

ASPECTS OF THE ECOLOGY OF HOLCUS LANATUS L.,
ALONE AND IN MIXTURE WITH
LOLIUM PERENNE L.

A thesis submitted for the degree of
Doctor of Philosophy

by

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Holcus lanatus L.

ABSTRACT

ASPECTS OF THE ECOLOGY OF HOLCUS LANATUS L., ALONE AND IN MIXTURE WITH LOLIUM PERENNE L.

Trudy A. Watt, Somerville College.
D. Phil. thesis. Michaelmas Term, 1977.

This thesis contains a literature review of Holcus lanatus and records studies on both the growth and spread of the species and the response of it and of Lolium perenne to several management and edaphic factors. Holcus lanatus is an adaptable, competitive species with ecotypes growing in a wide range of environments. It is valuable on hill land, acid, low nutrient soils and to prevent erosion. Beef cattle grazing it have made greater liveweight gains than on L. perenne.

Experiments used plants growing in pots and small field plots. A growth study of spaced H. lanatus plants showed they can produce up to 240,000 seeds, most of which germinated shortly after being shed onto moist soil. Seedlings established poorly in a closed sward. Spaced plants produced runners in autumn whose plantlets established better when plants were cut regularly in spring. Holcus lanatus plants needed vernalization in order to flower. This was enhanced by and to a small extent replaced by short days. When H. lanatus plants in bud were cut, useful summer vegetative regrowth resulted. The New Zealand cultivar Massey Basyn was more productive than Oxfordshire H. lanatus in a pot trial.

Holcus lanatus dominated a mixture with L. perenne in a glasshouse experiment, especially under high or infrequent cutting, but it was not so dominant in a field experiment. Cattle treading damaged H. lanatus more than it did L. perenne. Holcus lanatus responded to a high water table by producing adventitious and surface roots. Propyzamide at 2.24 and linuron at 1.12 kg a.i./ha in early summer and asulam at 1.12 or 2.24 kg a.i./ha in early September gave good control of established H. lanatus in L. perenne in preliminary trials. The agricultural significance of these results is discussed.

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CHAPTER 1

GENERAL INTRODUCTION

AIMS OF THIS WORK

Holcus lanatus is a widespread component of British grassland. It is commonly considered to be undesirable. This work aimed to study this species both by making a literature review and by experimentation.

LITERATURE REVIEW

Evidence in the literature about the growth and usefulness of the species was surveyed and used to determine in what situations H. lanatus is a weed. The review has been submitted for publication by Herbage Abstracts. As it is lengthy, the text has been placed in Appendix 1^(p.218) and the main points only are summarised here.

Summary. Holcus lanatus is a very adaptable and competitive grass. Its shoots and roots can grow very vigorously and it has ecotypes which allow it to tolerate a wide range of environmental conditions. It can reproduce well both by seed production and by runners. The quantity and fate of seeds produced by H. lanatus plants have been studied (Mortimer, 1974) but information about seedling establishment and plant growth throughout the year is lacking. Also, little is known about the timing and importance of spread by runners and how this may be affected by defoliation.

Several people have observed that the growth of young H. lanatus plants is favoured by lax cutting (Riveros, 1963; Froud-Williams, 1974), but quantitative studies of the effect of various heights and frequencies of cutting on the growth of established H. lanatus plants with and without

Lolium perenne have not been made. It has also often been noted that H. lanatus commonly grows on wet sites (Armstrong, 1945; Burbidge, 1966; Grant and Brock, 1974). However, there is little information about whether it produces more shoot material in poorly drained conditions or is just able to tolerate them better than other grasses e.g. L. perenne.

Holcus lanatus is clearly a weed in herbage seed crops (Harkess and Hope, 1974). It has also been regarded as a weed in lowland ryegrass swards because livestock reject it when flower shoots are formed (Stapledon and Milton, 1932). However, more recent work has contradicted this view. Beef cattle have made better liveweight gains on pure H. lanatus swards than on pure L. perenne swards (Moloney, 1962, 1963, 1964; Murphy, 1965) despite the fact that H. lanatus is damaged more by animal treading than is L. perenne. (Brown and Evans, 1963). This suggests that the reputation of H. lanatus as a weed may have arisen from estimates of its productivity under low nutrient conditions rather than under the same nutrient conditions as are applied to sown species.

On hill land, H. lanatus is a valuable and persistent species (Hughes and Nicholson, 1961a and b; Herriott, 1975). It has been sown both to prevent soil erosion (Dunbar, 1974; Hornung, 1976) and to provide fodder on acid, low nutrient soils (Davies, et al., 1971).

More information is required about animal production from swards of H. lanatus under various management systems. Because of the large amount of variability in the species, it should be possible to breed improved cultivars of H. lanatus for specific purposes, e.g. for beef production under high or low input systems or for the reclamation of spoil tips. Herbicides in current use in grassland have their limitations and new herbicides for the selective control of H. lanatus in ryegrass herbage seed crops are needed.

EXPERIMENTATION

The first part of this work describes a study of the growth of H. lanatus including its methods of spread, both sexual and vegetative. Later chapters investigate the effect of important management and edaphic factors : cutting, animal treading, height of soil water table and herbicides, on the growth of both H. lanatus and L. perenne. This information helps to explain why H. lanatus is so widespread and how the amount of it in a L. perenne sward can be altered.

CHAPTER 2

GROWTH STUDY OF H. LANATUS

"As a matter of fact, to speak roundly, the causes of such differences (in speed of germination) must be found in several different circumstances, in the seeds themselves, in the ground, in the state of the atmosphere and in the season at which each is sown, according as it is stormy or fair." Theophrastus, ~ 300 B.C. Enquiry into plants VII, I, 5.

INTRODUCTION

MONTHLY SOWINGS OF H. LANATUS

Little is known about the effect of environmental factors on the emergence, growth, flowering and seed production of Holcus lanatus sown at various times of the year in the field. The laboratory test recommended by the Association of Official Seed Analysts (1970) is that seed should be germinated under alternating conditions of 16h dark at 20°C and 8h light at 30°C, in moist conditions.

McNeill (1973) at Ascot, Berkshire, found H. lanatus flowering from late May onwards and Mortimer (1974) at Bangor, Gwynedd, found that it shed seed from June to September with a peak during the first two weeks of July. He sowed seed which was 64.8% viable on the soil surface in October 1970. Only 24% of the seeds germinated and the maximum number of seedlings occurred in November. By the following May only 11% of the seeds sown had given rise to established plants. Böcher and Larsen (1958) found that H. lanatus plants grown from northern European seed needed to be vernalized before they could flower.

An experiment was designed to study the emergence, number of tillers, dry weight of shoot growth, time and duration of flowering and the seed production of H. lanatus sown monthly during 1975 in the field. The results have been presented in a paper at the 1976 British Crop Protection Conference - Weeds, (Watt, 1976). A copy is in Appendix 2 (p.243). During the course of this experiment a number of questions arose and the following supplementary experiments were carried out to answer them.

TWO NON-DESTRUCTIVE METHODS OF ASSESSING TILLER NUMBERS

Tiller counts of twenty four spaced plants in the growth study experiment were carried out regularly up to 20 February 1976. On this date many of the larger (January to June sown) plants had between 500 and 1000 tillers each. It took a long time to count such large numbers of tillers. A quick, non-destructive method of estimating tiller numbers was required.

This experiment was designed to find out whether taking infra-red photographs of H. lanatus plants and calculating their area provided a more accurate method of estimating their tiller numbers than measuring the plants' length and breadth.

GERMINATION OF H. LANATUS CARYOPSES WITH LEMMAS AND PALEAS OF DIFFERENT COLOURS

The mean germination of the seeds (\equiv spikelets) of H. lanatus used in the growth study experiment was 60.3% in January, 1975. Each time they were sown in the field their germination was also tested in the laboratory. One hundred seeds were placed on filter paper over cotton wool, moist with distilled water, in each of four petri dishes. The number of seeds which had germinated fourteen days later was counted. The figures fell within the range 59.5 - 67%.

While counting out spikelets for the January sowing, I removed the glumes from some of them and noticed that the hardened lemmas and paleas round the caryopses varied in colour (Fig. 1, p. 7). The palea and lemma are very thin and cannot be removed easily from the caryopsis (Hayes, 1976). I wanted to find out whether H. lanatus caryopses, enclosed by lemmas and paleas of different colours, have correspondingly different germination percentages.

THE ATTACHMENT OF H. LANATUS SPIKELETS TO COTTON WITH ARALDITE

In a study of Poa annua, Wells (1974) not only sowed seeds just below the soil surface but also attached some to black cotton, using araldite. The cotton was pinned to the soil surface at either end. He aimed to note the germination of these seeds and to retrieve ungerminated seeds to find out whether they were dead or dormant. His laboratory tests showed no significant difference in germination between P. annua seeds attached or unattached to cotton on the soil surface. Before using such a technique to study H. lanatus germination on the soil surface in the field, I wanted to find out whether attaching the seeds (\equiv spikelets) to cotton with araldite affected their germination.

