71)
0	1	0	11.13(3.09)	0.38(0.91)	3.45(1.65)
0	0	1	1.13(1.23)	0.33(0.87)	1.20(1.11)
0	0	0	44.38(6.67)	36.78(6.06)	32.88(5.72)
LSD (P=0.05)			(2.32)	(1.04)	(1.84)

*A = Autumn † 1 = Grazing

W = Winter 0 = No Grazing

S = Spring

‡ Transformed means in brackets

- Transformation $\sqrt{X + 0.5}$ where X = percentage thistle survival.

Continuous grazing (111) significantly reduced thistle numbers, but was not as effective as the no grazing/grazing treatments.

TABLE 13

Inclined Point Quadrat Botanical Analyses, Sorell (October 1971)
Mean Number Hits/100 Points)

Treatment *A	W	S	Slender thistles	Subterranean Clover (Not Transformed)	Rye grass (Not Transformed)	Bromus spp.	Cynosurus echinatus ($\log_e X$)	Other Grasses	Other Species	Bare Ground ($\log_e X$)
† 1	1	1	6.75 (1.707) ‡	127.00	130.75	2.75 (1.180)	8.25 (1.703)	6.25 (1.534)	11.75 (2.266)	3.25 (1.125)
1	1	0	12.5 (1.320)	60.00	89.75	26.50 (3.101)	27.00 (3.051)	12.25 (2.563)	6.75 (1.724)	4.75 (1.488)
1	0	1	2.75 (1.151)	95.00	112.00	1.75 (0.749)	5.50 (1.619)	5.00 (1.488)	19.25 (2.946)	5.25 (1.543)
1	0	0	7.25 (1.798)	43.75	84.50	27.50 (3.180)	36.50 (3.342)	16.00 (2.770)	8.25 (2.161)	5.75 (1.657)
0	1	1	4.75 (1.690)	111.25	101.00	2.50 (1.108)	2.00 (0.621)	4.75 (1.717)	26.75 (3.177)	6.50 (1.796)
0	1	0	2.50 (1.70)	60.25	89.50	31.00 (3.402)	19.00 (2.835)	11.25 (2.392)	13.50 (2.319)	7.25 (1.874)
0	0	1	2.52 (1.197)	86.00	102.25	3.25 (1.400)	5.50 (1.628)	2.25 (1.125)	40.50 (3.686)	4.00 (1.197)
0	0	0	13.50 (2.081)	94.25	71.50	21.75 (2.962)	10.50 (2.001)	12.25 (2.469)	9.75 (2.139)	4.75 (1.527)
LSD P=0.05			(ns)	35.90	20.12	(0.977)	(0.934)	(0.705)	(0961)	(ns)
LSD P=0.01			(ns)	48.80	28.90	(1.330)	(1.272)	(0.960)	(1.308)	(ns)

*A = Autumn
W = Winter
S = Spring

† 1 = Grazing
0 = No Grazing

‡ Means of transformed data in parentheses: Transformation $\log_e(X + 1)$ where X = Number of hits/100 points.

Fixed quadrats set in high and low density populations facilitated observations on the possibility of an intra-specific competition effect. However, observations suggest such an effect to be insignificant.

Although there is considerable variation in the results between the three methods of sampling, the most effective treatments were consistently significant in all analyses (Appendix V), and any variant from these is the result of inadequate sampling procedures in a very variable population.

The effects of the grazing systems on pasture botanical composition in the following year are given in Table 13. Spring grazing had the most obvious effect on botanical composition. Subterranean clover, perennial ryegrass, and "other species", which included other thistles (Cirsium vulgare, C. arvense, and Silybum marianum) and broad-leafed weeds (Rumex spp., Plantago spp., and Taraxacum officinale), were increased significantly by spring grazing and "other grasses" (Vulpia spp., Poa annua) - which were reduced in frequency by spring grazing.

Grazing or no grazing in autumn and winter had little effect on the botanical composition except in influencing the clover component in the winter/spring grazing system and in increasing both ryegrass and clover in the continuous grazing treatment. Slender thistles showed only small effects of being controlled by the previous years grazing treatments. Spring grazing following no grazing in winter resulted in a reduction in the slender thistle component during the following year, but spring grazing following winter grazing did not. Also, winter grazing following no autumn grazing resulted in a slight increase in bare ground, whereas winter grazing following autumn grazing tended to reduce bare ground, possibly as an opposite effect on subterranean clover.

(ii) Richmond Grazing Trial

The results of the slender thistle counts in March, June, August and November, 1971 as mean number of thistles per m^2 are tabulated in Table 14.

TABLE 14

Slender Thistle Counts Richmond - 1971
Number of Thistles/m^2

Treatment			Time of Count			
*A	W	S	March	June	August	November
† 1	1	1	15.54(2.13)‡	43.89(3.69)	41.67(3.64)	22.64(2.92)
1	1	0	13.52(2.28)	51.71(3.93)	49.39(3.88)	18.44(2.84)
0	1	1	11.73(2.38)	6.14(1.77)	5.25(1.56)	1.94(0.39)
0	1	0	13.10(2.51)	6.73(1.88)	6.29(1.79)	1.19(-0.38)
LSD P=0.05			ns	(0.38)	(0.41)	(0.87)
LSD P=0.01			ns	(0.53)	(0.56)	(1.2)

*A = Autum
W = Winter
S = Spring
† 0 = no grazing
1 = grazing

‡ Means of transformed data in parentheses.

Transformation $\log_e X$ where X = number of thistles/m^2

Because of heavy summer rainfall in late December, 1970 (Table 10), early thistle germination occurred. This formed the population estimated in the March count and indicated the uniformity of the thistle population prior to commencing the grazing treatments. However, humid weather and the development of dense aphid populations (Capitophorous sp. and Brachycaudus sp.) during March and April resulted in extensive thistle mortality before the "true" autumn break in

May (Table 10). The June count estimated the May-germinated thistle population and showed a significant inhibition of germination in those plots ungrazed during the autumn (011 and 010). This effect was carried through to the August and November counts.

Table 15 shows the results of the 1972 slender thistle counts. The data, as the mean number of thistles per m^2, did not require transformation prior to analysis.

TABLE 15

Slender Thistle Counts 1972

Mean Number Thistles/m^2

Treatment			Time of Count		
*A	W	S	March	June/ July	November
† 1	1	1	122.18	55.95	54.27
1	1	0	98.30	50.68	58.28
0	1	1	110.93	91.75	74.62
0	1	0	91.95	75.15	82.23
LSD P=0.05			ns	34.1	ns

*A = Autumn
W = Winter
S = Spring

† 1 = grazing
0 = no grazing

The only significant treatment effect observed during 1972 was the relatively large number of thistles in the winter/spring grazing treatment (011) at the June/July count. This was related to a dense population in March and little reduction under no autumn grazing. There were no significant effects at the first count, although there is a

tendency for populations to be more dense in the spring grazed (that is spring grazed, 1971) treatments. This could be because of more bare gound in these plots for thistle establishment, and less bare ground in the spring ungrazed (1971) plots reducing thistle establishment. This is in contrast to the Sorell grazing trial where spring grazing had no effect on percentage bare ground. It is suggested that the "weaker" pasture and drier conditions at Richmond were more conducive to a high percentage bare ground following spring grazing than at Sorell.

By November 1972, no treatment effects were significant in the Richmond grazing trial.

Table 15 and the Analysis of Variance ($F_{1,30}$) suggest an overall effect of autumn grazing in reducing numbers of thistles. This is the reverse of the effect of the previous year and probably reflects increased grazing of the thistles under the drier conditions of 1972.

(cont. Page 61)

TABLE 16

Botanical Compositions - Richmond 1971

March and June - Eye estimates - Percentage by Weight

Treatment *A	W	S	Slender thistle $X = \log_e X$	Rye Grass $X = \log_e X$	Clover (Sub.) $X = \log_e X$	Other Grasses $X = \log_e X$	Other Species $X = \log_e X$	Inert $X = \log_e X$	Time of Sampling
† 1	1	1	8.58 (1.74) ‡	37.93 (3.60)	11.62 (2.42)	17.63 (2.72)	9.72 (2.01)	14.58 (2.64)	March
1	1	0	7.43 (1.70)	41.40 (3.71)	11.98 (2.44)	18.42 (2.88)	7.95 (1.96)	13.25 (2.51)	"
0	1	1	5.53 (1.50)	47.67 (3.85)	10.22 (2.28)	19.42 (2.94)	7.92 (1.80)	8.98 (2.12)	"
0	1	0	8.67 (2.04)	38.77 (3.64)	9.88 (2.19)	26.88 (3.25)	7.97 (1.85)	7.58 (1.98)	"
LSD (0.05)			ns	ns	ns	(0.29)	ns	(0.30)	"
LSD (0.01)			ns	ns	ns	(0.40)	ns	(0.42)	"
1	1	1	6.27 (1.78)	46.48 (3.81)	5.55 (1.71)	26.02 (3.18)	7.00 (1.74)	5.85 (1.76)	June
1	1	0	7.68 (2.00)	41.77 (3.73)	6.35 (1.82)	32.53 (3.47)	5.10 (1.60)	6.25 (1.83)	"
0	1	1	3.52 (1.06)	52.23 (3.92)	8.30 (2.09)	30.28 (3.40)	2.92 (1.00)	7.10 (1.94)	"
0	1	0	2.45 (0.72)	44.90 (3.78)	8.60 (2.11)	33.63 (3.48)	3.92 (1.33)	6.00 (1.79)	"
LSD (0.05)			(0.52)	ns	(0.27)	ns	(0.50)	ns	"
LSD (0.01)			(0.72)	ns	(0.38)	ns	(0.69)	ns	"

*A = Autumn
W = Winter
S = Spring

† 1 = Grazing
0 = No grazing

‡ Means of transformed data in parentheses.

TABLE 17

Botanical Composition - Richmond, 1971
September and November - Direct sampling to give percentage composition by weight

Treatment *A	W	S	Slender thistle $X = \log_e(X+1)$	Rye Grass $X = \log_e X$	Clover (Sub.) $X = \log_e X$	Other Grasses $X = \log_e X$	Other Species $X = \log_e X$	Inert $X = \log_e X$	Time of Sampling
† 1	1	1	0.80 (0.55) ‡	17.68 (2.82)	4.63 (1.10)	14.27 (2.50)	1.88 (0.17)	60.8 (4.11)	September
1	1	0	0.69 (0.37)	17.52 (2.76)	5.20 (1.60)	16.15 (2.63)	3.38 (0.76)	57.43 (4.04)	"
0	1	1	0.83 (0.43)	26.35 (3.22)	9.98 (2.12)	19.07 (2.91)	3.11 (0.75)	40.62 (3.68)	"
0	1	0	0.68 (0.32)	24.07 (3.15)	9.12 (2.03)	17.2 (2.82)	2.07 (0.46)	47.03 (3.84)	"
LSD (0.05)			ns	(0.42)	(0.80)	ns	ns	(0.21)	"
LSD (0.01)			ns	(0.58)	(1.11)	ns	ns	(0.29)	"
1	1	1	2.66 (1.06)	32.78 (3.48)	25.02 (3.14)	9.37 (2.04)	1.22 (-0.10)	3.33 (1.07)	November
1	1	0	1.48 (0.79)	27.97 (3.29)	28.64 (3.33)	9.83 (2.22)	1.37 (0.17)	3.92 (1.32)	"
0	1	1	0.74 (0.30)	35.18 (3.55)	14.68 (2.61)	6.80 (1.69)	3.93 (1.03)	8.51 (2.06)	"
0	1	0	0.11 (0.09)	32.81 (3.46)	14.89 (2.62)	7.26 (1.65)	2.84 (0.36)	4.35 (1.38)	"
LSD (0.05)			(0.62)	(0.19)	(0.49)	ns	ns	(0.60)	"
LSD (0.01)			(0.85)	(0.26)	(0.68)	ns	ns	(0.83)	"

*A = Autumn
W = Winter
S = Spring

† 1 = Grazing
0 = No grazing

‡ Means of transformed data in parentheses

The changes in botanical composition of the pasture at Richmond from March, 1971 to August, 1972, are tabulated in Tables 16, 17 and 18. As previously mentioned, because of drought conditions, it was not worthwhile making detailed analyses during the latter year.

As with the thistles, the March estimate of botanical composition indicated the uniformity of the trial area and the relative proportions of the pasture components. However, due to population variability, "other grasses", which included Bromus spp., Vulpia spp., Cynosurus echinatus, Poa annua and "inert" (dead material) showed significant differences between treatments. The June estimates demonstrate the effects of autumn grazing which resulted in a flush of slender thistle germination (during May), less clover, and more "other species" which included Cirsium vulgare, Silybum marianum, Rumex acetosella, Taraxacum and Plantago spp.

It must again be stressed that the above observations were by eye estimates in situ.

The September estimate of botanical composition was obtained from samples cut in grazing exclosures in the plots, all of which were grazed during the winter. This would be the same as cutting samples in winter ungrazed plots. Because of the short period (seven weeks) allowed for growth in the exclosures and the slow growing conditions (winter), it would be expected that these samples would show similar results to the June estimation, that is, the effects of the autumn treatments. However, the effects of no grazing in the grazing exclosures did have an effect on the botanical composition of the samples obtained. The June estimate showed that broad-

leafed species (slender thistles and "other species") were most frequent in the autumn grazed plots. The September estimate, however, showed no significant differences in broad-leafed species between treatments. This is probably the result of competition between the broad-leafed species and improved pasture species within the exclosures.

A high proportion of "inert" or dead plant material was recorded in the September estimate. During the summer prior to the start of the experiment, the pasture had only been lightly grazed, thus leaving considerable dead material which eventually formed a mulch at the bottom of the pasture. In March and June, the dry material was underestimated in the botanical composition. But sampling with clippers at ground level in September picked up sufficient of the dry material to form a significant portion of the botanical composition. Significantly more "inert" was recorded in the autumn grazed plots than in the autumn ungrazed plots, because the proportion of green to dry material was less in the former plots than in the latter. Also, there could have been a more rapid decomposition of the dead material in the ungrazed pasture than in the grazed pastures.

The November observations which were also obtained by direct sampling indicate the effects of autumn and winter grazing. The effects of no autumn grazing on slender thistles is again obvious. Although clover was reduced by autumn grazing in the June and September estimates, it was significantly increased by autumn and winter grazing in the November estimate. Autumn and winter grazing increased the proportion of ryegrass as compared with the September estimate. It appears that the high ryegrass recorded in the 011 treatment

is due to a carry-over from the September estimate. There is no apparent explanation for the high proportion of "inert" in the winter/spring grazing treatment.