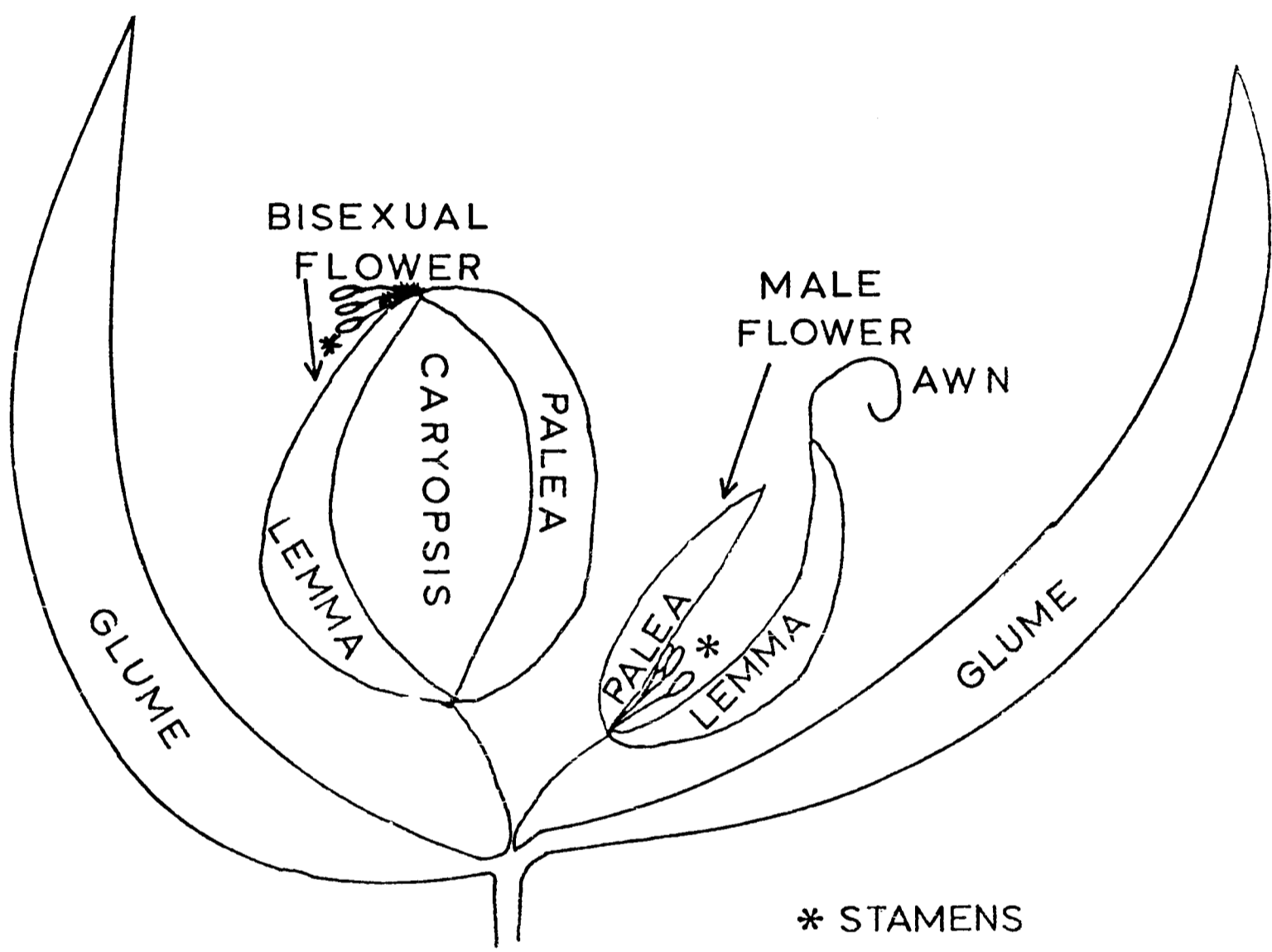
TESTING H. LANATUS FOR DORMANCY

In the growth study experiment H. lanatus seeds were sown monthly and seedling emergence noted over the succeeding months. I wanted to study the emergence of H. lanatus seedlings over at least two years to see if there was evidence of dormancy and also to sow freshly collected H. lanatus seed immediately so that its behaviour was not affected by laboratory storage.

FIGURE 1

Diagrammatic representation of an

H. lanatus spikelet



ESTABLISHMENT OF H. LANATUS SEEDLINGS

IN A SWARD

Although H. lanatus plants may establish well from seed in bare soil, as in the growth study experiment, this may not be so in a sward. It was necessary to distribute freshly collected H. lanatus seed over a sward and follow its fate to find out.

METHOD AND MATERIALS

MONTHLY SOWINGS OF H. LANATUS

The site (6m x 1.2m) was on a sandy loam soil at the Weed Research Organization, Oxford. The top 75mm of soil was removed and placed in a 'Camplex' electrical soil sterilizer. It was heated to 77°C and then left until the soil temperature stopped rising. It was then returned to the site. This technique is recommended by the manufacturers and it killed all seeds present in the soil.

Holcus lanatus seeds, collected the previous summer at WRO, were sown monthly during 1975. The seeds were stored at room temperature before sowing. Each plot measured 1m x 0.3m and 100 seeds per plot were sown 2mm deep at 30mm spacing in four rows each 50mm apart. The same number of seeds was sown every month into a freshly prepared seed bed with a fine tilth. Laboratory tests showed that the unsown seeds remained about 60% germinable throughout the year. The experiment was an unrestricted random design with two replicate plots for each month of sowing (Fig. 2, p. 9).

After sowing, each plot was protected from birds by plastic netting. Every week, the number of seedlings which had emerged (i.e. whose coleoptiles were visible) on each plot was recorded. As each month's seedlings grew they were thinned at intervals to prevent intra-specific competition. At each thinning the tiller number per plant and the shoot dry weight of harvested plants were noted (Appendix 3, p. 247). One plant was selected at random and left to grow on in each plot. The number of panicles was recorded each

FIGURE 2

Overall view of Growth Study experiment in
February 1976



week and the percentage of panicles which had produced anthers was noted.

The maximum height of plants above the ground was measured on 15 June, 1976 after which the plants were cut down to ground level on 29 June and their dry weights recorded. Twenty panicles (which appeared to have shed little, if any, seed) were selected from each plant at random at the time of harvest. Their fresh weight was recorded and they were kept in linen bags at ambient temperature for sixteen days. Then the seed was removed from the rachis and weighed. Two sub-samples, each of 100 seeds were taken from each sample and weighed. The mean number of seeds produced on each plant could then be estimated. Results were analysed as described in Appendix 4 (p. 248).

The term 'seed' refers to the caryopsis surrounded by the lemma, palea and glumes. Groups of plants are referred to by the months in which they were sown. Weekly rainfall and weekly maximum and minimum air temperatures were recorded at a nearby meteorological site and are shown in Figure 3 (p. 11). Monthly mean rainfall figures for 1975 are presented in Table 1 (p. 12). No artificial watering was used.

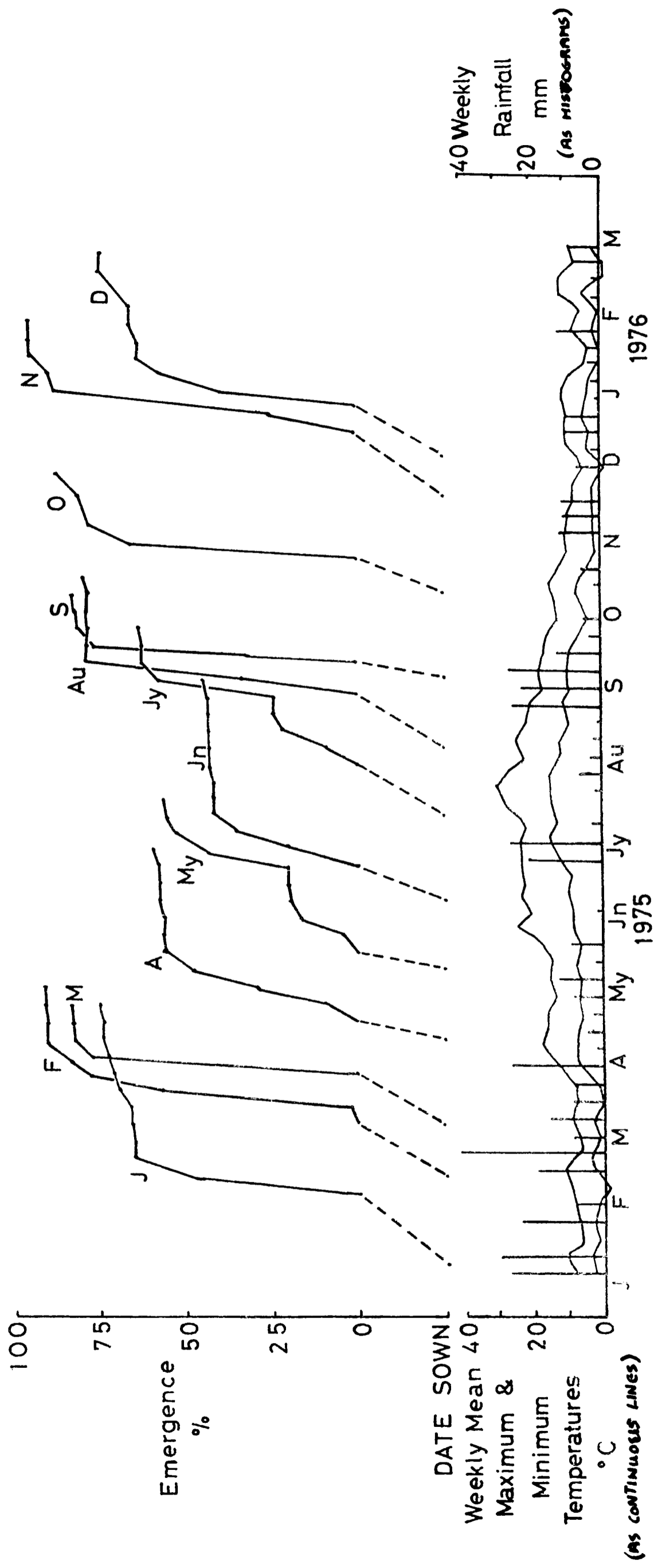
TWO NON-DESTRUCTIVE METHODS OF ASSESSING TILLER NUMBERS

Infra-red photographs. On 12 February 1976, infra-red photographs were taken of the January to September sown plants. The other plants were too small to give useful results by this method. Pieces of black cardboard were inserted under the leaves round the edge of the plants to ensure that only the required plant material would be recorded. A scale was included in each photograph.

The prints were developed so that the scales were approximately the same size. The length of the scales on the prints was accurately measured. The plants stood out white on a black background (Fig. 4, p. 13). Any

FIGURE 3

Emergence (% of viable seed sown) of *H.lanatus* sown each month during 1975 and also weekly rainfall (mm) and weekly maximum and minimum air temperatures (°C).



(AS CONTINUOUS LINES)

TABLE 1

Monthly rainfall mm

MONTH	1975	MEAN 1965-1974	1975 VERSUS 10 YEAR MEAN
Jan.	64.9	53.0	+ 11.1
Feb.	34.4	43.2	- 8.8
Mar.	85.1	31.7	+ 53.4
Apr.	45.6	43.6	+ 2.0
May.	39.7	55.5	- 15.8
Jun.	9.5	63.2	- 53.7
Jul.	48.0	53.6	- 5.6
Aug.	18.4	59.3	- 40.9
Sep.	85.9	51.9	+ 34.0
Oct.	16.8	51.1	- 34.3
Nov.	34.0	58.8	- 24.8
Dec.	18.8	46.4	- 27.6

Infra-red photograph of a clump of H. lanatus



extraneous white patches, together with the scales were blacked out with Indian Ink. The prints were then sent to R.H. Turner at Rothamsted Experimental Station for Quantimet analysis. This provided the area of the plants on the print in square centimetres. These results were corrected as necessary, using the accurate measurements taken of the scale in each print. A linear regression of tiller numbers on these results was calculated.

Plant length x breadth. On 20 February 1976 the number of tillers on each of twenty four spaced plants (two from each monthly sowing) was counted. At the same time the distance across each plant from North to South and West to East was measured. The length and breadth measurements were multiplied together. For the January to September sown plants a linear regression of tiller numbers onto these figures was calculated.

On 27 April, the tiller numbers of the larger spaced plants were estimated by measuring their length and breadth and reading off the appropriate tiller number from the regression. As the regression could not be extrapolated beyond the largest plants which were recorded in February, it was only possible to use the regression for some of the plants (Table 2, p. 15).

GERMINATION OF H. LANATUS CARYOPSES
WITH LEMMAS AND PALEAS OF DIFFERENT
COLOURS

Holcus lanatus spikelets were collected from the W.R.O. grassland in summer 1974. On 22 January 1975, three samples, each of 100 spikelets were taken at random. The glumes were carefully removed from each spikelet. The resultant caryopses, enclosed by a hardened lemma and palea, were sorted into groups by colour (Table 3, p. 30).

Each category of caryopses was placed on a layer of filter paper over cotton wool in a petri dish in the laboratory. The filter paper was kept

TABLE 2

The number of tillers per plant for each month of sowing, recorded on 27 April 1976

MONTH OF SOWING 1975	MEAN NUMBER OF TILLERS PER PLANT	
	FROM REGRESSION *	COUNTED
Jan.	1000 (too big)	-
Feb.	1180	-
Mar.	1000 (too big)	-
Apr.	1000 (too big)	-
May.	820	-
Jun.	1000 (too big)	-
Jul.	370	97
Aug.	300	109
Sep.	150	53
Oct.	100	12
Nov.	95	6
Dec.	0 (too small)	5

* REGRESSION ON LENGTH X BREADTH OF H. LANATUS PLANTS

TABLE 5

The categories into which spikelets of H. lanatus were placed after removal of their glumes

COLOUR OF LEMMA & PALEA	DESCRIPTION
Brown	The largest caryopses. Plump. Easily extracted from the glumes. Anthers never attached.
Pale (Creamy-brown to grey-green)	Flat caryopses. Often anthers and/or male flower still attached.
Green	Caryopses thinner than the brown ones but not as thin as the pale ones. Sometimes difficult to extract from the glumes. Sometimes anthers and/or male flower still attached.
Not present	No caryopses inside glumes.

TABLE 6

The distribution of the colours of lemma and palea within the samples of H. lanatus spikelets

COLOUR OF LEMMA & PALEA	BLOCK NUMBER			TOTAL
	I	II	III	
Brown	56	48	46	150
Pale	25	35	34	94
Green	10	7	11	28
Not present	9	10	9	28
Total	100	100	100	300

moist using distilled water. The petri dishes were arranged in three randomised blocks. The number of caryopses which had germinated fourteen days after sowing was recorded.

THE ATTACHMENT OF H. LANATUS

SPIKELETS TO COTTON

WITH ARALDITE

On 2 October 1975, three seed trays were filled with a 20mm layer of gravel on top of which was placed unsterilized sandy loam soil. The soil was firmed down well. H. lanatus seeds (\equiv spikelets) were taken at random from the supply to be used for the Growth Study experiment. Forty seeds were sown in each tray, in four rows of ten seeds. The seeds were 30mm apart within each row.

In two of the rows in each tray the seeds were placed on the surface of the soil. In the other two rows, the seeds were stuck onto a length of black cotton with araldite. The cotton was tied to pins at either end and secured in the soil. The seed trays were watered gently daily from above. Germination was noted daily.

TESTING OF H. LANATUS

FOR DORMANCY

On 18 November 1974, 2,000 seeds of H. lanatus, collected from the W.R.O. grassland in July 1974, were spread just under the ^{OF STERILISED SOIL,} surface \wedge 1,000 in each of two boxes (400mm x 400mm x 300mm deep) which were outside, under a birdproof cage. On 6 August 1975, a further 2,000 seeds were collected from the W.R.O. grassland and distributed between another two boxes in the same manner. The same procedure was carried out on 9 August 1976. ^{BOTH TIMES THE SEED WAS SOWN IMMEDIATELY AFTER COLLECTION.} At the end of each month from November 1974 to May 1977 the number of seedlings of H. lanatus in each box was counted and they were removed.

ESTABLISHMENT OF H. LANATUS

SEEDLINGS IN A SWARD

On 9 August 1976, H. lanatus seed was scattered over an area 18 m square on a two-year-old Lolium perenne sward in the W.R.O. grassland. The seed used was a mixture of samples between one and five years old. All of it originated from the W.R.O. grassland. The seed was applied at about 4,480 seeds/m². Laboratory tests showed that it was 35.7% viable so about 1,600 viable seeds were spread over each square metre of the experiment.

The number of seedlings of H. lanatus present in the area was sampled on 16 November 1976 and 18 April 1977. On each occasion, thirty six soil cores, 108mm across and about 25mm deep were removed from the experiment. The area was sampled systematically with one core being taken from within each of the 3m x 3m plots into which the area had been divided. The quarter of the plot from which the core was taken each time was chosen at random. Also, thirty six soil cores were taken from 2m outside the experimental area on both dates; nine on each side. The cores were examined for the presence of H. lanatus seedlings.

RESULTS

MONTHLY SOWINGS OF H. LANATUS

Germination and emergence. Seedlings emerged most rapidly from March to September sowings and took much longer under dry or cold conditions (June, January), (Fig. 5, p.19). In Figure 3 (p.11) weekly maximum and minimum air temperatures and weekly mean rainfall have been plotted to help explain these differences. Once a sowing had begun to emerge, most of its seedlings appeared rapidly but, the May and July sowings emerged in two batches (Fig. 3, p.11). Most months' sowings produced between 75% and 95% emergence of viable seeds but, far fewer seedlings emerged from April to July sowings (Fig. 6, p. 20).