TABLE 18

Botanical Composition - Richmond, August, 1972

Point Quadrat Analysis

No. Hits/100 points. (No Transformations)

Treatment *A	W	S	Slender Thistle	Ryegrass	Clover	Bromus spp.	Other Grasses	Other Species
†1	1	1	8.03	60.78	2.32	4.22	15.18	9.57
1	1	0	11.35	56.25	2.22	4.18	14.12	11.93
0	1	1	11.80	44.97	3.60	11.82	13.30	14.45
0	1	0	16.60	43.22	1.17	10.25	11.13	17.70
LSD (0.05)			ns	16.38	ns	6.90	ns	7.42

*A = Autumn †1 = Grazing

W = Winter 0 = No grazing

S = Spring

In August, 1972, ryegrass was still being favoured by the autumn/winter grazing (111 and 110), that is, by those treatments involving the most grazing. This is in contrast to Bromus spp. and "other species" which were being fostered by the lenient grazing treatments. Bare ground, although recorded, was insignificant and hence was omitted from Table 18.

d) Discussion

The significant feature of the Sorell grazing trial was the interaction of pasture/thistle competition and the

grazing habits of the sheep. In the autumn and autumn/winter ungrazed plots, competition for light between the pasture and slender thistles caused the thistles to become etiolated and lush with softened prickles, as compared with the non-etiolated and prickly thistles in the autumn grazed plots. (Similar morphological changes have been observed in the glasshouse with thistles grown under reduced light intensity). On grazing the former plots in either winter or spring, the etiolated thistles tended to be eaten in preference to the pasture, although the latter appeared to be also quite palatable being only 15 cm or less in height. Regrowth of etiolated thistles following grazing rarely occurred, as the growing points were well above ground level (approximately 2-3 cm) and hence vulnerable to grazing, in contrast to non-etiolated thistles where the growing point is below ground level.

No grazing during winter only (101) gave significant thistle control. It is thought that the chance occurrence of a mild winter allowed the pasture and thistles to freshen sufficiently to be more palatable for grazing in the spring. It is unlikely that this management system would give efficient thistle control in years or regions having severe winters.

Continuous grazing also gave good thistle control, although not as acceptable as the above treatments. The sheep tended to graze the terminal flower heads of the remaining thistles in these plots, which stimulated flowering in the leaf axils. These flowers were protected from grazing by the thistle foliage thus making the plants a potentially worse problem.

Autumn grazing only and autumn/winter grazing only gave very poor thistle control and the latter treatment is a common management practice to produce hay. No grazing all the year also had little effect on thistle populations.

In the Richmond grazing trial, the autumn ungrazed pastures had made considerable growth (10-15 cm in height) by the time of the late second flush of thistle germination, and germination in those plots was inhibited. This differential germination between the autumn grazed and ungrazed plots could be ascribed to the rapid uptake of moisture by the vigorous ungrazed pasture as compared with the less vigorous pasture (2-3 cm in height) in the grazed plots, where sufficient moisture was apparently available for germination. A similar explanation was suggested by Michael (1965) for the control of Onopordum acanthium L. by Medicago sativa (lucerne) and Dactylis glomerata (cocksfoot), and again (Michael 1968(b)) for the control of Silybum marianum by lucerne and Phalaris tuberosa.

In the drought year of 1972, little difference was observed between grazing treatments in their effects on thistle populations. In spite of pasture feed being scarce, grazing did not reduce the thistle populations below more than 50 thistles/m^2 in November (time of flowering), although many of these plants were small e.g. 2 to 3 flowers only. The results show the importance of good autumn rains for adequate pasture growth to ensure the success of grazing management in reducing slender thistle populations.

In both experiments, slender thistle showed no significant effects in the second year of having been controlled in the previous year (Table 13 and Table 18). This

is not surprising as seed could have been blown from adjacent plots in which the grazing treatment had not been effective and seed set had occurred. Also, the dormant thistle seed in the soil would be sufficient to form the basis of a population although seeding had been prevented in the previous year. For this reason, it would be essential that the effective grazing management practices be repeated for at least two years to deplete the "store" of the thistle seed in the soil to obtain satisfactory control.

Continuous grazing or near continuous grazing reduces the annual grass component of a pasture and increases the perennial component (Hamblyn 1954). This generality is reflected in the results with the increase in perennial ryegrass with continuous grazing, autumn/winter or autumn/spring grazing, and the related decrease in Bromus spp., Cynosurus, and "other grasses". The latter annual species are very susceptible to grazing through both the mechanical damage to growing points by defoliation or treading, and the effect of removal of photosynthetic tissue on subsequent regrowth (Brougham 1959). This is in contrast to the good grazing grasses such as perennial ryegrass in which the primary meristem is below ground level and protected, and the species are able to recover from the most drastic concentration of livestock (Bates 1948).

Intensive grazing in the late autumn causes a rapid change in the botanical composition from dominance of summer-growing species to dominance of winter-growing species (Brougham 1960). Cynosurus is a winter growing species and was was increased by autumn grazing. Spring grazing, however, reduced Cynosurus because of the reasons previously mentioned.

Clovers (Sub and White clover) were increased by those management practices which included the most grazing. This is in agreement with Brougham (1959) who demonstrated that intense grazing favours prostrate species.

Broad-leafed weeds or "other species" were reduced by autumn grazing and increased by spring grazing. The reduction by autumn grazing could be related to the increase in ryegrass by grazing at this time, and hence increased competition from the grass component. However, the significant increase in "other species" by spring grazing was probably due to overgrazing during this period followed by weed invasion because of reduced competition from the pasture. This may also be a factor in explaining the recurrence of slender thistles in the second year of the experiments. Although the ryegrass and clover components were subsequently increased by spring grazing, they were apparently not competitive enough to exclude the weeds. This effect was enhanced by the loss of competition from the annual grasses which were greatly reduced by spring grazing. These results are in contrast to work by George et al. (1970) where lenient spring grazing apparently favoured spear thistle invasion of various monospecific swards.

During late 1971 and 1972, drought conditions at Richmond made sampling for botanical composition questionable, but generally the results followed those previously discussed, with treatments involving the most grazing favouring ryegrass and clover, and a corresponding decrease in the grass weeds and broad-leafed weeds. The strong effects of spring grazing observed at Sorell were not apparent under the unfavourable conditions at Richmond.

With the exception of winter grazing only (010), those treatments which significantly reduced thistle populations also favourably altered pasture botanical composition by increasing perennial ryegrass and removing the grass weeds, thus reducing the possibility of thistle reinfestation. The increase in broad-leafed weeds due to possible over-grazing in the spring should not be a problem in a closely controlled grazing situation.

Deferred autumn grazing may be a useful management procedure for the control of slender thistle in pasture in areas and seasons having good autumn rains. In the trials, control of slender thistle was obtained by two different ecological mechanisms:

1. Deferred autumn grazing caused pasture/thistle competition for light, which resulted in etiolation of the thistles to the extent that they were readily eaten during subsequent grazing.

2. Deferred autumn grazing apparently reduced the availability of moisture to thistle seeds and germination was partially inhibited.

It is considered that the first ecological mechanism would be the most effective under "normal" conditions.

V Palatability of Etiolated Thistles

a) Introduction

In the Sorell grazing trial to study the effect of various grazing management systems on slender thistle populations in improved pasture, it was found that a period of deferred grazing followed by grazing was effective in reducing thistle populations. Deferred grazing allowed the pasture to make sufficient growth to actively compete with the thistles for light, resulting in etiolation of the thistles. In this state they were apparently very palatable to sheep and were selectively grazed even though the surrounding pasture appeared also to be in a palatable stage of growth.

Many investigations into the factors affecting selective grazing have been carried out. There is general agreement that sheep and cattle, at the single plant level, eat leaf in preference to stem, and green (or young) material in preference to dry (or old) material. The material eaten, when compared to the material offered, is usually higher in nitrogen and gross energy, but lower in "fibre". Opinion varies on whether eaten material is higher in sugars and minerals (Arnold 1964).

In the above studies on the control of slender thistles, it was not known whether the increased palatability was a physical or a chemical effect, or a combination of both.

A glasshouse experiment was established to study in detail the effect of etiolation on the chemical composition and digestibility of slender thistles and the results are discussed in relation to the 1971 Sorell grazing trial observations.

b) Materials and Methods

The experiment was commenced in April, 1971. The objective was to study the effect of shading or competition for light on the chemical composition and digestibility of slender thistle.

Thistles were grown in a 50:50 sand/peat mixture in 1.7l. buckets. A complete nutrient solution was applied every two weeks. The treatments were etiolated and non-etiolated thistles arranged in a completely random design with six replications. Twenty individual plants comprised each of the treatment replications. Black plastic cylinders, 9 cm in diameter, placed over the thistles at the 2-true-leaf stage simulated pasture conditions and a competition for light effect resulting in etiolation. The cylinders were periodically increased to a height of 12 cm at which time the thistles were harvested, eight weeks after germination. The thistles were dried at 64°C for 48 hours and ground in a Christy-Norris laboratory mill to pass a 1 mm mesh sieve. Individual plants were bulked into their respective treatments and stored at 1°C until required for analysis.

c) Analytical Methods

1. Acid-detergent Fibre and Acid-detergent Lignin

Acid-detergent fibre (ADF) and acid-detergent lignin (ADL) were determined using the method of van Soest (1963). The method utilises the capacity of cetyl trimethyl-ammonium bromide to dissolve plant proteins in acid solution. The residue, when washed with acetone, leaves only a fibrous extract (ADF). This is also the major preparatory step for

ADL determinations. The fibre is digested in H_2SO_4 and ignited in a muffle furnace. The loss upon ignition as a percentage of the oven-dry sample is the ADL.

2. "True" Cellulose

"True cellulose was assayed using the method of Sullivan (1962). Plant samples were digested in HNO_3, dried, and weighed. The loss upon ignition was reported as "true" cellulose.

3. Total Reducing Sugars

The method of Sullivan (1962) was used to determine total reducing sugars (TRS). This involved a $CuSO_4$ reduction to Cu_2O, which was dissolved in ferrous ammonium sulphate and titrated against $Ce(SO_4)_2$. Reducing sugars were calculated from a graph prepared using pure sugar.

4. Nitrate-Nitrogen

Nitrate-(N) was determined using the method of Clare and Stevenson (1964). Plant material was digested in hot water followed by analysis in an auto-analyser.

5. Protein-Nitrogen

The method of Terry (1966) was used for the assay of protein-nitrogen (protein (N)). A Kjeldhal digestion of plant material was followed by auto-analyser analysis.

6. Digestibility

Digestibility was determined *in vitro* by the method of Tilley and Terry (1963). The method involved two digestions, an initial anaerobic digestion with rumen micro-organisms which digested the fibre and some protein, and a second stage pepsin digestion which removed the undigested protein. The weight of undigested material was obtained. Digestibility was expressed as the weight of digestible material in each 100 g of herbage dry matter.

d) Results

The results of the chemical analyses are tabulated in Table 19, as mean percentage composition by weight and percentage digestible material by weight.

TABLE 19

Chemical Analysis of Normal and Etiolated Thistles

Mean Percentage Composition by Weight

Mean Percentage Digestible Material by Weight

	Normal Thistles	Etiolated Thistles	LSD P=0.01
ADF (Acid Detergent fibre)	15.2	16.4	1.0
ADL (Acid Detergent lignin)	2.3	2.9	0.3
"True" Cellulose	15.3	19.1	1.0
Nitrate (N)	1.9	2.9	0.08
Protein(N)	5.3	4.8	0.10
Total Reducing Sugars	2.80	3.24	0.07
Digestibility	75.8	70.5	4.1

Shading of thistles resulting in etiolation caused a significant increase in ADF, ADL, cellulose, nitrate(N) and total reducing sugars, and a decrease in protein (N) and also digestibility.

e) Discussion

Considerable work has been carried out in the past on the effect of reduced light on plant growth in relation to top and root growth, and effect on nitrate (N), protein and soluble carbohydrates. However, the effect of reduced light on fibre, lignin and cellulose appears to have been neglected.

The increase in fibre, lignin and cellulose with shading was surprising in view of the softness of the leaves and spines of the etiolated plants. However, these increases may be explained by the probable increase in the lengths of cell walls when the cells elongate during etiolation.

Digestibility, being closely related to fibre, lignin and cellulose contents (Tomlin et al. 1965; Minson 1971(b)) was correspondingly reduced by shading. These results appear to be in conflict with field observations of etiolated thistles being selectively grazed, since intake is generally reduced with decreasing digestibility (Blaser et al. 1960; Blaxter et al. 1961; Arnold 1964). However, it must be realised that intake can vary independently of digestibility (Raymond 1969) and that a relationship between intake and digestibility should not be over-emphasised.

There is general agreement that nitrate (N) increases with decreasing light intensity (Watkins 1940; Bathurst and Mitchell 1958; Stoughton 1955) as was observed in this experiment, but opinions vary as to whether soluble carbohydrates also increase with shading. Work by Watkins (1940) is in agreement with the results, but McIlroy (1967) states that water soluble carbohydrates, in grasses and clovers at least, decrease with shading. However, this reduction is apparently due to a reduction in the "storage" carbohydrates such as sucrose and fructosan which were not measured in the TRS technique.

The effect of shading on protein (N) appears to vary considerably between species. Klages (1942), observed that leaves of plants growing under partial shade become larger and thinner and tended to have a higher protein content. The

leaves of thistles under partial shade also become larger and thinner, but protein content was reduced. Langille and McKee (1970) observed an increase in protein content of the foliage of crownvetch grown under reduced light, but although Chan and McKenzie (1971) observed an increase in protein content of grass with shading, the protein content of lucerne was unaffected by reduced light intensity.

Intake of forage plants tends to increase with increasing nitrate (N) (Arnold 1960), and in general animals tend to select a diet of higher nutritive value than that found in samples obtained from normal cutting techniques (Hardison et al. 1954; Blaser et al. 1960). Opinion varies on whether the material selected is higher in sugars (Arnold 1964), although Bland and Dent (1964) established a positive relationship between soluble carbohydrates and animal preferences for varieties of cocksfoot.

Pearce (1970) suggested that the increase in palatability of annual weeds following spraying may be due to an increase in total sugars. Under shaded conditions, nitrate (N) and TRS of thistles increased which could explain the selective grazing of etiolated thistles although protein content and digestibility were reduced with shading.

Because shading of thistles resulted in reduced digestibility and a lower protein (N) content which would tend to reduce intake, and an increase in nitrate (N) and TRS which would tend to increase intake, it is possible that these chemical changes are unimportant in the grazing of etiolated thistles. The differences in selection of etiolated and non-etiolated thistles may be due only to physical factors, that is, more lush growth and softened prickles with etiolation.

It is not known why etiolated thistles tended to be eaten in preference to the pasture. Michell (1973) has shown that the *in vitro* digestibility of perennial ryegrass when harvested after 15-20 cm of growth is approximately 70% digestible material by weight during winter. The digestibility of etiolated thistles was similar to this. It is possible, however, that sheep will readily graze the less common, but obvious species (such as etiolated thistles) in the pasture if these species are palatable.

The selection of etiolated thistles by the grazing animal may be related more to physical changes than to chemical changes, although the high nitrate (N) and high TRS could make the etiolated thistles more favourable to the grazing animal. However, there may be dangers to the animal of nitrate-poisoning if large amounts of etiolated thistle relative to pasture species were ingested. The nitrate (N) levels observed were above those recognised as being toxic by Wright and Davidson (1964). If there is sufficient pasture to cause thistle etiolation, then the ratio of pasture to thistle should be such as to prevent any nitrate-toxicity problems.