FIGURE 5

The time which each monthly sowing of H. lanatus took to emerge

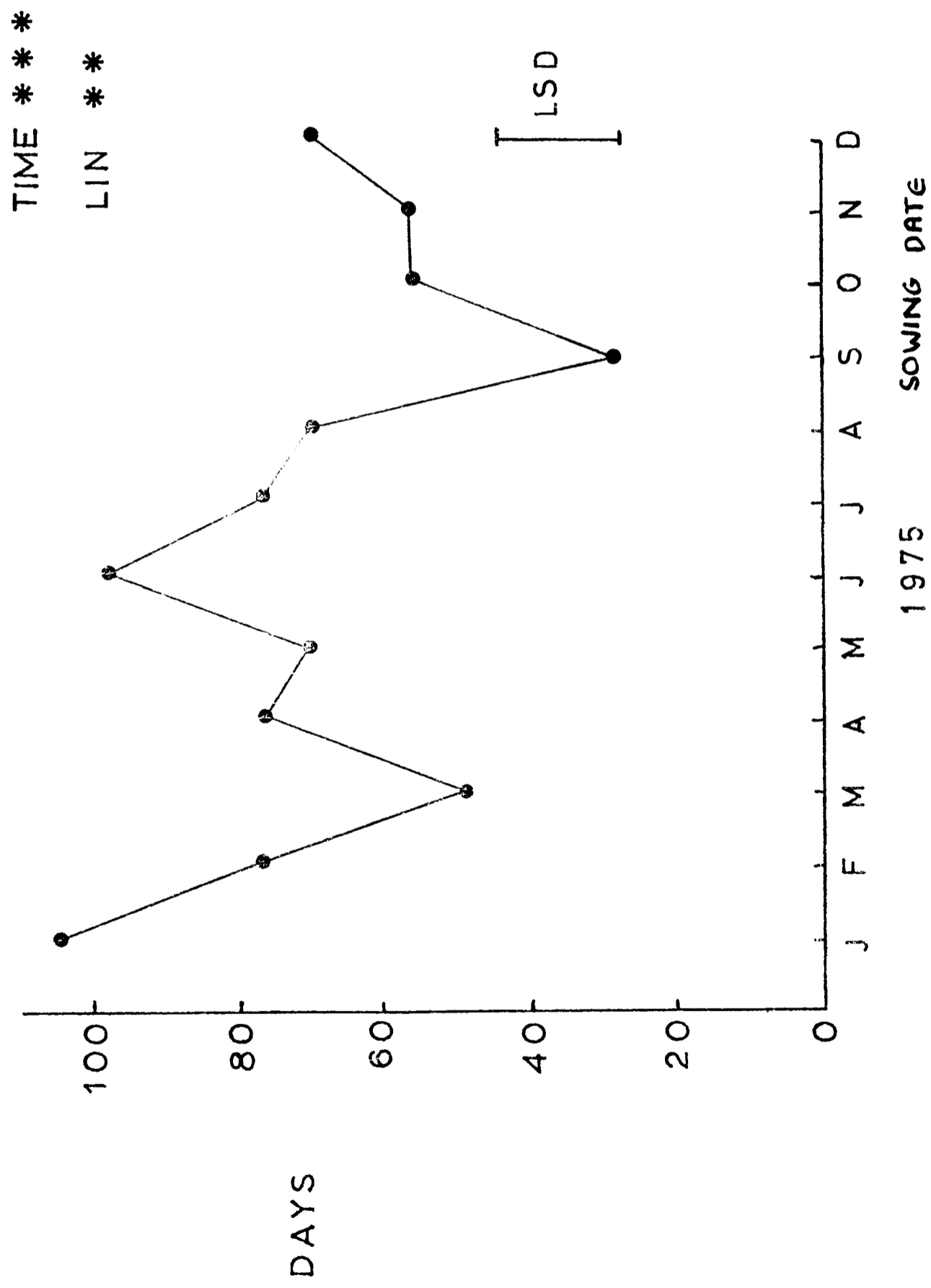
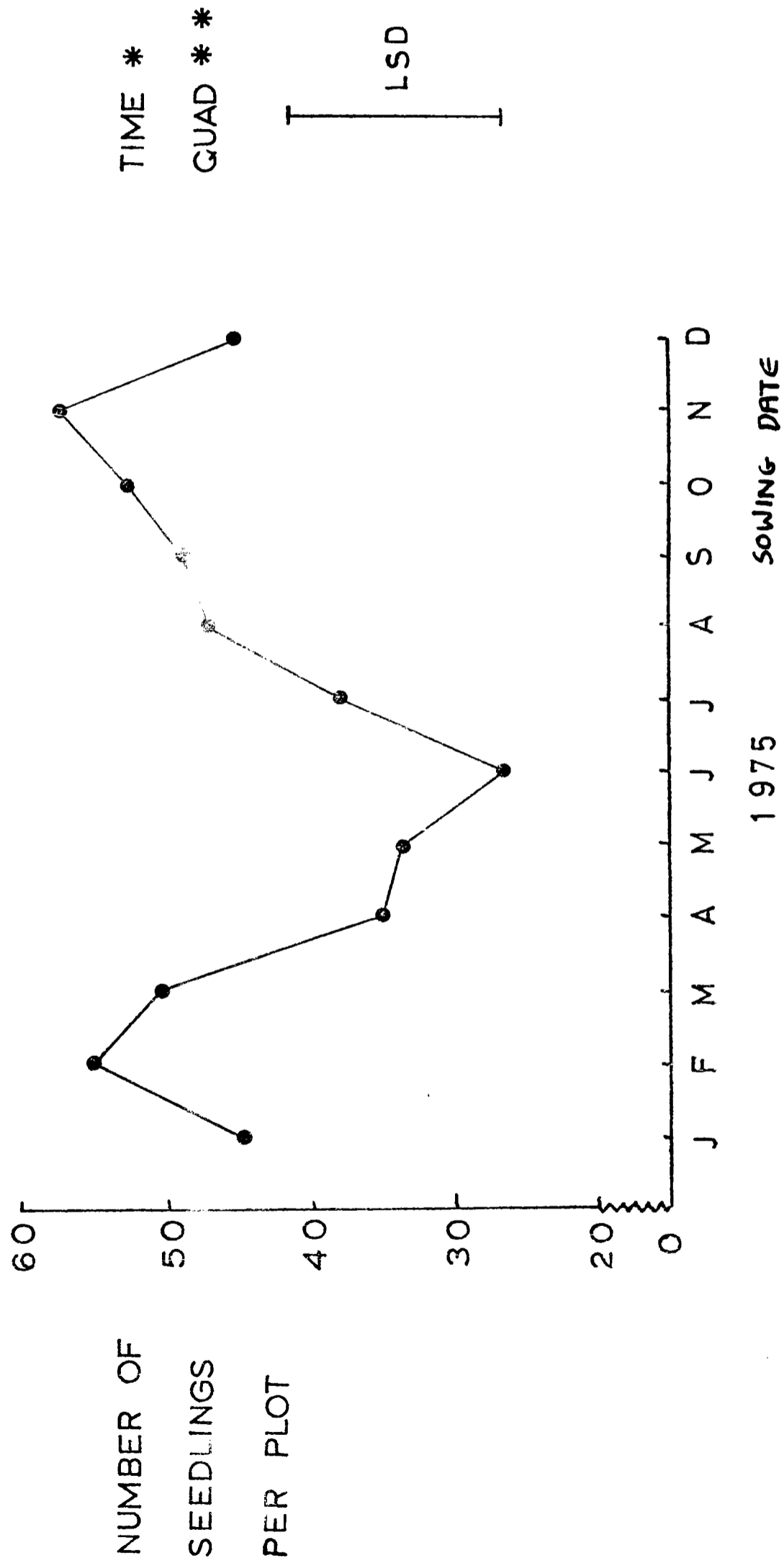


FIGURE 6

The number of H. lanatus seedlings from monthly sowings



Plant growth. Tiller numbers of plants from selected sowing dates at various times after 50% emergence are shown in Figure 7 (p. 22). The January to June sown plants all increased rapidly in tiller numbers between 100 and 200 days after the date of 50% seedling emergence. The plants from the July sowing onwards tillered much less.

When the maximum height of the plants was measured they were all more than 500mm tall with the exception of those from the last three sowing dates, October, November and December 1975 which were 435, 240 and 130mm tall respectively. The shoot dry weights of the plants on 29 June 1976 are shown in Figure 8 (p. 23). The January to June plants all weighed more than 300g, whereas plants from the July sowing onwards all weighed less than 150g.

Flowering and seed production. A large number of panicles was produced by all the early sown plants (Fig. 9, p.24). Thereafter there was a sharp drop in the number of panicles; from 759 per plant for the June sowing to 184 per plant for the July sowing. This decline continued throughout the later sowings with the October plants producing very few panicles. Only one of the November plants flowered and the December plants did not flower at all.

The mean time at which 50% of the panicles had emerged was during the first week in June for all plants with the exception of October and November sowings in which it did not occur until 13 and 15 June respectively. Likewise, the estimated mean time at which 50% anthesis occurred was between 10 and 14 June except for the October and November ones in which it was 23 and 29 June respectively.

In general the plants produced a large number of seeds, with a maximum of 240,000 seeds per plant from the March sowing. Very large numbers of seeds were produced by the January to June sown plants but the numbers declined from the July sowing onwards (Fig. 10, p. 25). The shape of this graph is similar to that of the number of panicles per plant (Fig. 9, p. 24) but, the July, August and September plants have more seeds per plant than might be

FIGURE 7

Tiller numbers present after 50% emergence of *H.lanatus* seed sown on a selection of the sowing dates.

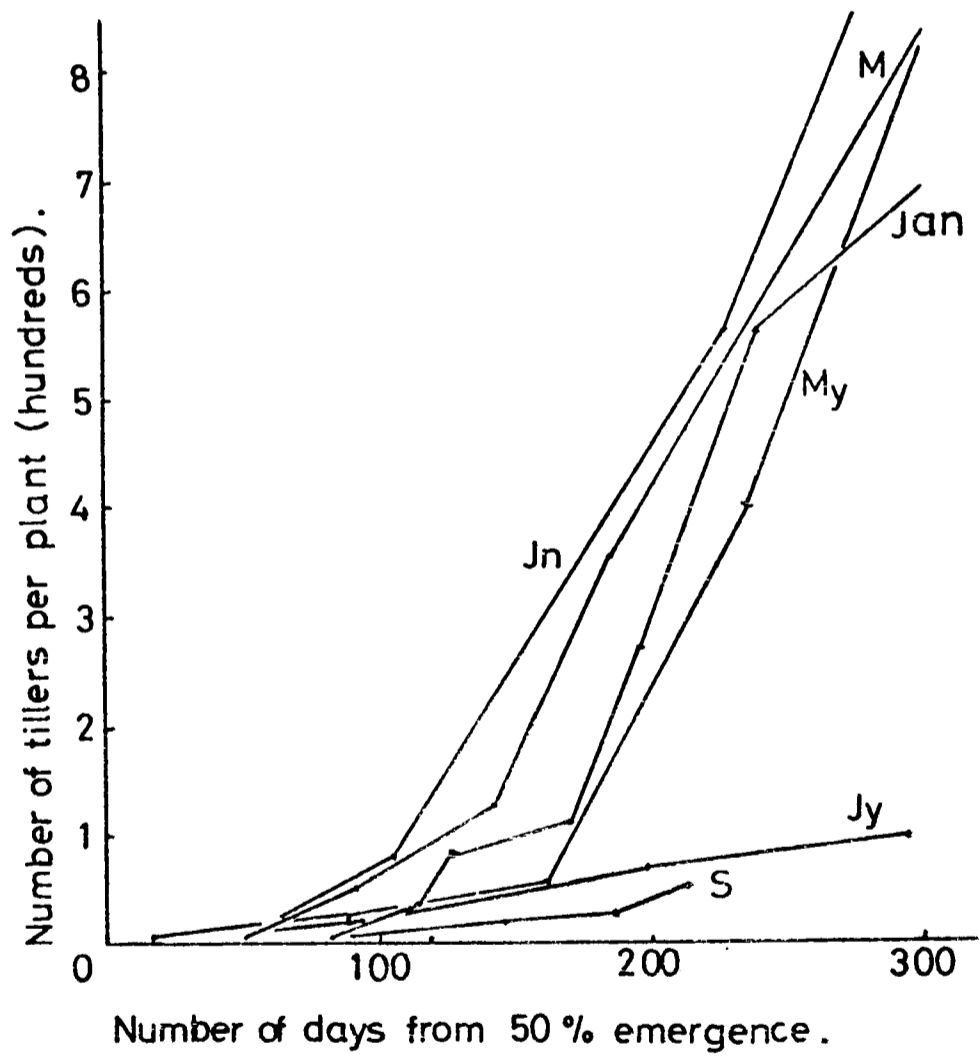


FIGURE 8
Shoot dry weight at harvest of monthly sowings of H.lanatus

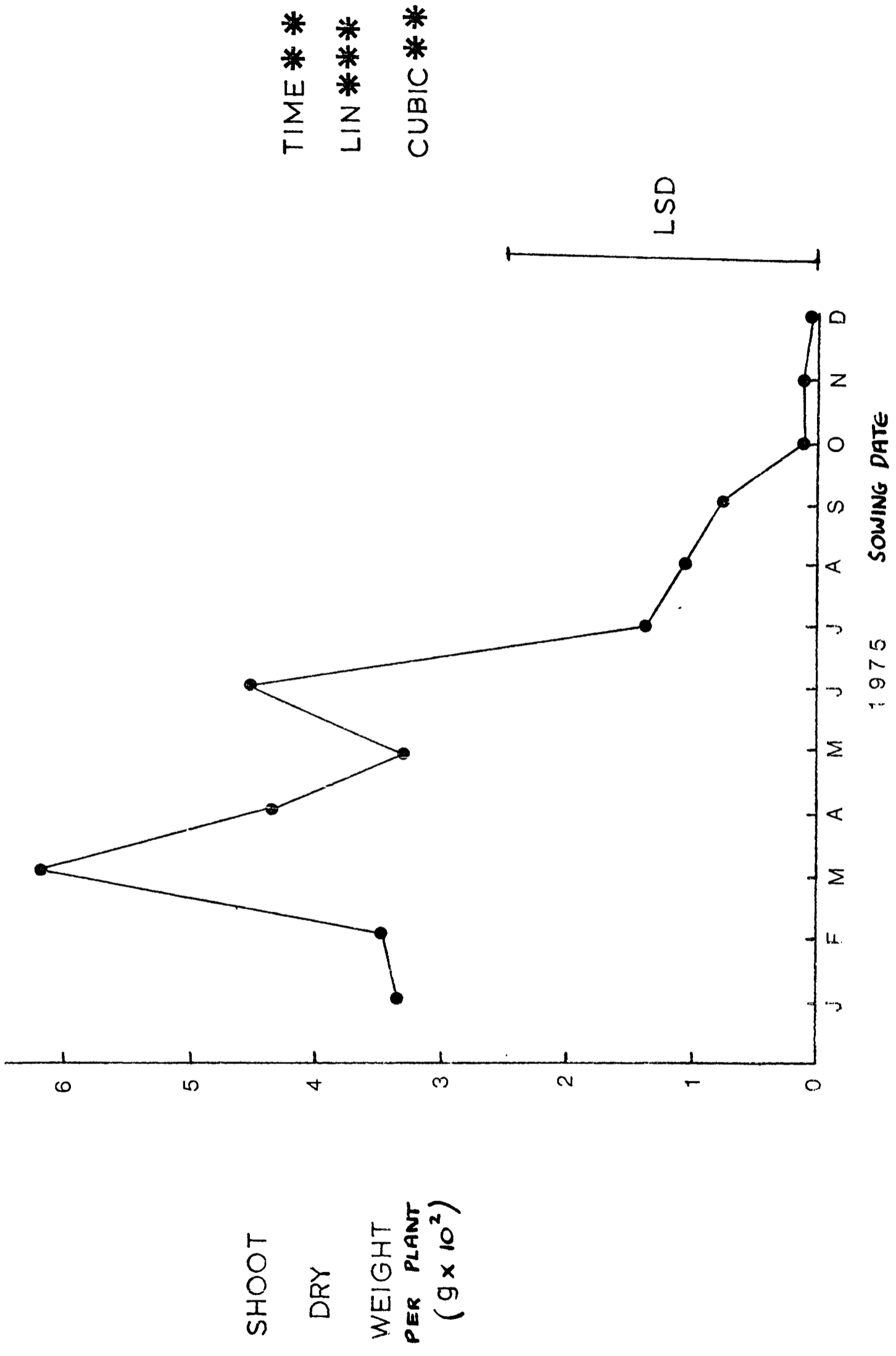


FIGURE 9

The number of panicles per plant on monthly sowings of H.lanatus

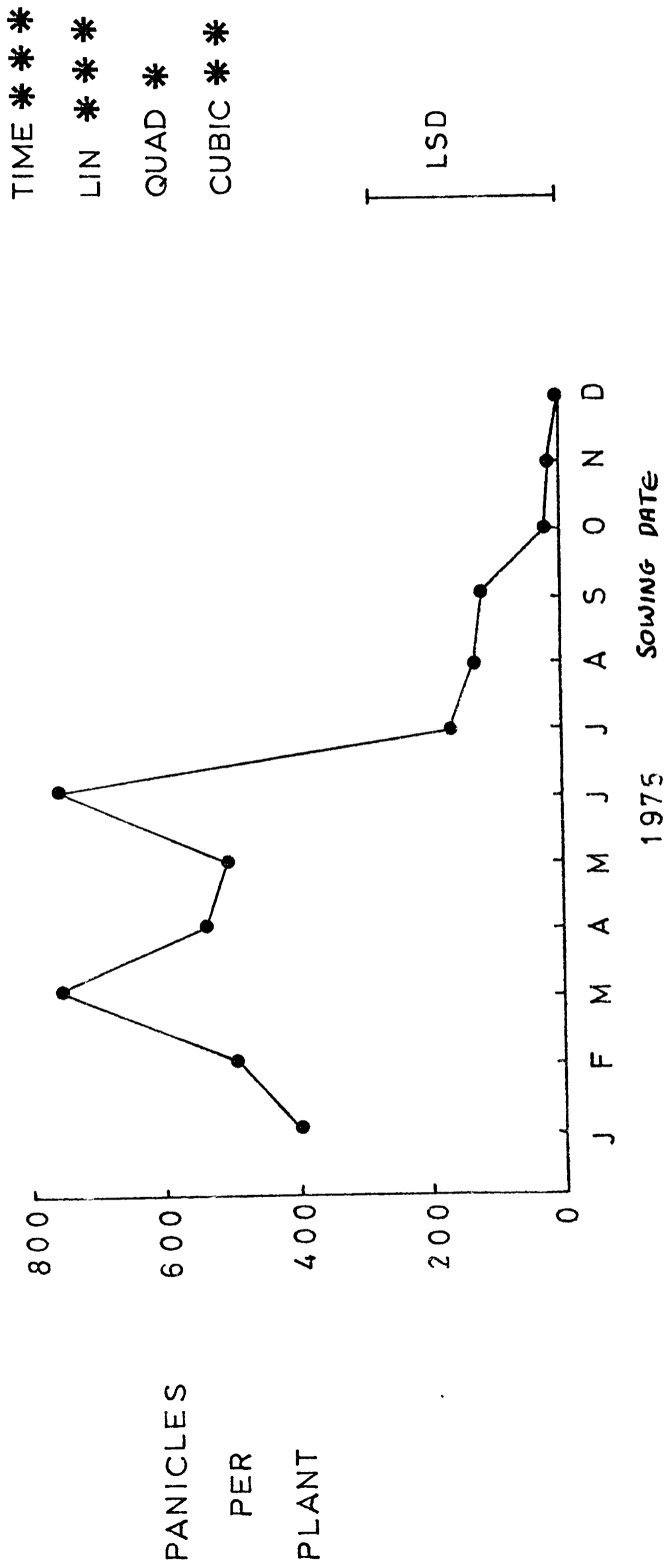
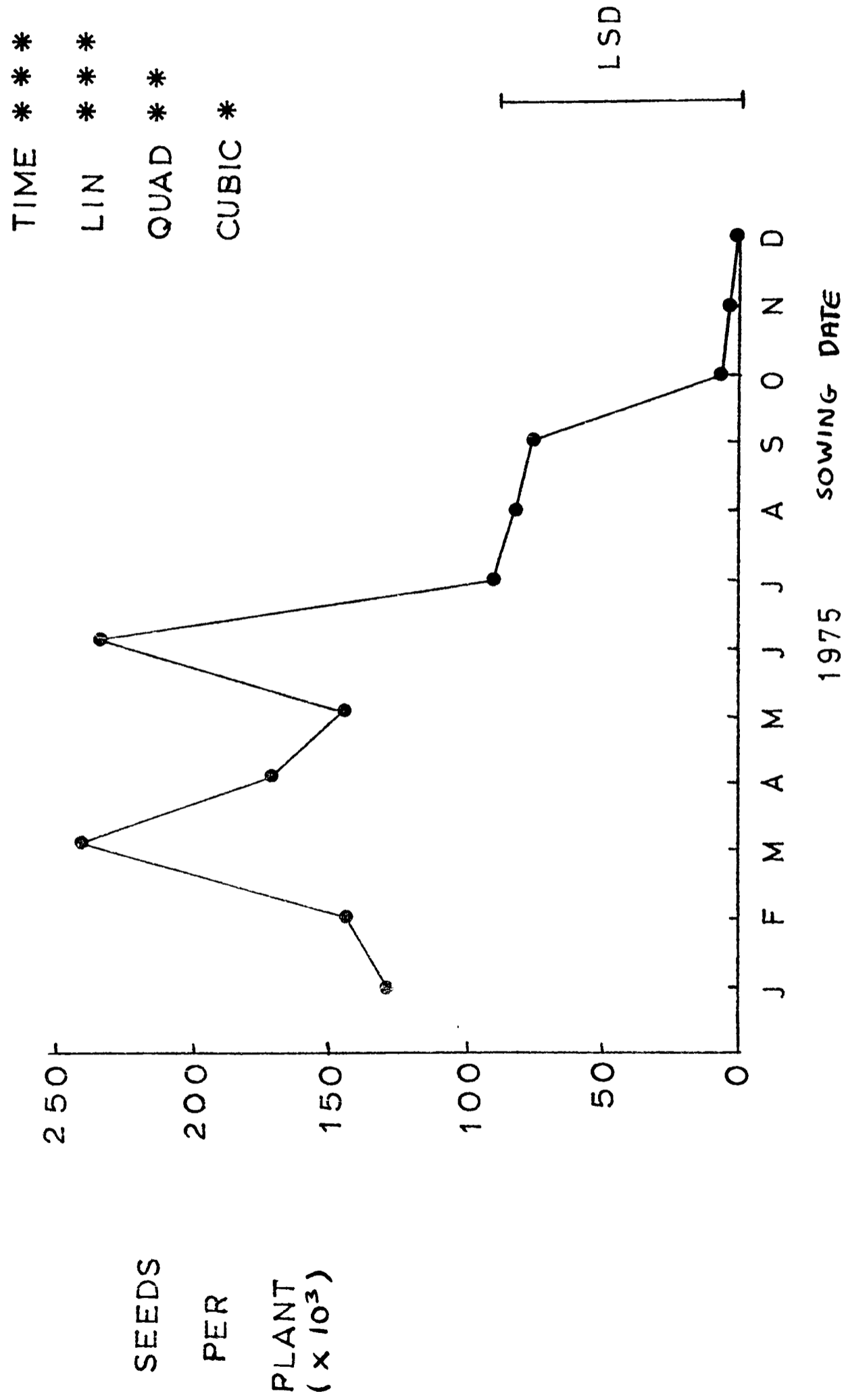


FIGURE 10

The number of seeds produced on H.lanatus plants from monthly sowings



expected from the number of panicles on the plants. This is because they have more seeds per panicle than the earlier sown plants (Fig. 11, p. 27). Even the relatively very small plants from the October and November sowings produced more than 2,000 seeds per plant.