Most plants including thistles show reduced root growth when grown under low light intensities. This has been attributed to the lack of mobilisation of carbohydrates into the roots, so that at low light intensities leaves are produced at the expense of roots (Blackman and Templeman 1940). Reduced root growth would be important in lessening the ability of etiolated thistles to recover following defoliation, by affecting water and nutrient uptake. A similar effect has been observed with undersown pasture species in cereal crops.

Because of shading, the pasture species have reduced root growth which affects their ability to survive when the cover crop is removed (Black 1957).

VI Chemical Control of Etiolated Thistles

a) Introduction

It has been observed (Kennedy per. comm.) that etiolated weeds in pea crops are more susceptible to herbicides than non-etiolated weeds. Also, recent work has shown that it is possible to alter growth form to precondition some plants for control by chemicals. Bendixen (1970) preconditioned yellow nutsedge (Cyperus esculentus L.) with gibberellic acid which increased its susceptibility to herbicides by virtue of the increased foliage available for herbicide adsorption.

In the Sorell grazing trial, deferred autumn grazing resulted in pasture/thistle competition for light and etiolation of the thistles, in which state they were acceptable to the grazing animal. If, for some reason (e.g. peculiarities of the grazing animal or a management problem) the thistles were not or could not be grazed in the etiolated condition, then they could be controlled by spraying with a hormone herbicide such as MCPA or 2,4-D.

A glasshouse experiment was set up to observe whether slender thistles are preconditioned to control by chemicals when etiolated by growth under reduced light or by application of gibberellic acid (GA).

b) Materials and Methods.

The experiment was commenced in the glasshouse in late March 1972. The objective of the experiment was to study any change in the susceptibility of slender thistle to MCPA following alterations in growth form (i.e. etiolation) by shading and by applications of GA.

Single plants were grown in a 50:50 sand/peat mixture in 1.7l buckets. A complete nutrient solution was regularly applied during the experiment.

The treatments were normal rosette thistles, shaded thistles (as in "Palatability of Etiolated Thistles" experiment) and thistles sprayed with 10 p.p.m. of "Grocel" GA (I.C.I. product). The plants grown under reduced light were shaded from the 3-true-leaf stage, and the GA treatment was applied 3 weeks after germination (about 5 true leaves). Spraying with Methoxone 30 (27.4% w/v a.e. MCPA) was carried out on the 1/5/72, five weeks after germination, at nil, 0.21 and 0.42 kg a.e. MCPA/ha. The MCPA and GA were applied using a cabinet sprayer. Treatments were arranged in a 3 x 3 factorial with six replications.

Thistles were harvested five weeks after spraying with MCPA, dried at 100°C for 24 hours, and weighed.

c) Results

Figure 6 shows the effect of shading and application of GA on the response of thistles to MCPA. GA had no significant effect on plant dry weights compared with shading which greatly reduced dry weights. At 0.21 and 0.42 kg a.e. MCPA/ha shaded plants had less than half the dry weight of normal plants.

At harvest, all shaded plants which had been sprayed with 0.42 kg a.e. MCPA/ha appeared to be dead as were some which were treated with 0.21 kg a.e. MCPA/ha. None of the surviving plants in the latter group were making any new growth as compared with the normal thistles which were growing quite readily after applications of both rates of spray.

Figure 6

Effect of shading and gibberellic acid on the response of slender thistles to MCPA

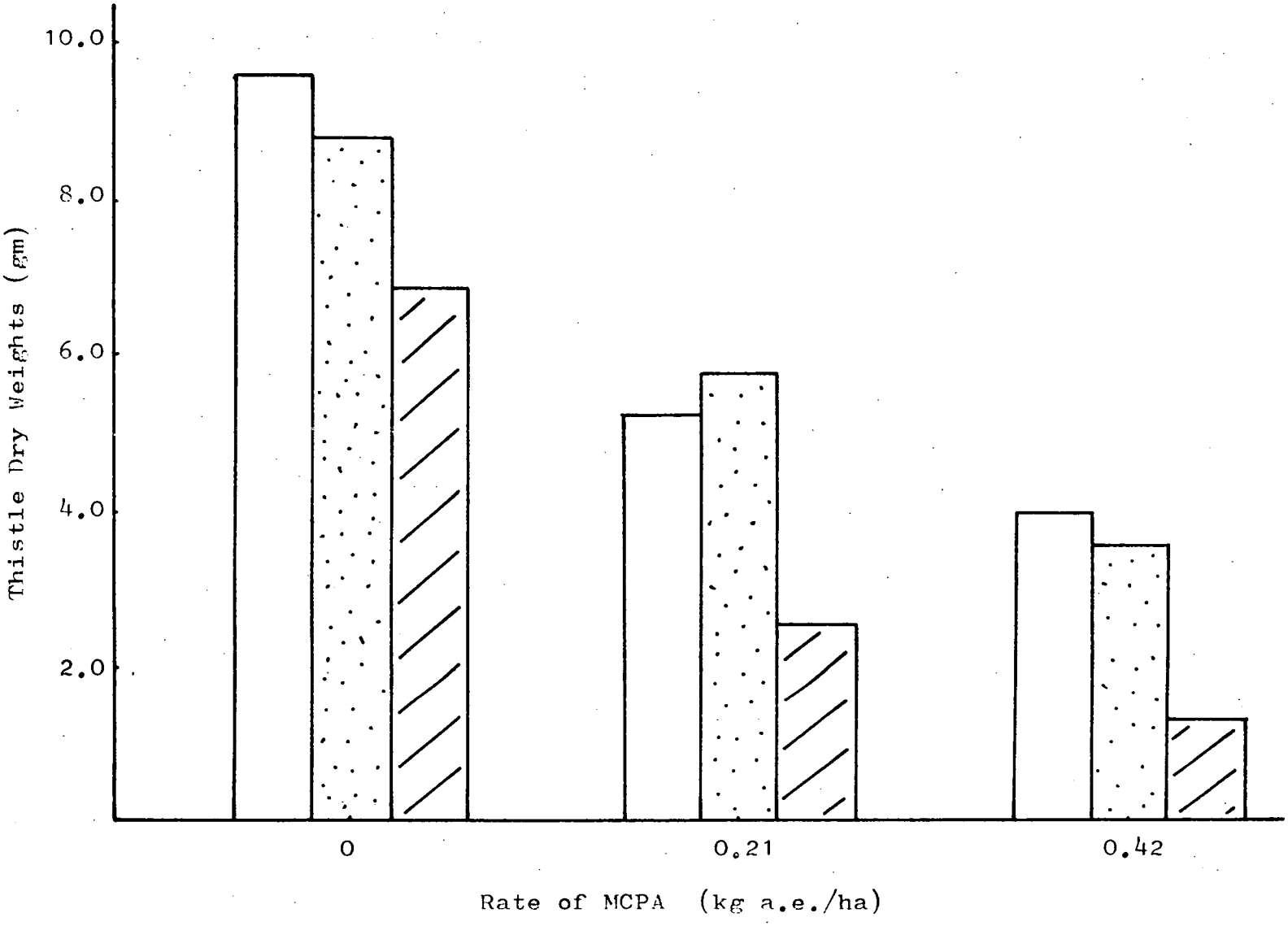
(Thistle dry weights, gm)


Normal plants


GA treated plants


Shaded plants

LSD = 0.54, P = 0.01


10.0
8.0
6.0
4.0
2.0
Thistle Dry Weights (gm)
0
0.21
0.42
Rate of MCPA (kg a.e./ha)

d) Discussion

The results show that slender thistles may be preconditioned for chemical control by growth under light-stress. The growth-hormone GA had no preconditioning effect.

The shading treatment simulated a competition for light effect between thistles and pasture following deferred autumn grazing. It is suggested that a combination of deferred autumn grazing and low rates of MCPA (0.2 - 0.3 kg a.e. MCPA/ha) may be an efficient method for the control of slender thistles in pasture. Although some thistles in the glasshouse experiment were not killed outright by such a low rate of MCPA, it is probable that the increased stress under field conditions of inter-specific competition and the effects of the grazing animal would contribute to satisfactory control. Furthermore, in addition to reducing foliage growth, shading greatly reduces root growth which would tend to inhibit the recovery rate of etiolated thistles following spraying.

Not only would spraying at such low rates be financially attractive compared with the recommended rate of 0.55 - 1.2 kg a.e. MCPA/ha (Anon. 1966), but detrimental effects of the spray on pasture legumes would be avoided.

VII Conclusion

Seed and seedling behaviour of a species largely determine its success in establishment, dispersal, and resistance to aggression from established species (Harper 1965). In the slender thistle, seed characteristics and seedling behaviour appear to contribute in large measure to the persistence of the species as a weed of importance.

Polymorphism, which may result in seed types representing different potential ecologies appears to be widespread in weedy species (Harper 1965). In slender thistles, seed polymorphism is well developed and is manifested in a differentiation of dispersal mechanisms, germination and dormancy, and seedling establishment requirements.

The most common of the diaspores, i.e., the sticky seeds, are primarily dispersed by wind and also by adherence to moving objects with which they may come into contact. The less-common, non-sticky seeds have reduced pappus development and remain in the prickly involucre which they use as a transport vehicle following abscission.

The diaspores also differ in requirements for germination, with the sticky seeds requiring leaching to facilitate germination. The presence of water soluble germination inhibitors in the testa prevent seed from germinating until sufficient moisture is availabe for seedling establishment. Conversely, the non-sticky seeds do not require leaching for germination, but possess a greater ability to survive moisture stress as seedlings. Because of this characteristic of heterocarpy, slender thistles are able to exploit a wider range of environmental conditions than

would otherwise be possible, and this must contribute to their ability to be successful weeds.

Slender thistles also appear to have fairly precise germination requirements which is a common characteristic of most weeds. This is in contrast to seeds of agricultural crops in which dormancy has been unconsciously selected against during domestication (Harper 1965). The leaching requirement of slender thistles for germination has already been mentioned. Germination also appears to be regulated by temperature and depth of burial. Maximum germination will occur only if the soil temperature is greater than 10°C, the seed is buried at 2 cm depth or less, and soil moisture is plentiful.

Persistence of slender thistles is enhanced by their ability to maintain viability of buried seed over a number of years. At least 20% of seed buried at more than 5 cm depth remains viable for more than one season, and 5% remains viable for at least 3 years. This provides a strong survival mechanism in preventing eradication by one year's control.

Slender thistles are weeds of high fertility and are especially favoured by high nitrogen (which appears to maximise their reproductive capacity) and by an alkaline pH. Since they are colonisers of shoreline areas (Black 1913), it is reasonable to expect that alkaline conditions are necessary for maximum growth, and also that the increase in soluble salts associated with fertility increases may be significant in their invasion of established pastures (Allen and Meeklah 1972).

During their adaptation to shoreline areas, slender

thistles have acquired characteristics advantageous to the invasion of, and persistence in, agricultural areas. The advantages of being an annual (Salisbury 1942), the occurrence of heterocarpy, and their adaptation to the high soil fertility associated with modern agriculture, convey to slender thistles the ability to persist as one of the main pasture weeds in the sheep grazing districts of Tasmania.

It is becoming increasingly recognised that the use of herbicides for broad-acre pasture weed control is, in most instances, uneconomic as well as having possible detrimental effects on the environment. In recent years, ecological methods of weed control, which overcome the disadvantages inherent in chemical methods, have been applied to a number of pasture weeds with favourable results.

This study showed that deferred autumn grazing may be a possible method for the control of slender thistles in pasture. Deferred autumn grazing either increased the acceptability of the thistles to the grazing animal, or inhibited germination, depending on seasonal conditions. The former is likely to be the "normal" response in most seasons. It appears that the increased acceptability was due to morphological changes which resulted in softened prickles and more lush foliage following etiolation, although an increase in carbohydrate content and nitrate-nitrogen may also have enhanced acceptability.

Control of thistles in one year had no significant effect on thistle populations in the second year. This is not surprising as about 20% of seed remains viable in the soil for more than one season and 5% for at least 3 years - the

source of a potentially dense population. There is also the possibility that overgrazing during spring aided thistle establishment in the following year, but this should not be a problem in a closely controlled grazing situation. As with other annual weeds, control of slender thistles must be repeated annually until the seed-store in the soil has been depleted (Thurston 1960).

Control of slender thistles by ecological techniques has the following advantages over control using herbicides:-

1. It involves little capital outlay as compared with the cost of chemicals, and may be repeated annually at small cost.

2. It favours pasture productivity by enhancing the growth of the sown pasture species, and improvement of the pasture would aid in preventing thistle reinfestation.

3. It avoids the use of chemicals and has no adverse environmental effects.

4. The weed is grazed and hence utilised as a pasture plant, rather than killed and wasted as a food source.

5. Ecological methods are not dependent on an input of fossil-fuel energy.

In the etiolated state, slender thistles are preconditioned to chemical control, and the use of low rates of herbicide in conjunction with grazing management also has obvious advantages over full-scale chemical control.

It is suggested that, with the adoption of effective ecological methods for slender thistle control, the species would cease to be a pasture weed of major importance, although it could be replaced by other species such as spear thistle or Californian thistle which have the potential to become

serious pasture weeds.

The study demonstrates that it can be profitable to examine alternative ways of controlling weeds, especially pasture weeds, where annual returns from pastures demand inexpensive weed control techniques.

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Personal Communications

1. Hardy, R.J., Tasmanian Department of Agriculture, New Town Research Laboratories, New Town.

2. Kennedy, J.P., Tasmanian Department of Agriculture, New Town Research Laboratories, New Town.

X Appendices

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Appendix I

Effect of Soil Moisture on Seedling Growth.

Root dry weights (gm)

Foliage dry weights (gm)

(Data on which Figure 2 is based)

Percentage Soil Moisture	Seed Type			
	Not sticky		Sticky	
	Roots	Foliage	Roots	Foliage
20%	0.1846	0.0507	0.0926	0.0495
	0.1735	0.0261	0.1105	0.0330
	0.2213	0.0336	0.0659	0.0129
	0.1633	0.0242	0.1178	0.0469
25%	*0.3093	0.0524	*0.3657	0.1079
	0.2195	0.0573	0.1725	0.0477
	0.1077	0.0485	0.1432	0.0720
	0.2951	0.1650	0.2861	0.0921
30%	*0.4526	0.2510	*0.3883	0.1689
	0.2350	0.1753	0.4014	0.2087
	0.2829	0.2081	0.2811	0.2082
	0.2751	0.2500	0.3173	0.1855

* Data not used in analysis because of excessive variability within treatments.

Analyses of Variance

A. Root dry weights at 20% soil moisture.

Source of Variation	df	SS	MS	F
Blocks	3	0.0001	0.00003	ns
Treatments	1	0.0158	0.0158	12.15*
Error	3	0.0039	0.0013	
Total	7	0.0198		

B. Foliage dry weights.

Source of Variation	df	SS	MS	F
Blocks	3	0.0047	0.0016	1.78
Treatments	5	0.1291	0.0258	28.67
Moisture	2	0.1275	0.0638	70.89**
Seeds	1	0.0005	0.0005	ns
Interaction	2	0.0011	0.0006	ns
Error	15	0.0133	0.0009	
Total	23	0.1471		

Appendix II

Effect of Temperature on Germination

Total Number Germinated After Five Days

(50 seeds/plot)

(Data from which Figure 3 is derived)

Replication	Temperature (°C)						
	5	10	15	20	25	30	35
I	0	42	50	50	50	38	0
II	0	46	50	50	48	39	0
III	0	44	50	49	50	41	0
IV	0	45	50	50	50	41	0
Total	0	177	200	199	198	159	0
Mean	0	44.3	50.0	49.8	49.5	39.8	0
Percentage Germination	0	88.6	100.0	99.6	99.0	79.6	0

Appendix III

A. First Year Emergence of Slender Thistle Seed Buried in Soil at Four Depths.

Percentage seedling emergence

(Data on which Table 5 is based)

Replication	Depth of Burial			
	Surface	1.3 cm	5 cm	10 cm
1	38.1	40.5	36.9	0
2	36.9	73.8	27.4	0
3	26.2	41.7	53.6	0
4	23.8	61.9	31.0	0
5	52.4	66.7	54.8	0
6	41.7	91.7	29.8	0

Analysis of Variance

Source of Variation	df	SS	MS	F
Blocks	5	788.98	157.80	ns
Treatments	3	12,000.00	4,000.00	24.14**
Error	15	2486.02	165.73	
Total	23	15275.00		

B. The Effect of Depth of Burial on the Longevity of Slender Thistle Seed.

Percentage viable seed present

March 1969 - March 1972

(Data from which Figure 4 is derived).

Time of Retrieval		Depth of Burial							
		*Surface		*1.3 cm		5 cm		10 cm	
		I	II	I	II	I	II	I	II
1969	March	0	0	0	0	28.5	14.0	28.5	19.0
	November	0	0	24.0	9.5	4.8	4.8	14.0	33.0
1970	March	0	0	0	0	4.8	4.8	19.0	19.0
	November	0	0	0	0	4.8	0	4.8	4.8
1971	March	0	0	0	0	4.8	4.8	9.5	4.8
	November	0	0	0	0	0	0	4.8	4.8
1972	March	0	0	0	0	0	0	0	0

* Data not included in analysis.

Analysis of Variance

Source of Var.	df	SS	MS	F
Blocks	1	7.51	7.51	ns
Treatments	13	2108.62	162.20	6.1**
Depth of Burial	1	288.63	288.63	10.8**
Harvest Time	6	1516.71	252.79	9.5**
Interaction	6	303.28	50.55	1.9ns
Error	13	345.80	26.60	
Total	27	2461.93		

Appendix IV

A. Effect of N, P, and K on Growth and Seed Production.

(i) Plant Diameters (cm)

(Data on which Table 6 is based)

	k_o			k_1			k_2		
	p_o	p_1	p_2	p_o	p_1	p_2	p_o	p_1	p_2
n_o	26,27	33,27	31,33	30,29	30,27	31,30	27,28	27,16	30,28
n_1	36,43	46,44	48,46	48,43	43,47	46,44	46,39	45,47	45,51
n_2	52,44	46,55	49,58	43,42	51,48	53,45	44,47	52,38	38,47

Analysis of Variance

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	Variance Ratio
Reps	9.80	1	9.80	.68
Blocks	133.93	4	33.48	2.31
* A	3837.00	2	1918.50	132.51***
B	96.78	2	48.39	3.34
C	70.78	2	35.39	2.44
AB	39.89	4	9.97	.69
AC	108.89	4	27.22	1.88
BC	54.11	4	13.53	.93
Error	434.33	30	14.48	
Total	4785.50	53		

* A, B, and C ≡ N, P, and K respectively

(ii) Number of basal branches per thistle.

(Data from which Table 7 is derived)

	k_o			k_1			k_2		
	p_o	p_1	p_2	p_o	p_1	p_2	p_o	p_1	p_2
n_o	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
n_1	1,0	0,0	0,0	3,1	1,2	0,1	1,1	1,2	2,2
n_2	3,3	3,3	3,4	4,6	3,3	2,2	6,3	4,3	5,3

Analysis of Variance

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	Variance Ratio
Reps	.67	1	.67	1.78
Blocks	2.00	4	.50	1.34
A	105.33	2	52.67	140.79***
B	1.44	2	.72	1.93
C	5.44	2	2.72	7.28**
AB	1.22	4	.31	.82
AC	4.89	4	1.22	3.27*
BC	3.11	4	.78	2.08
Error	11.22	30	.37	
Total	135.33	53		

(iii) Number of flowers per thistle.

(Data on which Table 8 is based)

	k_o			k_1			k_2		
	p_o	p_1	p_2	p_o	p_1	p_2	p_o	p_1	p_2
n_o	7,7	10,8	12,9	11,4	15,8	12,8	11,5	10,4	7,8
n_1	22,25	32,27	28,26	31,28	23,36	33,43	39,22	29,16	25,33
n_2	38,27	28,66	22,22	33,33	31,37	51,27	30,29	21,40	39,48

Analysis of Variance

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	Variance Ratio
Reps	.67	1	.67	.01
Blocks	85.26	4	21.31	.30
A	6556.59	2	3278.30	45.89**
B	116.04	2	58.02	.81
C	106.81	2	53.41	.75
AB	77.85	4	19.46	.27
AC	69.41	4	17.35	.24
BC	406.30	4	101.57	1.42
Error	2143.22	30	71.44	
Total	9562.15	53		

B. Effect of pH on the growth of slender thistles.

Thistle dry weights (gm)

(Data on which Figure 5 is based)

	Treatment		
Replication	pH 4	pH 5.2	pH 6.5
1	2.8	21.0	24.0
2	1.8	19.0	24.5
3	2.0	18.0	21.0
4	1.8	19.5	21.0

Analysis of Variance

Source of Variation	df	SS	MS	F
Blocks	3	9.33	3.11	2.78
Treatments	2	973.69	486.85	434.69**
Error	6	6.72	1.12	
Total	11	989.74		

Appendix V

A. Sorell Grazing Trial

1. Percentage thistle survival, August, 1970.

(Data from which Table 11 is derived)

(i) Random Counts (raw data)

	Replication			
Treatment	1	2	3	4
111	18.70	3.90	33.30	13.60
110	26.30	5.40	63.60	14.90
101	20.70	27.90	42.90	92.90
100	29.30	12.60	38.50	44.40
011	.30	1.10	6.50	1.30
010	.80	5.80	14.30	17.20
001	23.40	21.90	42.90	3.50
000	29.90	20.50	50.00	16.00

Random Counts - Transformed ($Y = \sqrt{x + 0.5}$)

	Replication			
Treatment	1	2	3	4
111	4.38	2.10	5.81	3.75
110	5.18	2.43	8.01	3.92
101	4.60	4.29	6.59	9.66
100	5.46	3.62	6.24	6.70
011	.89	1.26	2.65	1.34
010	1.14	2.51	3.85	4.21
001	4.89	4.73	6.59	2.00
000	5.51	4.58	7.11	4.06

Random Counts - Analysis of Variance

Source of Variation	df	SS	MS	F
Blocks	3	29.88	9.96	5.03
Treatments	3	57.79	12.26	9.73**
Grazed after growth v.not grazed after growth* (01 v. 00, 10, 11)	1	49.11	49.11	24.81**
Ungrazed v. grazed (within not grazed after growth) (00 v. 10, 11)	1	0.30	0.30	0.15ns
Continuous grazing v. Autumn grazing only (11 v. 10)	1	8.38	8.38	4.24*
Blocks x Treatment	9	33.51)	1.979	
Error (within blocks)	16	15.96)		
Total	31	137.14		

* "not grazed after growth" includes all treatments which do not contain a period of grazing following a period of no grazing.

(ii) Fixed quadrat - high density (raw data)

	Replication			
Treatment	1	2	3	4
111	21.40	27.10	3.10	4.20
110	11.30	20.40	47.80	29.10
101	25.20	24.50	14.40	23.20
100	30.00	19.40	16.00	22.40
011	0	.50	0	.70
010	0	0	0	.50
001	50.00	62.50	63.90	85.70
000	56.00	53.60	70.00	58.90

Fixed quadrat - high density

Transformed $(Y = \sqrt{X + 0.5})$

	Replication			
Treatment	1	2	3	4
111	4.68	5.25	1.90	2.17
110	3.44	4.57	6.95	5.44
101	5.07	5.00	3.86	4.87
100	5.52	4.46	4.06	4.79
011	.71	1.00	.71	1.10
010	.71	.71	.71	1.00
001	7.11	7.94	8.02	9.28
000	7.52	7.36	8.40	7.71

Fixed quadrat - high density

Analysis of Variance

Source of Variation	df	SS	MS	F
Blocks	3	0.34	0.11	0.11
Treatments	3	201.64	67.21	65.32**
01 v. 00, 10, 11	1	138.77	138.77	134.86**
00 v. 10, 11	1	62.22	62.22	60.47**
11 v. 10	1	0.65	0.65	0.63
Blocks x Treatments	9	4.74	1.029	
Error (within Blocks)	16	20.97		

(iii) Fixed quadrat - low density (raw data)

	Replication			
Treatment	1	2	3	4
111	27.50	27.30	16.70	7.70
110	42.90	38.50	12.50	19.40
101	72.00	25.00	55.20	52.00
100	42.50	15.60	46.20	41.90
011	11.80	0	8.00	4.30
010	8.30	0	0	5.60
001	0	25.80	19.00	41.90
000	61.20	13.30	50.00	51.20

Fixed quadrat - low density

Transformed $Y = \sqrt{X + 0.5}$

Treatment	Replication			
	1	2	3	4
111	5.29	5.27	4.15	2.86
110	6.59	6.24	3.61	4.46
101	8.51	5.05	7.46	7.25
100	6.56	4.01	6.83	6.51
011	3.51	.71	2.92	2.19
010	2.97	.71	.71	2.47
001	.71	5.13	4.42	6.51
000	7.85	3.71	7.11	7.19

Fixed quadrat - low density

Analysis of Variance

Source of Variation	df	SS	MS	F
Blocks	3	8.54	2.84	1.09
Treatments	3	87.10	29.03	11.10**
01 v. 00, 10, 11	1	74.75	74.75	28.58**
00 v. 10, 11	1	0.61	0.61	0.23
11 v. 10	1	11.75	11.75	4.50*
Blocks x Treatments	9	26.74	2.62	
Error (Within Blocks)	16	38.63		
Total	31	161.01		

2. Percentage thistle survival, November, 1970.

(Data from which Table 12 is derived)

(i) Random counts.

Factor Level	Raw Data	Transformed ($\sqrt{X + 0.5}$)
0000 Block 1	50.50	7.14
0001 2	32.80	5.77
0002 * 3	54.20	7.39
0003 4	40.00	6.36
0010	1.10	1.26
0011	2.20	1.64
0012		.71
0013	1.20	1.30
0100	1.60	1.45
0101	7.40	2.81
0102	28.60	5.39
0103	6.90	2.72
0110	1.40	1.38
0111	4.30	2.19
0112		.71
0113	3.80	2.07
1000	18.50	4.36
1001	18.10	4.31
1002	19.20	4.44
1003	40.00	6.36
1010	5.20	2.39
1011	.70	1.09
1012		.71
1013	7.10	2.76
1100	22.80	4.83
1101	14.40	3.86
1102	100.00	10.02
1103	11.90	3.52
1110	20.10	4.54
1111	.70	1.09
1112	27.80	5.32
1113		.71

* 0, 1, 2, and 3 indicates block number (copied from computer print-out)

Random counts - Analysis of Variance

Source of Variation	df	SS	MS	F
Blocks	3	9.60	3.20	1.29
Treatments	7	114.23	16.32	6.58**
Grazed after growth v. not grazed after growth (001,010,011,101 v. 000, 100, 110, 111)	1	76.38	76.38	30.88**
Within not grazed after growth				
000 v. 100, 110, 111	1	14.80	14.80	5.9*
100 v. 110, 111	1	1.06	1.06	0.42ns
110 v. 111	1	13.96	13.96	5.62*
Within grazed after growth				
010 v. 001, 011, 101	1	7.43	7.43	2.99ns
001 v. 011, 101	1	0.50	0.50	0.20ns
011 v. 101	1	0.045	0.095	0.018ns
Error	21	52.18	2.48	
Total	31	175.96		

(ii) Fixed quadrats - high density.

Factor Level	Raw Data	Transformed $\sqrt{X + 0.5}$
0000	42.40	6.55
0001	24.30	4.98
0002	47.10	6.90
0003	33.30	5.81
0010		.71
0011	1.30	1.34
0012		.71
0013		.71
0100	.40	.95
0101		.71
0102	1.10	1.26
0103		.71
0110	.80	1.14
0111		.71
0112		.71
0113		.71
1000	7.30	2.79
1001	6.40	2.63
1002	4.00	2.12
1003	5.40	2.43
1010	3.00	1.87
1011	6.60	2.66
1012	.80	1.14
1013	.60	1.05
1100	2.80	1.82
1101	3.10	1.90
1102	14.50	3.87
1103	5.80	2.51
1110	6.50	2.64
1111	9.40	3.15
1112	.60	1.05
1113		.71

Fixed quadrat - high density.

Analysis of Variance

Source of Variation	df	SS	MS	F
Blocks	3	1.16	0.39	0.78
Treatments	7	83.7	11.96	23.92**
Grazed after growth v. not grazed after growth (001,010,011,101 v. 000, 100, 110, 111)	1	37.8	37.8	75.6**
Within not grazed after growth				
000 v. 100, 110, 111	1	42.4	42.4	84.8**
100 v. 110, 111	1	0.2	0.2	0.4ns
110 v. 111	1	0.8	0.8	1.6ns
Within grazed after growth				
010 v. 001, 011, 101	1	0.1	0.1	0.2ns
001 v. 011, 101	1	0.4	0.4	0.8ns
011 v. 101	1	1.5	1.5	3.0ns
Error	21	10.58	0.50	
Total	31	95.44		

(iii) Fixed quadrat - low density.

Factor Level	Raw Data	Transformed $\sqrt{X + 0.5}$
0000	44.90	6.74
0001	23.30	4.88
0002	38.90	6.28
0003	24.40	4.99
0010		.71
0011		.71
0012	4.80	2.31
0013		.71
0100		.71
0101		.71
0102	2.70	1.79
0103	11.10	3.41
0110		.71
0111		.71
0112		.71
0113		.71
1000	12.50	3.60
1001	6.30	2.61
1002	23.10	4.86
1003	27.90	5.33
1010	24.00	4.95
1011		.71
1012	6.90	2.72
1013	8.00	2.91
1100	40.00	6.36
1101		.71
1102	12.50	3.60
1103		.71
1110		.71
1111		.71
1112	3.30	1.95
1113		.71

Fixed quadrat - low density.