TWO NON-DESTRUCTIVE METHODS

OF ASSESSING TILLER NUMBERS

The coefficients of determination (r^2) for these two linear regressions were 0.905 for the measurements and 0.819 for the infra-red photographs. The regressions are shown in Figures 12 and 13 (pp. 28 and 29).

GERMINATION OF H. LANATUS CARYOPSES

WITH LEMMAS AND PALEAS OF

DIFFERENT COLOURS

The distribution of the colours of lemma and palea within the spikelet samples is shown in Table 4 (p. 30). In Table 5 (p. 16) the number of caryopses within each colour class which did or did not germinate are given, together with the χ^2 expected values for each category if each colour class had the same germination percentage.

$$\chi^2 \text{ for the data} = 47.9$$

$$\text{From tables, } \chi^2 \text{ (p = 0.001) (2 d.f.)} = 13.8$$

Thus, caryopses of different colours differed in their germination percentage. The data shows that caryopses with a brown lemma + palea are more likely to germinate than those with a green lemma + palea. Caryopses with a pale lemma + palea were even less likely to germinate (Table 6, p. 16).

FIGURE 11

Number of seeds per panicle on monthly sowings of H. lanatus

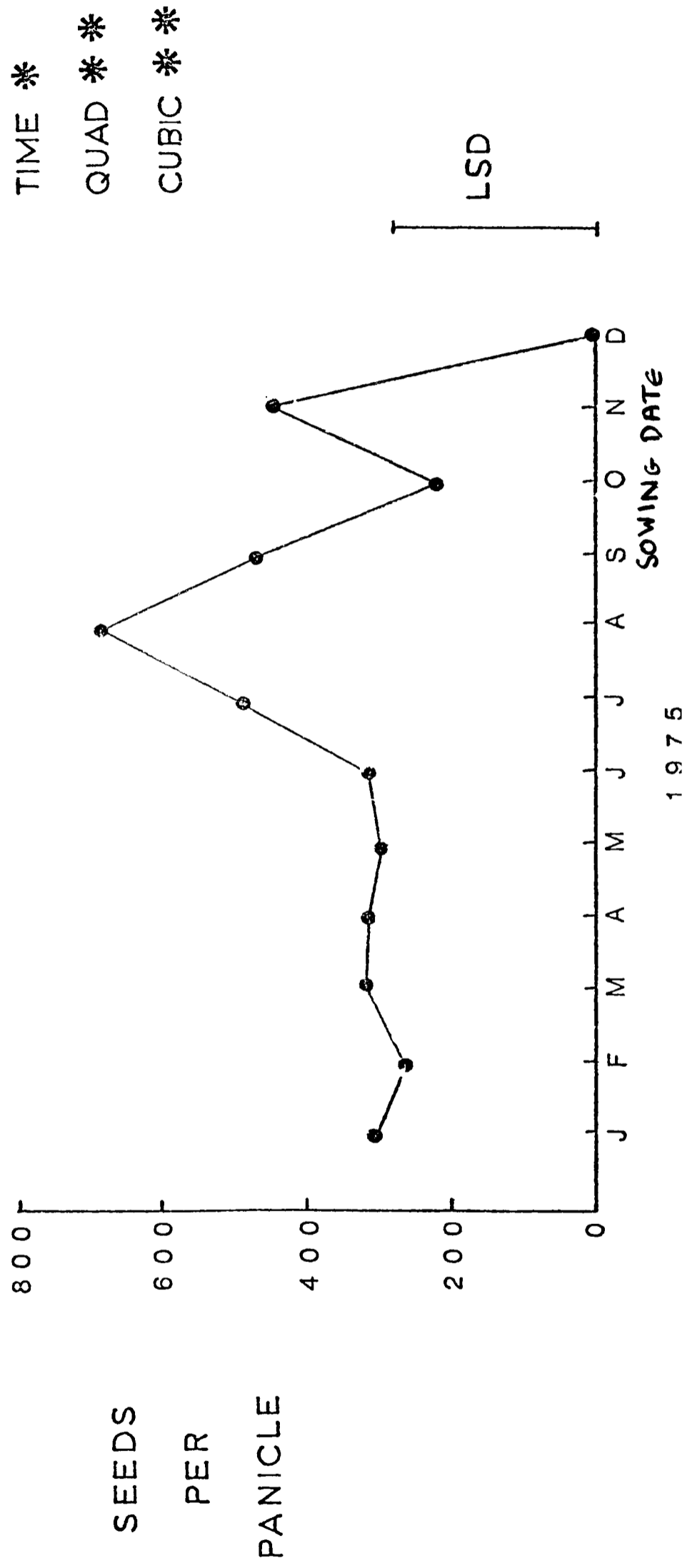


FIGURE 12

Linear regression of tiller numbers on plant area of H.lanatus (from infra-red photographs)