Analysis of Variance

Source of Variation	df	SS	MS	F
Blocks	3	13.32	4.44	2.82
Treatments	7	84.93	12.13	7.72**
Grazed after growth v. not grazed after growth (001,010,011,101 v. 000, 100,110,111)	1	27.35	27.35	17.42**
Within not grazed after growth				
000 v. 100, 110, 111	1	28.21	28.21	17.97**
100 v. 110, 111	1	12.54	12.54	7.99*
110 v. 111	1	6.68	6.68	4.25ns
Within grazed after growth				
010 v. 001, 011, 101	1	0.03	0.03	0.02ns
001 v. 011, 101	1	1.16	1.16	0.74ns
011 v. 101	1	8.96	8.96	5.7*
Error	21	32.90	1.57	
Total	31	131.15		

3. Inclined Point Quadrat Botanical Analyses (October 1971)

No. Hits Per 100 Points

(Data from which Table 13 is derived)

Treatment	Rep	Slender Thistle	Sub. Clover	Rye Grass	*Bromus* spp.	*Cynosurus echinatus*	Other Grasses	Other Species	Bare Ground
111	1	11 (2.49)	114	136	6 (1.95)	14 (2.64)	13 (2.64)	17 (2.89)	3 (1.10)
	2	10 (2.40)	132	128	1 (0.69)	13 (2.56)	2 (1.10)	23 (3.18)	3 (1.10)
	3	0 (0)	100	110	3 (1.39)	1 (0)	10 (2.40)	4 (1.61)	5 (1.61)
	4	6 (1.95)	162	149	1 (0.69)	5 (1.61)	0 (0)	3 (1.39)	2 (0.69)
110	1	1 (0.69)	74	85	8 (2.20)	13 (2.56)	14 (2.71)	2 (1.10)	3 (1.10)
	2	48 (3.89)	28	103	18 (2.94)	26 (3.25)	14 (2.71)	14 (2.71)	4 (1.39)
	3	0 (0)	109	56	24 (3.22)	10 (2.30)	13 (2.64)	1 (0.69)	8 (2.08)
	4	1 (0.69)	29	115	56 (4.04)	59 (4.08)	8 (2.20)	10 (2.40)	4 (1.39)
101	1	4 (1.61)	65	84	3 (1.39)	9 (2.19)	10 (2.40)	29 (3.90)	4 (1.39)
	2	4 (1.61)	109	129	0 (0)	4 (1.39)	4 (1.61)	12 (2.56)	3 (1.10)
	3	0 (0)	95	93	4 (1.61)	3 (1.10)	6 (1.95)	23 (3.18)	10 (2.30)
	4	3 (1.39)	111	142	0 (0)	6 (1.79)	0 (0)	13 (2.64)	4 (1.39)
100	1	6 (1.95)	49	95	9 (2.30)	12 (2.48)	15 (2.77)	5 (1.79)	4 (1.39)
	2	18 (2.94)	22	107	20 (3.04)	38 (3.64)	9 (1.39)	14 (2.71)	7 (1.95)
	3	1 (0.69)	83	45	29 (3.40)	18 (2.89)	26 (1.79)	6 (1.95)	3 (1.10)
	4	4 (1.61)	21	91	52 (3.97)	78 (4.36)	14 (1.61)	8 (2.20)	9 (2.20)
011	1	5 (1.79)	104	102	6 (1.95)	3 (1.10)	7 (2.08)	11 (2.48)	4 (1.39)
	2	7 (2.08)	115	99	1 (0.69)	1 (0)	3 (1.39)	42 (3.76)	6 (1.79)
	3	2 (1.10)	123	83	1 (0.69)	2 (0.69)	5 (1.79)	15 (2.77)	11 (2.40)
	4	5 (1.79)	103	120	2 (1.10)	2 (0.69)	4 (1.61)	39 (3.69)	5 (1.61)
010	1	2 (1.10)	67	79	20 (3.04)	13 (2.56)	12 (2.56)	1 (0.69)	3 (1.10)
	2	5 (1.80)	35	98	52 (3.97)	30 (3.40)	10 (2.40)	17 (2.89)	10 (2.30)
	3	2 (1.10)	83	69	26 (3.30)	9 (2.20)	19 (3.00)	10 (2.40)	6 (1.79)
	4	1 (0.69)	56	112	26 (3.30)	24 (3.18)	4 (1.61)	26 (3.30)	10 (2.30)
001	1	3 (1.39)	88	136	4 (1.61)	7 (1.95)	2 (1.10)	31 (3.47)	5 (1.61)
	2	4 (1.79)	70	103	2 (1.10)	8 (2.08)	1 (0.69)	43 (3.78)	1 (0)
	3	1 (0.69)	99	61	5 (1.79)	3 (1.10)	4 (1.61)	29 (3.40)	6 (1.79)
	4	2 (1.10)	87	109	2 (1.10)	4 (1.39)	2 (1.10)	59 (4.09)	4 (1.39)
000	1	3 (1.39)	91	74	6 (1.95)	5 (1.61)	17 (2.89)	2 (1.10)	5 (1.61)
	2	42 (3.76)	124	61	20 (3.04)	15 (2.71)	11 (2.48)	16 (2.83)	3 (1.10)
	3	2 (1.10)	104	47	24 (3.22)	2 (0.69)	17 (2.89)	5 (1.79)	5 (1.61)
	4	7 (2.08)	58	104	37 (3.64)	20 (3.00)	4 (1.61)	16 (2.83)	6 (1.79)

Note: Transformed data in parentheses Transformation $\log_e(X + 1)$

C. echinatus and Bare Ground - Transformation $\log_e X$

The numerical code pp. 121-4 relates to a CØFAC computer programme. The analyses are the result of treating the experimental design as a 2^3 factorial in which the factors are times of grazing:-

0001	spring grazing
0010	winter grazing
0011	winter x spring grazing
⋮	
1000	blocks

This programme partitions the block x treatment interaction (the usual error term in a randomised complete block design) to indicate whether any of the main effects interact with blocks. In this series of analyses there were no significant block x treatment interaction effects and hence they were excluded.

Inclined Point Quadrat Botanical Analyses - October 1971

No. Hits Per 100 Points - Transformed Means

Analyses of Variance - Without Partitioning

Slender Thistle (Y = log e (X + 1))

Source of Variation	df	SS	MS	F
0001	1	0.195	0.195	0.479
0010	1	0.058	0.058	0.142
0011	1	2.974	2.974	7.318 *
0100	1	0.013	0.013	0.033
0101	1	0.006	0.006	0.014
0110	1	0.122	0.122	0.301
0111	1	0.068	0.068	0.168
1000	3	14.940	4.980	12.253
Error (1)	21	8.536	0.406	

Note: Partitioning of error term in all analyses excluded since not significant.

Clover (No transformation)

Source of Variation	df	SS	MS	F
0001	1	12960.5	12960.5	21.8**
0010	1	780.1	780.1	1.3
0011	1	2812.5	2812.5	4.7*
0100	1	338.0	338.0	0.6
0101	1	2850.1	2850.1	4.8*
0110	1	1624.5	1624.5	2.7
0111	1	946.1	946.1	1.6
1000	3	2381.1	793.7	1.3
Error (1)	21	12485.9	594.6	

Rye grass (No transformation)

Source of Var.	df	SS	MS	F
0001	1	6132.8	6132.8	29.5**
0010	1	830.3	830.3	4.0
0011	1	16.5	16.5	0.08
0100	1	1391.3	1391.3	6.7*
0101	1	344.5	344.5	1.7
0110	1	26.3	26.3	0.1
0111	1	536.3	536.3	2.6
1000	3	9414.8	3138.3	15.1
Error (1)	21	4370.4	208.1	

Bromus spp. (Y = log e (X + 1))

Source of Var.	df	SS	MS	F
0001	1	33.69	33.69	76.13**
0010	1	0.12	0.12	0.28
0011	1	0.02	0.02	0.06
0100	1	0.22	0.22	0.50
0101	1	0.12	0.12	0.28
0110	1	0.02	0.02	0.05
0111	1	0.77	0.77	1.74
1000	3	0.74	0.25	0.56
Error (1)	21	9.29	0.44	

Cynosurus echinatus (Y = log e X)

Source of Var.	df	SS	MS	F
0001	1	16.02	16.02	39.69**
0010	1	0.07	0.07	0.18
0011	1	1.07	1.07	2.66
0100	1	3.46	3.46	8.57**
0101	1	0.12	0.12	0.29
0110	1	0.001	0.001	0.001
0111	1	2.46	2.46	6.09*
1000	3	6.23	2.08	5.15
Error (1)	21	8.47	0.40	

"Other Grasses" (Y = log e X + 1)

Source	df	SS	MS	F.Ratio
0001	1	9.373362	9.373362	40.553 **
0010	1	.062631	.062631	.271
0011	1	.423936	.423936	1.834
0100	1	.212944	.212944	.921
0101	1	.042506	.042506	.184
0110	1	.228557	.228557	.989
0111	1	.086653	.086653	.375
1000	3	6.384727	2.128242	9.208
Error (1)	21	4.853930	.231140	

"Other Species" (Y = log e X + 1)

Source	df	SS	MS	F.Ratio
0001	1	6.961822	6.961822	16.285 **
0010	1	1.044655	1.044655	2.444
0011	1	.435292	.435292	1.018
0100	1	2.474771	2.474771	5.789 *
0101	1	.581103	.581103	1.359
0110	1	.309468	.309468	.724
0111	1	.099512	.099512	.233
1000	3	4.958119	1.652706	3.866
Error (1)	21	8.977431	.427497	

Bare Ground (Y = log e X)

Source of Var.	df	SS	MS	F
0001	1	0.39	0.39	1.66
0010	1	0.06	0.06	0.27
0011	1	0.00	0.00	0.00
0100	1	0.17	0.17	0.72
0101	1	0.002	0.002	0.01
0110	1	1.18	1.18	4.98 *
0111	1	0.13	0.13	0.53
1000	3	1.37	0.46	1.94
Error (1)	21	4.96	0.24	

B. Richmond Grazing Trial

1. Number Thistles per Square Metre, 1971.

(Data on which Table 14 is based)

(i) March Count.

	Replication					
Treatment	1	2	3	4	5	6
111	11.00	2.00	1.25	44.50	16.75	17.75
	*(2.40)	(0.69)	(0.22)	(3.80)	(2.82)	(2.88)
110	8.50	7.12	2.00	10.25	27.50	25.75
	(2.14)	(1.96)	(0.69)	(2.33)	(3.31)	(3.25)
011	11.00	12.50	8.12	10.62	21.87	6.25
	(2.40)	(2.53)	(2.09)	(2.36)	(3.09)	(1.83)
010	13.37	16.37	6.87	9.25	12.75	20.00
	(2.59)	(2.80)	(1.93)	(2.22)	(2.55)	3.00

* Transformed data in parentheses - Transformation $\log_e X$.

Analysis of Variance

Source of Var.	df	SS	MS	F
Blocks	5	7.9048	1.5810	3.0
Treatments	3	.4637	.1546	.3
Error	15	7.9672	.5311	
Total	23	16.3356		

(ii) June Count.

Treatment	Replication					
	1	2	3	4	5	6
111	77.12	36.12	16.66	48.37	38.12	97.00
	(4.35)	(3.59)	(2.81)	(3.88)	(3.64)	(3.85)
110	54.62	55.50	46.62	35.87	54.87	62.75
	(4.00)	(4.02)	(3.84)	(3.58)	(4.00)	(4.14)
011	8.87	6.62	3.25	6.87	5.75	5.50
	(2.18)	(1.89)	(1.18)	(1.93)	(1.75)	(1.70)
010	7.62	5.62	8.50	4.62	8.25	5.75
	(2.03)	(1.73)	(2.14)	(1.53)	(2.11)	(1.75)

Analysis of Variance

Source of Var.	df	SS	MS	F
Blocks	5	0.8888	0.1778	1.82
* Treatments	1	23.5620	23.5620	241.66**
Treatments x Blocks	5	0.2041	0.0403	0.0975
Error Within Blocks	12	1.4568	0.1214	
	17			
Total	23	26.1090		

* Only two treatments at June count, grazed or not grazed in autumn.

(iii) August Count.

Treatment	Replication					
	1	2	3	4	5	6
111	73.75	29.00	20.63	51.13	31.75	43.75
	(4.30)	(3.37)	(3.03)	(3.93)	(3.46)	(3.78)
110	63.25	55.50	44.25	35.13	46.13	52.13
	(4.15)	(4.02)	(3.79)	(3.56)	(3.83)	(3.95)
011	8.88	6.88	4.63	4.75	4.38	2.00
	(2.18)	(1.93)	(1.53)	(1.56)	(1.48)	(0.69)
010	8.50	8.50	6.00	4.25	6.63	3.88
	(2.14)	(2.14)	(1.79)	(1.45)	(1.89)	(1.36)

Analysis of Variance

Source of Var.	df	SS	MS	F
Blocks	5	1.4636	0.2927	2.57
Treatments	1	26.1042	26.1042	229.1853***
Treatments x Blocks	5	0.9040	0.1808	
	17			0.1139
Error Within Blocks	12	1.0317	0.0860	
Total	23	29.5035		

* Only two treatments at August count, grazed or not grazed in autumn.

(iv) November Count.

Treatment	Replication 1	2	3	4	5	6
(1) 111	45.80	20.13	5.75	33.75	14.25	16.13
	(3.82)	(3.00)	(1.75)	(3.52)	(2.66)	(2.78)
(2) 110	31.00	24.50	10.88	17.38	11.38	15.38
	(3.43)	(3.20)	(2.39)	(2.86)	(2.43)	(2.73)
(3) 011	4.50	3.00	0.50	1.50	1.38	0.75
	(1.50)	(1.10)	(-0.69)	(0.41)	(0.32)	(-0.29)
(4) 010	0.63	3.38	2.00	0.75	0.25	0.13
	(-0.46)	(1.22)	(0.69)	(-0.29)	(-1.39)	(-2.04)

Analysis of Variance

Source of Var.	df	SS	MS	F
Blocks	5	6.7166	1.3433	2.6
Treatments	3	51.3533	17.1178	33.5
A	1	49.5585	49.5585	97.0***
B	1	1.0867	1.0867	2.1ns
A*B	1	.7081	.7081	1.4ns
Error	15	7.6608	.5107	
Total	23	65.7306		

Note: A effect compares treatments 1 and 2 with 3 and 4.

B effect compares treatments 1 and 3 with 2 and 4.

AxB tests whether the spring grazing effect was influenced by autumn grazing.

A tests the effect of autumn grazing.

B tests the effect of spring grazing.

2. Number of Thistles per Square Metre, 1972.

(Data on which Table 15 is based)

(i) March Count

	Replication					
Treatment	1	2	3	4	5	6
111	104.40	40.50	71.00	258.10	75.20	183.90
110	76.40	27.10	48.80	105.80	150.40	181.30
011	91.50	85.90	126.10	130.00	176.30	55.80
010	57.60	84.70	135.40	86.00	81.10	106.90

Analysis of Variance

Source of Var.	df	SS	MS	F
Blocks	5	20944.5883	4188.9177	1.5
Treatments	3	3256.9817	1085.6606	.4
A	1	464.6400	464.6400	.2
B	1	2756.3267	2756.3267	1.0
A*B	1	36.0150	36.0150	.0
Error	15	43219.6283	2881.3086	
Total	23	67421.1983		

(ii) June/July Count.

Treatment	Replication					
	1	2	3	4	5	6
111	52.00	42.80	30.50	88.50	39.30	82.60
110	48.40	27.70	22.10	46.80	78.90	80.20
011	72.40	100.50	96.00	90.50	142.60	48.50
010	48.80	97.20	93.40	51.00	65.40	95.10

Analysis of Variance

Source of Var.	df	SS	MS	F
Blocks	5	1896.1333	379.2267	.5
Treatments	3	6358.0000	2119.3333	2.8
A	1	5448.1067	5448.1067	7.1*
B	1	717.2267	717.2267	.9
A*B	1	192.6667	192.6667	.3
Error	15	11536.7600	769.1173	
Total	23	19790.8933		

(iii) November Count.

	Replication					
Treatment	1	2	3	4	5	6
111	41.00	37.40	27.50	101.10	39.60	79.00
110	63.60	15.60	26.20	60.00	76.10	108.20
011	51.70	64.50	85.30	82.50	111.70	52.00
010	58.70	95.30	102.30	56.20	67.20	113.70

Analysis of Variance

Source of Var.	df	SS	MS	F
Blocks	5	3870.9950	774.1990	1.0
Treatments	3	3166.1767	1055.3922	1.3
A	1	2943.7350	2943.7350	3.8
B	1	203.0017	203.0017	.3
A*B	1	19.4400	19.4400	.0
Error	15	11729.2883	781.9526	
Total	23	18766.4600		

3. Botanical Composition, Richmond - 1971.

Percentage composition by weight.

March, June) Eye estimation in situ

September, November) Cutting and weighing

(Data from which Tables 16 and 17 are derived)

Transformation $X = \log_e X$

(i) Slender Thistle

Time of Sampling	Treatment	1	2	3	4	5	6
March	111	3.80 (1.34)	3.10 (1.13)	1.30 (0.26)	23.80 (3.17)	10.60 (2.36)	8.90 (2.19)
	110	6.00 (1.79)	4.70 (1.55)	1.60 (0.47)	6.60 (1.89)	8.10 (2.09)	17.60 (2.87)
	011	4.10 (1.41)	2.80 (1.03)	1.30 (0.26)	6.90 (1.93)	10.00 (2.30)	8.10 (2.09)
	010	16.60 (2.81)	9.70 (2.27)	3.10 (1.13)	6.60 (1.89)	6.90 (1.93)	9.10 (2.21)
June	111	10.90 (2.39)	5.60 (1.72)	3.40 (1.22)	5.90 (1.77)	5.90 (1.77)	5.90 (1.77)
	110	1.60 (2.36)	5.90 (1.77)	8.70 (2.16)	10.00 (2.30)	5.00 (1.61)	5.90 (1.77)
	011	5.00 (1.61)	5.60 (1.72)	3.10 (1.13)	5.00 (1.61)	1.50 (0.41)	0.90 (-0.11)
	010	3.40 (1.22)	4.30 (1.46)	3.10 (1.13)	2.10 (0.74)	0.90 (-0.11)	0.90 (-0.11)
Sept.	111	1.20 (0.79)	0.50 (0.41)	0.30 (0.26)	1.70 (0.99)	0.60 (0.47)	0.50 (0.41)
	110	0.65 (0.50)	0.40 (0.34)	0.60 (0.47)	0.20 (0.18)	0.40 (0.34)	0.50 (0.41)
	011	2.40 (1.22)	0 (0)	0.15 (0.14)	2.40 (1.22)	0 (0)	0 (0)
	010	0.10 (0.10)	0 (0)	3.70 (1.55)	0.15 (0.14)	0 (0)	0.15 (0.14)
Nov.	111	8.40 (2.24)	3.15 (1.42)	0 (0)	1.65 (0.97)	1.25 (0.81)	1.50 (0.92)
	110	2.90 (1.36)	2.40 (1.22)	2.50 (1.25)	0.50 (0.41)	0.25 (0.22)	0.30 (0.26)
	011	0 (0)	4.35 (1.68)	0 (0)	0 (0)	0 (0)	0.10 (0.10)
	010	0 (0)	0.35 (0.30)	0 (0)	0.30 (0.26)	0 (0)	0 (0)

Analysis of Variance

(Note: Only those analyses which show significant treatment effects are given).

- June Estimate

Source of Var.	df	SS	MS	F
Blocks	5	3.6392	.7278	4.0
Treatments	3	6.4176	2.1392	11.8
A	1	5.9283	5.9283	32.8**
B	1	.0205	.0205	.1
A*B	1	.4687	.4687	2.6
Error	15	2.7123	.1808	
Total	23	12.7691		

- November Estimate

Source of Var.	df	SS	MS	F
Blocks	5	2.8143	.5629	2.2
Treatments	3	3.5422	1.1807	4.7
A	1	3.1968	3.1968	12.6**
B	1	.3377	.3377	1.3
A*B	1	.0076	.0076	.0
Error	15	3.8054	.2537	
Total	23	10.1619		

(ii) Rye-grass

Time of Sampling	Treatment	Replication 1	2	3	4	5	6
March	111	51.00 (3.93)	37.20 (3.62)	44.70 (3.80)	20.90 (3.04)	35.00 (3.56)	38.80 (3.66)
	110	49.10 (3.89)	49.10 (3.89)	42.20 (3.74)	36.00 (3.58)	39.20 (3.67)	32.80 (3.49)
	011	54.10 (3.99)	57.50 (4.05)	50.30 (3.92)	39.70 (3.68)	44.70 (3.80)	39.70 (3.68)
	010	46.60 (3.84)	25.60 (3.24)	43.10 (3.76)	46.00 (3.83)	35.00 (3.56)	36.30 (3.59)
June	111	48.40 (3.88)	45.60 (3.82)	55.30 (4.01)	28.70 (3.36)	40.30 (3.70)	60.60 (4.10)
	110	34.30 (3.54)	44.30 (3.79)	49.60 (3.90)	38.10 (3.64)	41.20 (3.72)	43.10 (3.76)
	011	43.10 (3.76)	41.50 (3.73)	45.00 (3.81)	84.50 (4.44)	52.80 (3.97)	46.50 (3.84)
	010	41.20 (3.72)	27.10 (3.30)	55.00 (4.01)	51.50 (3.94)	45.60 (3.82)	49.00 (3.89)
Sept.	111	18.40 (2.91)	14.50 (2.67)	21.70 (3.08)	8.80 (2.17)	17.70 (2.87)	25.00 (3.22)
	110	9.90 (2.29)	23.00 (3.14)	30.90 (3.43)	9.50 (2.25)	11.50 (2.44)	20.30 (3.01)
	011	14.70 (2.69)	27.30 (3.31)	32.50 (3.48)	19.00 (2.94)	24.10 (3.18)	40.50 (3.70)
	010	20.10 (3.00)	18.40 (2.91)	24.80 (3.21)	35.40 (3.57)	26.60 (3.28)	19.10 (2.95)
Nov.	111	33.20 (3.50)	28.40 (3.35)	28.45 (3.35)	32.80 (3.49)	39.20 (3.67)	34.65 (3.55)
	110	20.35 (3.01)	17.95 (2.89)	33.80 (3.52)	24.90 (3.21)	31.10 (3.44)	39.70 (3.68)
	011	28.90 (3.36)	30.85 (3.43)	31.35 (3.45)	39.00 (3.66)	38.25 (3.64)	42.70 (3.75)
	010	26.55 (3.28)	21.40 (3.06)	31.25 (3.44)	37.90 (3.63)	31.30 (3.44)	48.45 (3.88)

Analyses of Variance

- September Estimate

Source of Var.	df	SS	MS	F
Blocks	5	1.1515	.2303	2.0
Treatments	3	.9561	.3187	2.8
A	1	.9326	.9326	8.1*
B	1	.0235	.0235	.2
A*B	1	.0000	.0000	.0
Error	15	1.7360	.1157	
Total	23	3.8436		

- November Estimate

Source of Var.	df	SS	MS	F
Blocks	5	.7218	.1444	6.2
Treatments	3	.2157	.0719	3.1
A	1	.0802	.0802	3.5
B	1	.1209	.1209	5.2*
A*B	1	.0145	.0145	.6
Error	15	.3478	.0232	
Total	23	1.2852		

(iii) Clover

Time of Sampling	Treatment	Replication 1	2	3	4	5	6
March	111	10.30 (2.33)	14.70 (2.69)	10.00 (2.30)	7.20 (1.97)	14.70 (2.69)	12.80 (2.55)
	110	7.50 (2.01)	9.70 (2.27)	11.60 (2.45)	12.20 (2.50)	20.30 (3.01)	10.60 (2.36)
	011	12.50 (2.53)	7.80 (2.05)	6.60 (1.89)	7.20 (1.97)	12.80 (2.55)	14.40 (2.67)
	010	5.30 (1.67)	5.00 (1.61)	17.20 (2.84)	8.40 (2.13)	12.50 (2.53)	10.90 (2.39)
June	111	5.30 (1.67)	5.60 (1.72)	5.30 (1.67)	5.60 (1.72)	6.20 (1.82)	5.30 (1.67)
	110	5.00 (1.61)	5.90 (1.77)	71.0 (1.96)	4.90 (1.59)	4.30 (2.23)	5.90 (1.77)
	011	8.40 (2.13)	5.90 (1.77)	7.50 (2.01)	6.50 (1.87)	10.90 (2.39)	10.60 (2.36)
	010	8.40 (2.13)	5.30 (1.67)	11.80 (2.47)	10.90 (2.39)	9.60 (2.26)	5.60 (1.72)
Sept.	111	1.30 (0.26)	4.00 (1.39)	8.40 (2.13)	0.60 (0.51)	10.90 (2.39)	2.60 (0.96)
	110	3.30 (1.19)	4.60 (1.53)	7.30 (1.99)	5.90 (1.77)	6.60 (1.89)	3.50 (1.25)
	011	5.10 (1.63)	4.30 (1.46)	5.40 (1.69)	18.30 (2.91)	18.50 (2.92)	8.30 (2.12)
	010	3.00 (1.10)	6.50 (1.87)	5.90 (1.77)	6.50 (1.87)	15.30 (2.73)	17.50 (2.86)
Nov.	111	14.65 (2.68)	24.55 (3.20)	37.50 (3.62)	14.15 (2.65)	38.10 (3.64)	21.15 (3.05)
	110	26.05 (3.26)	35.40 (3.57)	24.75 (3.21)	30.20 (3.41)	37.30 (3.62)	18.15 (2.90)
	011	14.45 (2.67)	5.55 (1.71)	14.35 (2.66)	15.00 (2.71)	16.95 (2.83)	21.75 (3.08)
	010	21.25 (3.06)	7.85 (2.06)	16.30 (2.79)	15.70 (2.75)	20.35 (3.01	7.90 (2.07)

Analyses of Variance

- June Estimate

Source of Var.	df	SS	MS	F
Blocks	5	.4560	.0912	1.8
Treatments	3	.6927	.2309	4.7
A	1	.6550	.6550	13.2**
B	1	.0243	.0243	.5
A*B	1	.0134	.0134	.3
Error	15	.7435	.0496	
Total	23	1.8922		

- September Estimate

Source of Var.	df	SS	MS	F
Blocks	5	4.5507	.9101	2.1
Treatments	3	3.9238	1.3079	3.1
A	1	3.1461	3.1461	7.4*
B	1	.2613	.2613	.6
A*B	1	.5163	.5163	1.2
Error	15	6.4049	.4270	
Total	23	14.8794		

- November Estimate

Source of Var.	df	SS	MS	F
Blocks	5	1.0130	.2026	1.3
Treatments	3	2.3875	.7958	5.0
A	1	2.2843	2.2843	14.4**
B	1	.0586	.0586	.4
A*B	1	.0446	.0446	.3
Error	15	2.3818	.1588	
Total	23	5.7822		

(iv) "Other Grasses"

Time of Sampling	Treatment	1	2	3	4	5	6
March	111	19.70 (2.98)	33.80 (3.52)	9.10 (2.21)	25.00 (3.22)	9.40 (2.24)	8.80 (2.17)
	110	24.40 (3.19)	23.40 (3.15)	11.90 (2.48)	18.80 (2.93)	17.40 (2.86)	14.60 (2.68)
	011	21.00 (3.04)	23.80 (3.17)	16.90 (2.83)	26.00 (3.26)	16.00 (2.77)	12.80 (2.55)
	010	23.10 (3.14)	45.30 (3.81)	21.60 (3.07)	24.40 (3.19)	28.80 (3.36)	18.10 (2.90)
June	111	26.50 (3.28)	31.60 (3.45)	20.30 (3.01)	45.60 (3.82)	15.00 (2.71)	17.10 (2.84)
	110	40.30 (3.70)	32.50 (3.48)	24.30 (3.19)	32.80 (3.49)	32.50 (3.48)	32.80 (3.49)
	011	29.60 (3.39)	35.00 (3.56)	37.90 (3.63)	24.00 (3.18)	24.00 (3.18)	31.20 (3.44)
	010	33.70 (3.52)	53.70 (3.98)	21.80 (3.08)	29.60 (3.39)	27.10 (3.30)	35.90 (3.58)
Sept.	111	8.90 (2.19)	14.20 (2.65)	9.70 (2.27)	31.80 (3.46)	5.30 (1.67)	15.70 (2.75)
	110	8.80 (2.17)	21.70 (3.08)	10.30 (2.33)	34.00 (3.53)	14.90 (2.70)	7.20 (1.97)
	011	27.00 (3.30)	18.30 (2.91)	13.40 (2.60)	18.50 (2.92)	13.50 (2.60)	23.70 (3.17)
	010	23.60 (3.16)	19.40 (2.97)	14.90 (2.70)	11.00 (2.40)	17.40 (2.86)	16.90 (2.83)
Nov.	111	6.55 (1.88)	2.70 (.099)	4.45 (1.49)	18.00 (2.89)	10.95 (2.39)	13.55 (2.61)
	110	9.45 (2.25)	4.45 (1.49)	9.75 (2.28)	13.60 (2.61)	7.45 (2.01)	14.30 (2.66)
	011	5.35 (1.68)	1.25 (0.22)	7.70 (2.04)	7.80 (2.05	14.45 (2.67)	4.25 (1.45)
	010	2.85 (1.05)	7.45 (2.01)	2.60 (0.96)	2.05 (0.72)	9.15 (2.21)	19.45 2.97)