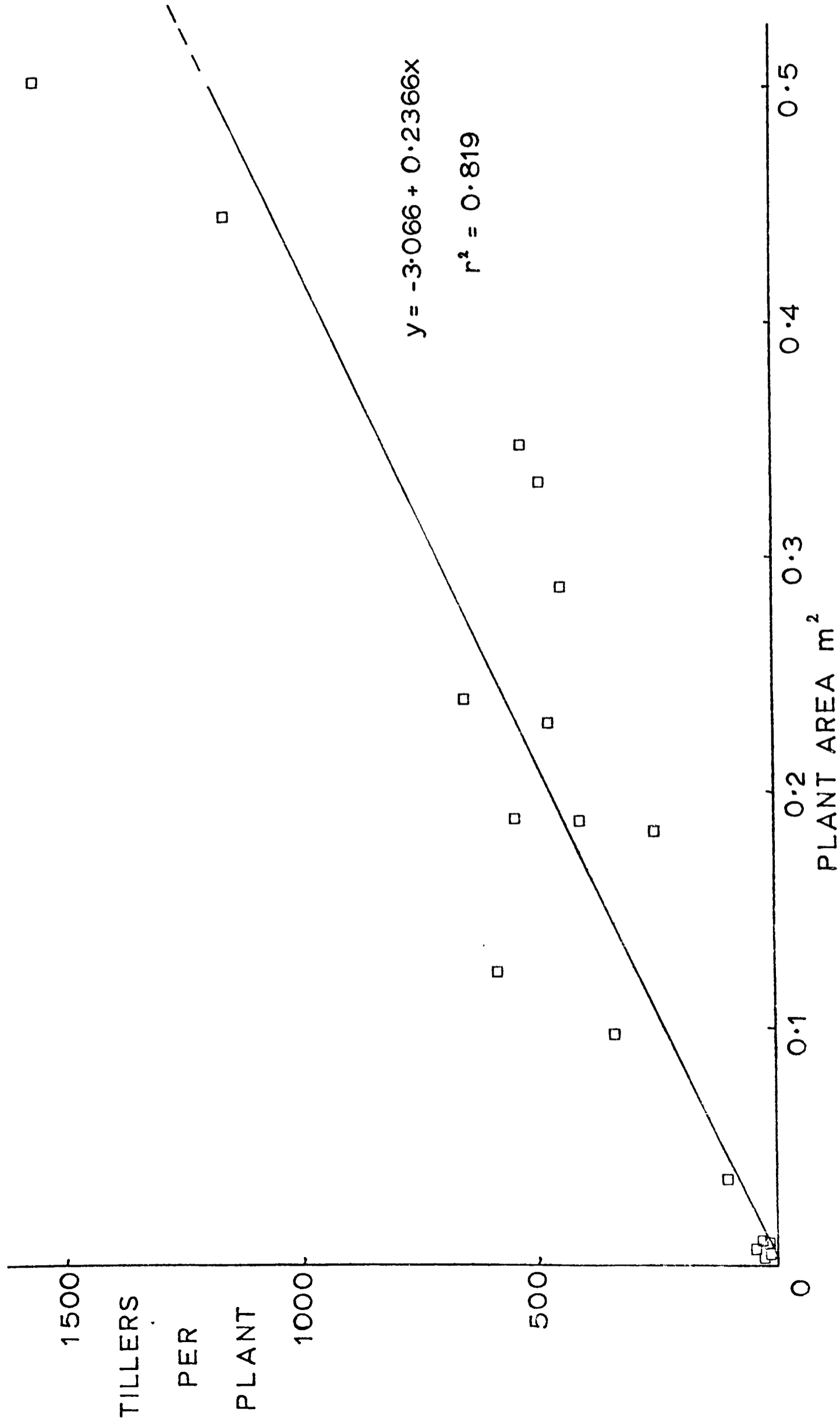


FIGURE 13

Linear regression of tiller numbers on length x breadth of H.lanatus plants

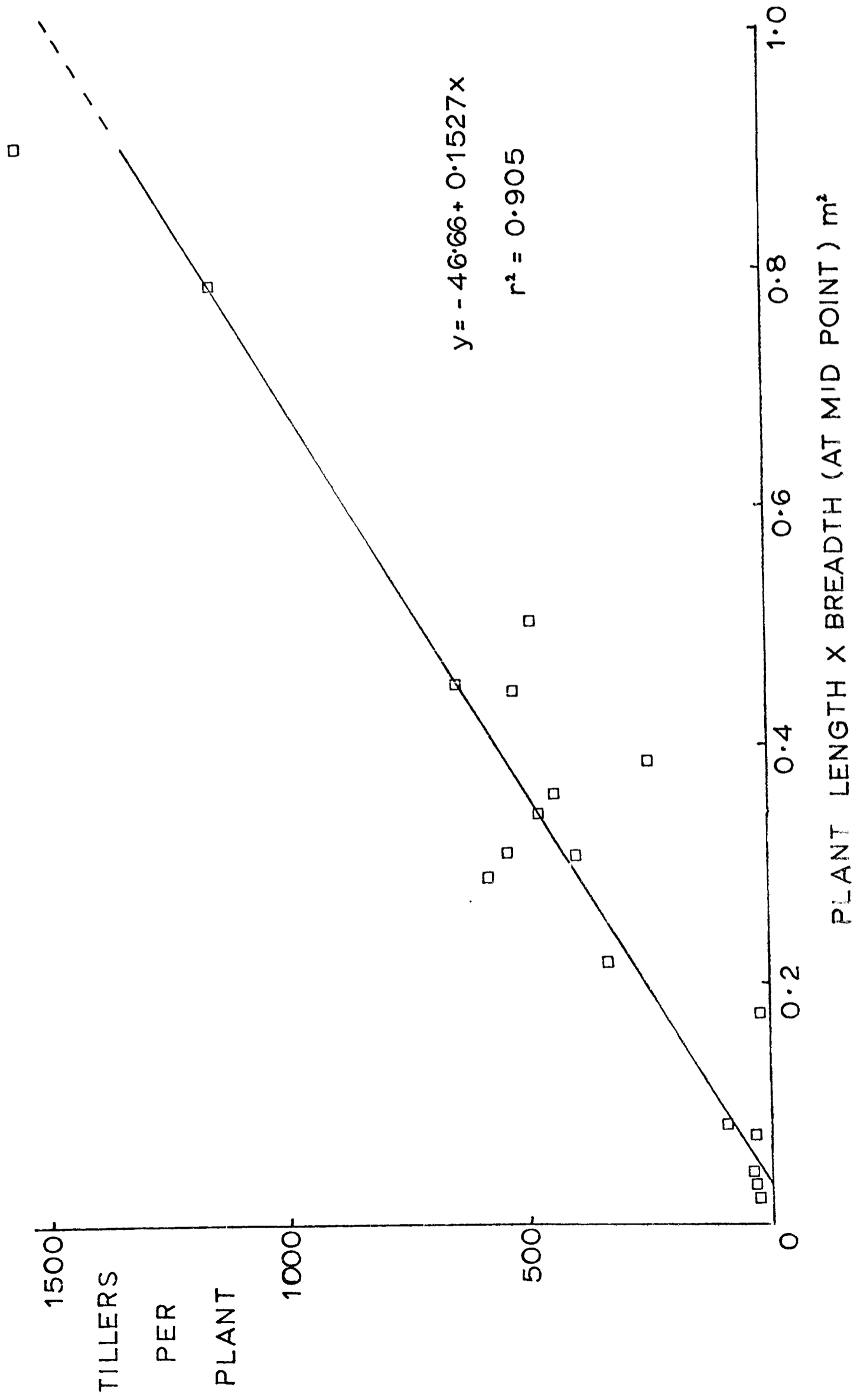


TABLE 3

The number of caryopses within each colour class which did or did not germinate. The figures in brackets are χ^2 expected values

GERMINATION CLASS	COLOUR OF LEMMA & PALEA			TOTAL
	BROWN	GREEN	PALE	
Germinated	125 (99.9)	18 (18.6)	38 (62.6)	181
Not germinated	25 (50.1)	10 (9.4)	56 (31.4)	91
Total	150	28	94	272

TABLE 4

The mean germination percentages of the 4 types of caryopses

CLASS	GERMINATION %	
No caryopsis	0	
Lemma + Palea	Pale	40.4
	Green	64.2
	Brown	83.3

THE ATTACHMENT OF H. LANATUS

SPIKELETS TO COTTON

WITH ARALDITE

Twenty seven days after sowing, the mean germination of the seeds on the cotton was 50% whereas for the unattached seeds it was only 26.5%. This was a statistically significant difference ($p = 0.05$). Thus, attaching H. lanatus spikelets to cotton increased their chance of germination.

TESTING OF H. LANATUS

FOR DORMANCY

The graphs of monthly seedling emergence for the three sowings are shown in Figure 14 (p. 32). Most of the seeds germinated within six weeks of sowing. However, in all cases, a few seedlings emerged during the subsequent year.

ESTABLISHMENT OF H. LANATUS

SEEDLINGS IN A SWARD

Only one H. lanatus seedling was found from within the experiment and none from outside it during the autumn sampling. None were found in either area from the spring sampling. If all the viable seeds spread on the area had established as seedlings by the autumn, a total of 540 seedlings might have been expected to be present within the area sampled by soil cores.

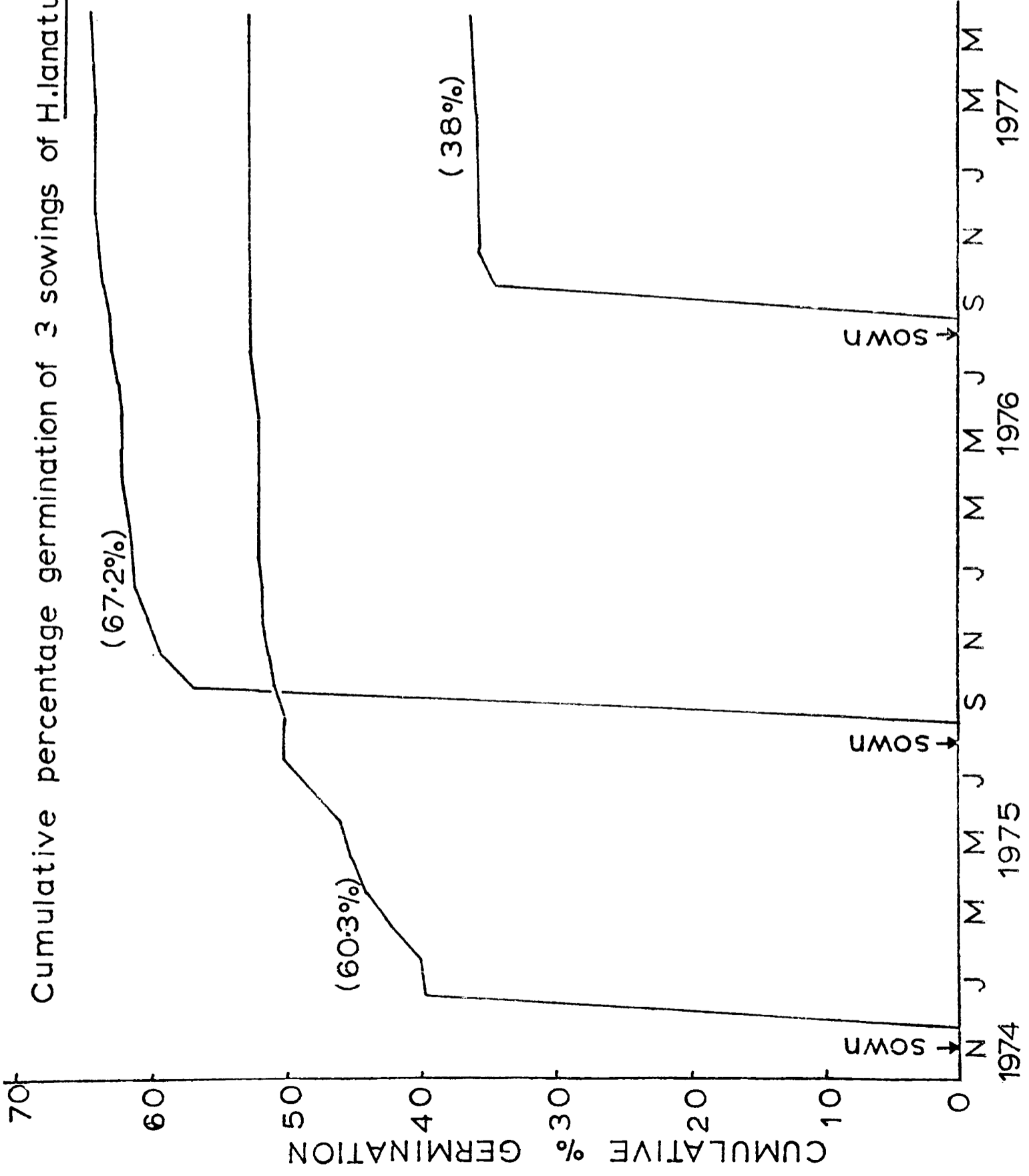
DISCUSSION

MONTHLY SOWINGS OF H. LANATUS

Germination and emergence. The very hot, dry summer of 1975 and the very mild winter of 1975/6 must be taken into account when considering these results. May and June were unusually dry (Table 1, p. 12). Few seedlings emerged from sowings during these months. As the viability of the seeds was about the same for all sowings, either many seedlings died between

FIGURE 14

Cumulative percentage germination of 3 sowings of H.lanatus spikelets



Figures in brackets are the % germinations of the 3 samples in the laboratory

germination and emergence or they were in a state of INDUCED dormancy. Air temperatures were high in June, July and August and what little rain there was evaporated quickly and plants wilted. Many April sown seedlings died when they had only just emerged or had only one or two leaves. Both the May and June sowings emerged in two batches, the second batch in each case coinciding with rainfall after a dry period. The relatively mild weather in January 1976 allowed the November and December sowings to emerge rapidly.

With the exception of the summer months, during which seedling emergence was slow, H. lanatus seedlings emerged rapidly. This is consistent with the seed being mainly non-dormant. Mortimer (1974) found a peak in seedling numbers in early September from H. lanatus seed sown at the natural time in summer. This experiment, however shows a peak in seedling numbers in late September - early October for summer sowings. The exact time of the peak may depend on the amount and timing of autumn rain.

Plant growth. June plants had many more tillers than July plants at comparable intervals after 50% seedling emergence (Fig. 7, p. 22). In order to begin tillering a grass must have reached a certain stage of growth. After that, the degree to which it tillers depends to a large extent on environmental conditions. The June sowing reached 50% seedling emergence on 10 July whereas the July sowing did not reach this level until 14 September. At the thinning on September 11, the July sown plants which had emerged were only just beginning to tiller whereas the June sown plants already had eleven tillers. This difference in plant growth stage in early autumn was probably very important in determining the absolute increase in tiller numbers in both groups of plants over the winter. By February 20, 1976, the June plants had 500 tillers compared to the July plants 60 tillers. This large difference between the June and July sowings was also reflected in both plant dry weight on 29 June 1976 and in panicle numbers.

Flowering and seed production. The larger number of tillers formed during the autumn and winter by the June plants compared with the July plants meant that a much larger number of tillers on the June plants were formed in time to be vernalized in the winter and were therefore able to flower in the following summer. Mortimer (1974) found that H. lanatus shed seed from June to September with a peak during the first two weeks of July. In a dry summer like 1975, the seed shed before mid-June would have been at a great advantage, in terms of subsequent plant growth, over the later shed seed.