Analysis of Variance

- March Estimate

Source of Var.	df	SS	MS	F
Blocks	5	2.1136	.4227	7.3
Treatments	3	.8609	.2870	4.9
A	1	.4987	.4987	8.6**
B	1	.3282	.3282	5.7*
A*B	1	.0340	.0340	.6
Error	15	.8713	.0581	
Total	23	3.8458		

(v) "Other Species"

Time of Sampling	Treatment	Replication 1	2	3	4	5	6
March	111	1.90 (0.64)	3.10 (1.13)	14.40 (2.67)	9.40 (2.24)	15.30 (2.73)	14.20 (2.65)
	110	5.60 (1.72)	2.80 (1.03)	11.30 (2.42)	12.80 (2.55)	7.50 (2.01)	7.70 (2.04)
	011	2.20 (0.79)	1.90 (0.64)	8.10 (2.09)	8.10 (2.09)	10.60 (2.36)	16.60 (2.81)
	010	2.20 (0.79)	7.20 (1.97)	3.40 (1.22)	8.10 (2.09)	8.10 (2.09)	18.80 (2.93)
June	111	2.50 (0.92)	2.50 (0.92)	9.60 (2.26)	71.0 (1.96)	15.00 (2.71)	5.30 (1.67)
	110	4.00 (1.39)	4.00 (1.39)	3.70 (1.31)	6.80 (1.92)	6.50 (1.87)	5.60 (1.72)
	011	1.80 (0.59)	1.50 (0.41)	2.80 (1.03)	3.10 (1.13)	4.30 (1.46)	4.00 (1.39)
	010	6.20 (1.82)	3.40 (1.22)	3.70 (1.31)	3.70 (1.31)	4.00 (1.39)	2.50 (0.92)
Sept.	111	3.20 (1.16)	1.25 (0.22)	0.75 (-0.29)	0.60 (-0.51)	5.20 (1.65)	0.30 (-1.20)
	110	11.40 (2.43)	2.15 (0.77)	0.70 (-0.36)	0.95 (-0.05)	1.80 (0.59)	3.30 (1.19)
	011	2.65 (0.97)	0.60 (-0.51)	2.35 (0.85)	0.80 (-0.22)	9.00 (2.20)	3.25 (1.18)
	010	0.80 (-0.22)	3.30 (1.19)	1.60 (0.47)	1.35 (0.30)	4.75 (1.56)	0.60 (-0.51)
Nov.	111	2.00 (0.69)	0.25 (-1.39)	2.65 (0.97)	0.60 (-0.51)	1.25 (0.22)	0.55 (-0.60)
	110	2.45 (0.90)	1.35 (0.30)	0.40 (-0.92)	1.15 (0.14)	0.95 (-0.05)	1.90 (0.64)
	011	0.90 (-0.11)	2.70 (0.99)	7.95 (2.07)	1.75 (.56)	8.70 (2.16)	1.60 (0.47)
	010	0.10 (-2.30)	4.00 (1.39)	3.25 (1.18)	2.90 (1.06)	6.45 (1.86)	0.35 (-1.05)

Analysis of Variance

- June Estimate

Source of Var.	df	SS	MS	F
Blocks	5	1.8720	.3744	2.3
Treatments	3	1.9094	.6365	3.9
A	1	1.5281	1.5281	9.4**
B	1	.0533	.0533	.3
A*B	1	.3281	.3281	2.0
Error	15	2.4460	.1631	
Total	23	6.2274		

(vi) "Inert"

Time of Sampling	Treatment	Replication 1	2	3	4	5	6
March	111	13.40 (2.60)	8.40 (2.13)	20.6 (3.03)	13.80 (2.62)	14.10 (2.65)	17.20 (2.84)
	110	7.50 (2.01)	10.30 (2.33)	21.60 (3.07)	15.60 (2.75)	7.80 (2.05)	16.70 (2.82)
	011	6.90 (1.93)	6.00 (1.79)	16.00 (2.77)	12.20 (2.50)	5.90 (1.77)	6.90 (1.93)
	010	4.40 (1.48)	7.20 (1.97)	11.60 (2.45)	6.60 (1.89)	8.80 (2.17)	6.90 (1.93)
June	111	6.20 (1.82)	5.60 (1.72)	5.90 (1.77)	6.80 (1.92)	5.00 (1.61)	5.60 (1.72)
	110	5.90 (1.77)	5.90 (1.77)	6.80 (1.92)	6.80 (1.92)	5.60 (1.72)	6.50 (1.87)
	011	7.10 (1.96)	10.00 (2.30)	6.50 (1.87)	7.50 (2.01)	5.00 (1.61)	6.50 (1.87)
	010	6.80 (1.92)	5.90 (1.77)	5.60 (1.72)	5.60 (1.72)	6.50 (1.87)	5.60 (1.72)
Sept.	111	67.20 (4.21)	65.50 (4.18)	59.00 (4.08)	56.60 (4.04)	60.60 (4.10)	55.90 (4.02)
	110	66.30 (4.19)	48.20 (3.88)	50.30 (3.92)	49.50 (3.90)	64.90 (4.17)	65.40 (4.18)
	011	48.30 (3.88)	49.03 (3.89)	46.30 (3.84)	41.00 (3.71)	34.90 (3.55)	24.20 (3.19)
	010	52.60 (3.96)	52.40 (3.96)	49.80 (3.91)	45.60 (3.82)	36.10 (3.59)	45.70 (3.82)
Nov.	111	3.50 (1.25)	1.20 (0.18)	2.75 (1.01)	3.35 (1.21)	2.35 (0.85)	6.80 (1.92)
	110	4.95 (1.60)	5.15 (1.64)	4.55 (1.52)	3.75 (1.32)	2.70 (0.99)	2.40 (0.88)
	011	6.90 (1.93)	4.00 (1.39)	14.80 (2.69)	6.45 (1.86)	8.55 (2.15)	10.35 (2.34)
	010	3.05 (1.12)	6.55 (1.88)	6.85 (1.92)	3.85 (1.35)	3.75 (1.32)	2.05 (0.72)

Analyses of Variance

- March Estimate

Source of Var.	df	SS	MS	F
Blocks	5	1.8849	.3770	6.2*
Treatments	3	1.7633	.5878	9.7**
A	1	1.6523	1.6523	27.3**
B	1	.1109	.1109	1.8
A*B	1	.0000	.0000	.0
Error	15	.9086	.0606	
Total	23	4.5568		

- September Estimate

Source of Var.	df	SS	MS	F
Blocks	5	.1755	.0351	1.2
Treatments	3	.6846	.2282	7.7
A	1	.5887	.5887	19.9**
B	1	.0156	.0156	.5
A*B	1	.0804	.0804	2.7
Error	15	.4434	.0296	
Total	23	1.3035		

- November Estimate

Source of Var.	df	SS	MS	F
Blocks	5	.6399	.1280	.5
Treatments	3	3.2117	1.0706	4.5
A	1	1.6511	1.6511	7.0*
B	1	.2680	.2680	1.1
A*B	1	1.2927	1.2927	5.5
Error	15	3.5443	.2363	
Total	23	7.3960		

4. Botanical Composition, Richmond - 1972

Point Quadrat Analysis

Number hits per 100 points

(Data from which Table 18 is derived)

(i) Slender thistles.

	Replication					
Treatment	1	2	3	4	5	6
111	5.10	7.70	1.60	21.10	2.10	10.60
110	9.60	3.60	15.20	11.20	15.00	13.50
011	22.30	10.10	12.50	15.40	8.50	2.00
010	17.80	27.10	9.70	20.00	16.40	8.60

Analysis of Variance

Source of Var.	df	SS	MS	F
Blocks	5	182.0471	36.4094	.8
Treatments	3	224.0713	74.6904	1.7
A	1	121.9504	121.9504	2.8
B	1	98.8204	98.8204	2.3
A*B	1	3.3004	3.3004	.1
Error	15	644.9212	42.9947	
Total	23	1051.0396		

(ii) Rye-grass

	Replication					
Treatment	1	2	3	4	5	6
111	69.40	56.70	83.50	32.00	49.70	73.40
110	44.00	83.30	63.40	57.60	29.80	59.40
011	50.00	60.00	56.20	41.00	30.80	31.80
010	50.00	29.10	50.80	37.70	39.70	52.00

Analysis of Variance

Source of Var.	df	SS	MS	F
Blocks	5	1887.1871	377.4374	2.1
Treatments	3	1319.3246	439.7749	2.5
A	1	1248.4838	1248.4838	7.0*
B	1	59.2204	59.2204	.3
A*B	1	11.6204	11.6204	.1
Error	15	2664.5779	177.6385	
Total	23	5871.0896		

(iii) Clover

	Replication					
Treatment	1	2	3	4	5	6
111	3.10	3.00	.70	2.10	1.50	3.50
110	0	1.10	1.20	1.20	7.50	2.30
011	4.40	.90	1.00	.90	8.50	5.90
010	0	1.00	2.00	.60	3.40	0

Analysis of Variance

Source of Var.	df	SS	MS	F
Blocks	5	48.5150	9.7030	2.7
Treatments	3	17.8750	5.9583	1.7
A	1	.0817	.0817	.0
B	1	9.6267	9.6267	2.7
A*B	1	8.1667	8.1667	2.3
Error	15	53.4750	3.5650	
Total	23	119.8650		

(iv) Bromus spp.

Treatment	Replication					
	1	2	3	4	5	6
111	5.10	4.80	2.40	9.60	.70	2.70
110	8.10	2.40	6.30	5.00	2.20	1.10
011	7.10	13.80	2.20	13.70	1.60	32.50
010	6.90	15.60	9.70	10.00	8.70	10.60

Analysis of Variance

Source of Var.	df	SS	MS	F
Blocks	5	193.7983	38.7597	1.0
Treatments	3	287.5333	95.8444	2.4
A	1	280.1667	280.1667	7.1*
B	1	3.8400	3.8400	.1
A*B	1	3.5267	3.5267	.1
Error	15	588.5017	39.2334	
Total	23	1069.8333		

(v) "Other Grasses"

Treatment	Replication					
	1	2	3	4	5	6
111	12.30	21.20	5.50	15.70	26.60	9.80
110	22.40	2.40	9.00	16.20	23.40	11.30
011	10.70	2.00	10.50	18.20	28.40	10.00
010	10.00	11.50	7.70	10.00	19.00	8.60

Analysis of Variance

Source of Var.	df	SS	MS	F
Blocks	5	716.5233	143.3047	5.4
Treatments	3	53.0233	17.6744	.7
A	1	35.5267	35.5267	1.3
B	1	15.6817	15.6817	.6
A*B	1	1.8150	1.8150	.1
Error	15	399.8667	26.6578	
Total	23	1169.4133		

(vi) Other species

Treatment	Replication					
	1	2	3	4	5	6
111	5.10	6.80	6.20	19.70	19.60	0
110	16.00	7.10	5.10	8.80	22.20	12.40
011	5.40	12.90	17.60	11.00	22.30	17.50
010	15.40	15.60	20.10	21.80	13.00	20.30

Analysis of Variance

Source of Var.	df	SS	MS	F
Blocks	5	226.6438	45.3288	1.2
Treatments	3	218.6246	72.8749	2.0
A	1	170.1337	170.1337	4.7 *
B	1	47.3204	47.3204	1.3
A*B	1	1.1704	1.1704	.0
Error	15	547.3779	36.4919	
Total	23	992.6463		

Appendix VI

Chemical Analyses of Slender Thistles

(a) Percentage composition by weight

(b) Percentage digestible material by weight

(Data on which Table 19 is based)

	Treatment	ADF(%)	ADL(%)	Percentage "true" Cellulose	Nitrate (N)	Protein (N)	TRS(%)	Digestibility
Non Etiolated	1N	15.5	2.5	15.2	2.2	5.3	2.72	77.7
	2N	15.4	2.3	15.4	1.7	5.3	2.88	77.3
	3N	14.0	1.9	15.4	2.0	5.2	2.79	75.7
	4N	14.9	2.0	15.2	2.0	5.4	2.80	75.8
	5N	15.6	2.3	15.0	1.9	5.3	2.91	73.4
	6N	15.7	2.5	15.4	1.8	5.3	2.71	74.9
Etiolated	1E	15.9	2.9	20.2	2.9	4.8	2.98	73.7
	2E	16.0	3.4	18.7	3.0	4.8	3.40	71.2
	3E	17.0	2.6	19.2	2.8	4.8	3.16	70.1
	4E	16.5	2.6	19.7	3.0	4.7	3.26	68.4
	5E	16.3	2.6	18.3	2.9	4.9	3.26	73.3
	6E	16.7	3.2	18.4	2.9	4.8	3.39	66.1

Chemical Analyses - Analyses of Variance

Acid-Detergent Fibre

Source of Var.	df	SS	MS	F
Between	1	4.44	4.44	15.1*
Within	10	2.95	0.29	
Total	11	7.39		

Acid-Detergent Lignin

Source of Var.	df	SS	MS	F
Between	1	1.20	1.20	13.00**
Within	10	0.92	0.09	
Total	11	2.13		

True Cellulose

Source of Var.	df	SS	MS	F
Between	1	43.70	43.70	145.6**
Within	10	3.00	0.30	
Total	11	46.70		

Nitrate (N)

Source of Var.	df	SS	MS	F
Between	1	2.90	2.90	159.7**
Within	10	0.18	0.20	
Total	11	3.08		

Protein (N)

Source of Var.	df	SS	MS	F
Between	1	0.750	0.75	187.5**
Within	10	0.040	0.004	
Total	11	0.790		

Total Reducing Sugars

Source of Var.	df	SS	MS	F
Between	1	0.58	0.58	37.2**
Within	10	0.16	0.02	
Total	11	0.74		

Digestibility (in vitro)

Source of Var.	df	SS	MS	F
Between	1	90.75	90.75	17.8**
Within	10	50.97	5.10	
Total	11	141.72		

Appendix VII

Chemical Control of Etiolated Thistles

Thistle dry weights (gm)

(Data on which Figure 6 is based)

	Normal Thistles E_N	Shaded Thistles Es	+ G.A. E_G	Total
	9.0	6.4	8.1	
	8.6	6.8	8.9	
0	8.8	6.3	9.1	
(No spray)	9.8	7.1	9.0	
	10.4	7.2	8.5	
	10.4	7.0	8.9	
Total	57.0	40.8	52.5	150.3
Mean	9.5	6.8	8.75	
	4.6	2.0	4.3	
(i)	5.7	1.9	3.8	
	5.3	3.6	6.4	
0.21 kg a.e. MCPA/ha	4.2	2.5	7.2	
	5.8	2.8	6.7	
	5.7	2.4	5.6	
Total	31.3	15.2	34.0	80.5
Mean	5.2	2.5	5.7	
	3.5	1.1	2.9	
(ii)	2.8	1.1	3.5	
	4.8	1.8	4.2	
0.42 kg a.e. MCPA/ha	4.0	1.0	3.4	
	4.3	1.1	4.4	
	4.2	1.4	2.3	
Total	23.6	7.5	20.7	51.8
Mean	3.9	1.25	3.75	

Analysis of Variance

Source of Var.	df	SS	MS	F
Blocks	5	7.9933	1.5987	4.0
Treatments	8	367.4467	45.9308	114.0
A (Sprays)	2	285.1478	142.5739	353.8***
B (Etiolation)	2	79.1544	39.5772	98.2***
A*B (Interaction)	4	3.1444	.7861	2.0
Error	40	16.1200	.4030	
Total	53	391.5600		

Appendix VIII

TITLE

The control of slender thistle, *Carduus pycnocephalus* L. and *C. tenuiflorus* Curt. (*Compositae*), in pasture by grazing management.

ABRIDGED TITLE

Slender thistle control by grazing

by

G.M. Bendall *

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Tasmania.

Summary

The effect of grazing management on slender thistle populations and botanical composition of improved pasture was studied in two field trials in Southern Tasmania. Deferring grazing until winter or spring reduced slender thistle populations in both trials. The reasons underlying these observations are discussed.

Spring grazing favourably altered pasture botanical composition by increasing the frequency of perennial ryegrass and subterranean clover and reducing the frequency of weed grasses. These changes are discussed in relation to thistle control.

It is suggested that deferred autumn grazing may be incorporated into the farm programme as an economical method for the control of slender thistle in pasture.

I. Introduction

Slender thistles (*Carduus pycnocephalus* L., and *C. tenuiflorus*, Curt.) occur as natives in Great Britain and and Western Europe (Clapham *et.al.* 1957) and have been introduced into both North America (Robbins *et al.* 1951) and Australia.

In Tasmania, slender thistles are the most troublesome pasture weeds because of their widespread occurrence and their propensity to form dense populations. At present, herbicides are used to control slender thistles, but this method is frequently inefficient and uneconomical and may suppress pasture legumes. Since slender thistles occur predominantly in sheep grazing areas, it was decided to use grazing management as a possible means of control.

This paper reports two field experiments designed to study the effectiveness of various grazing management systems in controlling slender thistles in pasture.

II Phenology

The life-cycle of slender thistles may be divided into three broad periods, viz. germination to rosette, over-wintering rosette, and overwintering rosette to flowering and seed-fall. These periods are approximately correlated to the following months and seasons of the year respectively - March, April, May and June (autumn), July and August (winter), and September, October, and November (spring).

Occasionally, germination may occur during spring or early summer; these plants act as biennials by over-summering as rosettes rather than as dormant achenes and flower the following spring.

The experiments were established to test the hypothesis that pasture/thistle competition during rosette establishment (autumn) followed by grazing reduced thistle populations.

III Materials and Methods

(a) Grazing Trial - Sorell

The first experiment was started in March 1970 in the Sorell district of Southern Tasmania on a six year old pasture with the dominant species being Lolium perenne, (perennial ryegrass) Bromus spp., Cynosurus echinatus, and Trifolium subterraneum (subterranean clover). The soil type was a Black Soil on Basalt (Loveday 1957) and the district has an average annual rainfall of 575 mm (Table 1).

Grazing and no grazing treatments were applied in the three life-cycle periods in the form of a 2^3 factorial design arranged in four randomised complete blocks (Table 2).

Plots of size 20 m x 10 m were arranged within a 1.7 ha area in two ranks of 16 plots each. Plots were not stocked individually, but Corriedale x Merino wethers at 17/ha grazed the area around the plots. Those plots when requiring grazing had the short end fences removed so that the boundary area and the plots were grazed at the same rate.

Thistle populations were sampled in August (at the end of winter treatment) and November 1970 (at the end of spring treatment) by 24 random counts per plot using 929 cm^2 (1 ft^2) quadrats.

Botanical composition of the pasture was determined in October 1971 using an inclined (32.5^o) point quadrat. Twenty frames of 10 points each were taken at random in each plot with all hits being recorded to the point of reaching ground

level. During 1971, all plots and the boundary area were grazed continuously. Thus differences in pasture composition between the plots had their origin in the grazing treatments of the previous year.

(b) Grazing Trial - Richmond

The second experiment was established in the Richmond district of Southern Tasmania to study in further detail those grazing management systems which were effective in controlling slender thistle in the Sorell trial. This experiment started in March 1971 on a 3 years old pasture with the dominant species being Lolium perenne, Trifolium subterraneum, and Bromus spp. Other species present were Vulpia spp. and broad-leafed weeds: Rumex spp., Cirsium vulgare, and Plantago spp. The soil type was a Podzolic Soil on Dolerite (Loveday 1957) with a mean annual rainfall for the area of 525 mm (Table 1). Grazing and no grazing treatments were applied in autumn and spring in a 2 x 2 factorial design in six randomised complete blocks (Table 4). All treatments were grazed during the winter. The layout of the experiment was similar to that at Sorell,,but with a plot size of 20 m x 8 m and stocked with Polwarth wethers at 15/ha.

Because of some variability in the thistle density at Sorell, a more rigorous sampling technique was adopted at Richmond. Thistle populations were sampled in March and at the end of each grazing period in the first year using 8 permanent m^2 quadrats selected at random in each plot. Botanical composition was determined as before in the second year of the experiment (1972), but due to unusually severe drought conditions for the district (Table 1), the results have little relevance and have been omitted.

(c) Rainfall at Trial Sites, 1970-72

Table 1 tabulates the rainfall at meteorological stations close to the two experimental sites for 1970 at Sorell and from October 1970 to December 1972 at Richmond.

Insert table 1.

(d) Statistical Analyses

Where necessary, raw data were transformed to a suitable scale for analysis on the basis of Tukey's test for non-additivity and an examination of residuals plotted against expected values was made. Percentage thistle survival was the variable analysed at Sorell, in which the number of thistles counted at each time was expressed as a percentage of the initial population estimate. The initial thistle populations at Richmond were sufficiently uniform to allow the actual number of thistles to be analysed. Randomised complete block analyses of variance were performed on the measures of thistle survival at each site and botanical composition estimates at Sorell, to test the main hypothesis, that a period of pasture competition followed by a grazing period reduced thistle populations.

IV Results

(a) Grazing Trial - Sorell

The mean percentage slender thistle survivals at the August and November counts are tabulated in Table 2.

Insert table 2.

The results show that grazing after a no grazing period consistently gave significant thistle control. At the August count, grazing during winter only (010) was the most effective

treatment in reducing thistle populations. By November, spring grazing only (001) and no winter grazing (101) were also proving effective. Continuous grazing (111) significantly reduced thistle numbers, but was not as effective as the no grazing/grazing treatments.

The effects of the grazing systems on pasture botanical composition are given in Table 3. Spring grazing had the most obvious effect on botanical compositions. Subterranean clover, perennial ryegrass, and "other species" which included other thistles (Cirsium vulgare, C. arvense, and Silybum marianum) and broad-leafed weeds (Rumex spp., Plantago spp., and Taraxacum officinale) were increased significantly by spring grazing in contrast to the weed grasses - Bromus spp., Cynosurus echinatus, and "other grasses" (Vulpia spp., Poa annua) which were reduced in frequency by spring grazing. Grazing or no grazing in autumn and winter had little effect on the botanical composition except in influencing the clover component in the winter/spring grazing system and in increasing both ryegrass and clover in the continuous grazing treatment.

Insert table 3.

Slender thistle showed no significant effects of being controlled by the previous year's grazing treatments. Bare ground, although recorded, was insignificant and hence was omitted from table 3.

(b) Grazing Trial - Richmond

The results of the slender thistle counts in March, June, August, and November 1971 as mean number of thistles per m^2 are tabulated in Table 4.

Insert table 4.

Because of heavy summer rainfall in late December, 1970 (Table 1) early thistle germination occurred. This formed the population estimated in the March count and indicated the uniformity of the thistle population prior to commencing the grazing treatments. However, humid weather and the development of dense aphid populations (Capitophorous sp. and Brachycaudus sp.) during March and April resulted in extensive thistle mortality before the "true" autumn break in May (Table 1). The June count estimated the May-germinated thistle population and showed a significant inhibitation of germination in those plots ungrazed during the autumn (011 and 010). This effect was carried through to the August and November counts.

V Discussion

The significant feature of the Sorell grazing trial was the interaction of pasture/thistle competition and the grazing habits of the sheep. In the autumn and autumn/winter ungrazed plots, competition for light between the pasture and slender thistles caused the thistles to become etiolated and lush with softened prickles, as compared with the non-etiolated and prickly thistles in the autumn grazed plots. Similar morphological changes have been observed in the glasshouse when thistles were grown under reduced light intensity.

On grazing the former plots in either winter or spring, the etiolated thistles tended to be eaten in preference to the pasture, although the latter appeared to be also quite palatable being only 15 cm or less in height. Regrowth of etiolated thistles following grazing rarely occurred, as the growing points, by virtue of the etiolation, were well above

ground level (approx. 2-3 cm) and hence vulnerable to grazing as compared with non-etiolated thistles where the growing point is below ground level.

In the Richmond grazing trial, the autumn ungrazed pastures had made considerable growth (10-15 cm in height) by the time of the late second flush of thistle germination and germination in those plots was inhibited. This differential germination between the autumn grazed and ungrazed plots could be ascribed to the rapid uptake of moisture by the vigorous ungrazed pasture as compared with the less vigorous pasture (2-3 cm in height) in the grazed plots where sufficient moisture was apparently available for germination. A similar explanation was suggested by Michael (Unpublished work) for the control of Onopordum acanthium L.by Medicago sativa (lucerne) and Dactylis glomerata (cocksfoot)

With the exception of winter grazing only (010), those treatments which effectively reduced thistle populations also favourably altered pasture botanical composition by increasing perennial ryegrass and removing the grass weeds, thus reducing the possibility of thistle reinfestation.

However, grazing effects on slender thistle populations were not carried through to the second year. This is not surprising as seed could have blown from adjacent plots in which the grazing treatments had not been effective and seed set had occurred. Also, the dormant thistle seed in the soil would probably the sufficient to form the basis of a population even though seeding had been prevented in the previous year. Again, the recurrence of thistles and also the increase in broad-leafed weeds could have been due to overgrazing in the spring. This, however, should not be a problem in the closely controlled grazing situation.

It is thought that the success of the deferred winter grazing treatment (101) was due to the chance occurrence of a favourable winter for pasture growth. Of the other successful treatments, it would appear that deferred autumn grazing would be the most practical system for incorporation into the farm management programme as an alternative to herbicides for the control of slender thistle. Such a deferment has the advantage of being less expensive than herbicidal treatments and favours general pasture improvement.

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VII References

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Table 1

Rainfall at Sorell, 1970; Richmond October 1970 - December 1972

Month	Rainfall (mm) - Sorell		Rainfall (mm) - Richmond			
	1970	28-year average	1970	1971	1972	52-year average
January	85	38		97	55	44
February	37	46		54	36	44
March	39	39		36	10	39
April	21	54		14	55	45
May	52	53		73	5	41
June	26	42		28	13	43
July	29	48		8	78	40
August	77	45		55	33	39
September	23	43		76	19	37
October	76	60	58	59	25	54
November	61	50	42	83	29	43
December	160	57	158	49	27	56
Total	686	575		632	385	525

Table 2

Mean Percentage Thistle Survival - Sorell 1970

Treatment	‡ August Count		November Count	
*A W S	No./929 cm^2 Actual Numbers	§§ Transformed Percentage Survival	No./929 cm^2 Actual Numbers	Transformed Percentage Survival
+1 1 1	0.44	2.78	0.35	1.74
1 1 0			0.51	3.27
1 0 1	1.17	3.44	0.91	1.11
1 0 0			0.96	3.16
0 1 1	0.11	0.75	0.17	1.03
0 1 0			0.18	2.13
0 0 1	0.73	3.04	0.07	0.67
0 0 0			1.17	3.80
LSD P 0.05		0.82		1.44
P 0.01		1.11		1.95

* A = Autumn
W = Winter
S = Spring

+1 = Grazing
0 = No grazing

‡ Essentially only 4 treatments at August count.

§§ Transformation $\log_e X$ where X = Percentage thistle survival.

Table 3

Inclined Point Quadrat Botanical Analyses, Sorell (October 1971)
(Mean Number Hits/100 Points)

Treatment * A	W	S	Slender thistles	Subterranean Clover (Not Transformed)	Rye grass (Not Transformed)	Bromus spp.	Cynosurus echinatus	Other Grasses	Other Species
+ 1	1	1	6.75 +(1.707)	127.00	130.75	2.75 (1.180)	8.25 (1.703)	6.25 (1.534)	11.75 (2.266)
1	1	0	12.5 (1.320)	60.00	89.75	26.50 (3.101)	27.00 (3.051)	12.25 (2.563)	6.75 (1.724)
1	0	1	2.75 (1.151)	95.00	112.00	1.75 (0.749)	5.50 (1.619)	5.00 (1.619)	19.25 (2.946)
1	0	0	7.25 (1.798)	43.75	84.50	27.50 (3.180)	36.50 (3.342)	16.00 (2.770)	8.25 (2.161)
0	1	1	4.75 (1.690)	111.25	101.00	2.50 (1.108)	2.00 (0.621)	4.75 (1.717)	26.75 (3.177)
0	1	0	2.50 (1.170)	60.25	89.50	31.00 (3.402)	19.00 (2.835)	11.25 (2.392)	13.50 (2.319)
0	0	1	2.52 (1.197)	86.00	102.25	3.25 (1.400)	5.50 (1.628)	2.25 (1.125)	40.50 (3.686)
0	0	0	13.50 (2.081)	94.25	71.50	21.75 (2.962)	10.50 (2.001)	12.25 (2.469)	9.75 (2.139)
LSD P 0.05			(ns)	35.90	20.12	(0.977)	(0.934)	(0.705)	(0.961)
LSD P 0.01			(ns)	48.80	28.90	(1.330)	(1.272)	(0.960)	(1.308)

* A = Autumn
W = Winter
S = Spring

\+ 1 = Grazing
0 = No grazing

‡ Means of transformed data in parentheses: Transformation $\log_e(X + 1)$
where X = Number of hits/100 points.

Table 4

Slender Thistle Counts Richmond - 1971

Number of Thistles/m^2

Treatment			Time of Count			
*A	W	S	March	June	August	November
+1	1	1	15.54 (2.13)+	43.89 (3.69)	41.67 (3.64)	22.64 (2.92)
1	1	0	13.52 (2.88)	51.71 (3.93)	49.39 (3.88)	18.44 (2.84)
0	1	1	11.73 (2.38)	6.14 (1.77)	5.25 (1.56)	1.94 (0.39)
0	1	0	13.10 (2.51)	6.73 (1.88)	6.29 (1.79)	1.19(-0.38)
LSD P 0.05			n.s.	(0.38)	(0.41)	(0.87)
LSD P 0.01			n.s.	(0.53)	(0.56)	(1.2)

*A = Autum +1 = grazing + Means of transformed data in brackets

W = Winter 0 = no grazing Transformation $\log_e X$ where X = No. thistle/m^2

S = Spring