The fact that neither of the two December plants and only one of the November plants flowered confirms the statement of Evans (1964) that H. lanatus plants need to undergo a period of vernalization as vegetative plants before they can flower. He found no record of any effect of day length on the flowering of H. lanatus. Böcher and Larson (1958) collected H. lanatus seed from all over Europe and sowed it indoors in spring, transplanting the seedlings outside in June. They found that plants from southern Europe flowered in the first year without 'reinforcement' (a long vegetative period before wintering) and before wintering. Plants from northern Europe only flowered in the second year and required 'reinforcement' and overwintering.

Plants from the July, August and September sowings in this experiment produced a larger number of seeds per panicle than plants from the earlier sowings. This indicates that the vernalized tillers on these plants grew well in 1976 and were able to compensate, to some extent, for their low numbers by producing more seeds per panicle. Thus, the direct effect of sowing at different times was on total tiller numbers and numbers of vernalized tillers rather than on seed numbers per plant. The November and December plants were very small and produced little or no seed. But, if they were kept free from competition they would probably produce a large amount of seed in summer 1977. The times of 50% panicle emergence and

anthesis were approximately the same for all the plants which flowered except the October and November sowings in which they were delayed by about a week. Thus, there is a gradient in the plants from the various sowing dates from those which flowered at the normal time, through those which flowered late to those which did not flower at all.

The number of seeds produced by plants from the late summer - early autumn sowings was very large. If there was one H. lanatus plant per square metre in a sward and each plant produced about 100,000 seeds a year, of which 60% were viable, 600 million viable seeds would be shed over a hectare in one year. These figures are based on spaced plants however and would be lower for plants in the competitive situation of a sward.

Estimates of the number of viable H. lanatus seeds per hectare present beneath old hill swards to a depth of 180mm have ranged mainly between two and ten million (Chippindale and Milton, 1934; Milton, 1943; Milton, 1948) but were as low as 0.7 million beneath an eight-year-old lowland sward (Douglas, 1965). Mortimer (1974) has worked out a relevant seed population flux diagram. He has shown that the seeds are very vulnerable both when they are on the soil surface and when they become part of the buried seed bank.

These results show that a large percentage of H. lanatus seeds are either non-dormant or have a very short dormancy. However, the potential number of seeds which a plant can produce is so large that even a 1% level of innate or enforced dormancy would result in a large amount of buried viable seed. Dormant H. lanatus seeds may be brought to near the soil surface by moles and worms so that, potentially, they may germinate at any time of year. This has been shown by Jalloq (1975) who found a few H. lanatus seedlings germinating from seeds brought up in mole hill soil and McRill (1974) found a mean of 158.2 seedlings germinated per 100g of worm cast soil removed from a permanent sward in February and kept moist for one year.

TWO NON-DESTRUCTIVE METHODS OF ASSESSING TILLER NUMBERS

The measurements of the length and breadth of these plants provided a more accurate method of estimating their tiller numbers than did infra-red photographs. The method also has the advantage of being quicker and cheaper.

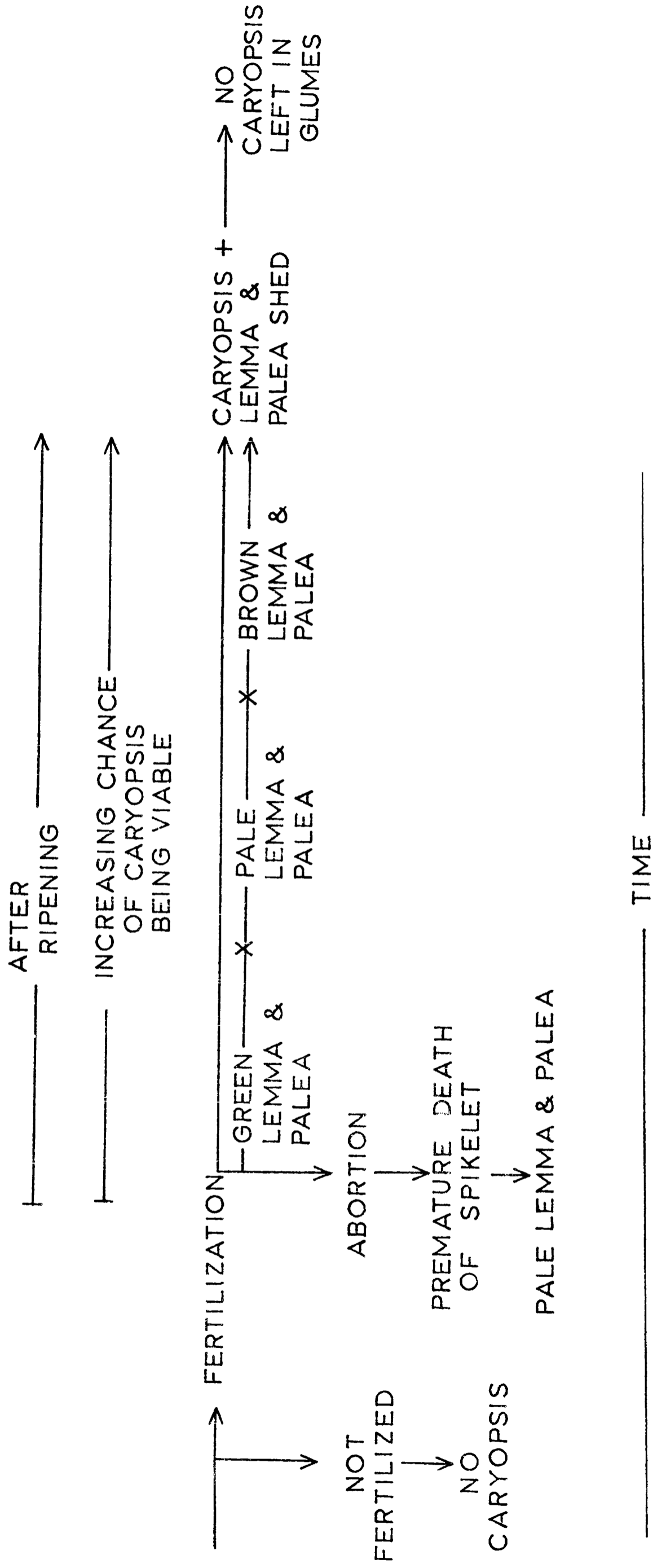
However, a major problem is that the regression is only useful for a short time as it is only reliable for a certain range of plant size. Two months after the regression had been established many plants had become too large for their tiller numbers to be estimated from it. Other plants were still too small and so their tiller numbers tended to be overestimated by the equation (Table 2, p. 15). Thus, further regressions need to be established at different times of the year. In this case there are so few plants that it would be necessary to count the tillers on most of them just to establish the new regression. A possible compromise would be to estimate tiller number by counting only the tillers of a random quadrant of each plant.

GERMINATION OF H. LANATUS CARYOPSES WITH LEMMAS AND PALEAS OF DIFFERENT COLOURS

A possible scheme to explain the differences in germination between caryopses with lemmas and paleas of different colours is given in Figure 15 (p. 37). Spikelets which do not contain a caryopsis may occur either because there has been no fertilization or because the caryopsis, together with its lemma and palea has been dislodged from the glumes. However, the entire spikelet is the normal form of seed dispersal (Mortimer, 1974).

It would seem reasonable to suppose that the colour of the lemma plus palea changes from green, through green/brown to brown as the caryopsis ripens. Such a colour change would be accompanied by an increase in the potential germination percentage of the caryopsis. Bittera and Gruber

FIGURE 15
 A possible scheme to explain the differences in viability between caryopses
 with lemmas & paleas of different colours



(1937) found that H. lanatus caryopses reached maximum viability 20 days after anthesis.

Most of the caryopses assigned to the 'pale' category were flattened. Possibly the caryopses had ceased to develop for some reason, e.g. competition for limited resources or attack by an heteropteran, resulting in the premature death and discolouration of the spikelet. The caryopses assigned to the 'pale' category which did germinate were plumper and may have been intermediate in maturity between the 'green' and 'brown' groups.

It is possible that the 'green' group of caryopses may have had more innate dormancy than the 'brown' group. If this was so, there is no evidence of the dormancy decreasing while the spikelets were stored in the laboratory, for the mean germination of the seed in December 1975 was still only 62%.

Hart (1961), noted the effect of various treatments on the germination of one-year-old H. lanatus seed. He found that removing the glumes from the spikelets significantly decreased their germination from 87% to 76%. He ascribed this to the embryo being injured by the removal of the glumes rather than to the presence of any germination promoting substance in the glumes. Brief exposure to infra-red light had no significant effect on germination. However, both pre-chilling for 139 hours at 5°C and germinating the seeds in 0.2% potassium nitrate solution significantly increased the germination of the seeds from 79% to 84% (Hart, 1961).

The small amount of dormancy, which these results suggest is present in H. lanatus, when combined with the large numbers of seeds which the species can produce (Watt, 1976), could account for the presence of considerable numbers of viable H. lanatus seeds in the soil (Milton, 1948).

THE ATTACHMENT OF H. LANATUS

SPIKELETS TO COTTON

WITH ARALDITE

When the seeds were watered, using a rose sprinkler, some of the ones which were not attached to the threads often moved sideways out of their original position, whereas, the ones attached to the cotton could not move. The seeds on the cotton had a greater chance of being in continuous contact with moist soil and, hence, of being able to germinate. This technique therefore, was not used in the growth study experiment.

Under natural conditions in the field the soil surface is likely to be much rougher than in these seed trays. Seeds would tend to fall into a depression and not be dislodged from it by rain or wind. Mortimer (1974) placed marked H. lanatus seeds on the surface of soil plots ranging from fine sand to coarse lumps. The smoother the soil surface, the further the seeds moved each day.

TESTING OF H. LANATUS

FOR DORMANCY

The 1975 and 1976 sowings were of freshly-shed seed and therefore more relevant to field conditions than the 1974 sowing of stored seed. Over 86% of the viable seed sown in boxes outside in 1975 and 1976 germinated within six weeks. During the subsequent twenty months another 8% of the seed sown in soil in 1975 germinated. In the case of the seed sown in 1976, a further 2% germinated during the subsequent eight months.

Thus, although most viable H. lanatus seed will germinate in the autumn in which it is shed, there is evidence of some enforced and/or induced dormancy. This supports the findings of Hart (1961) and Mortimer (1974).

ESTABLISHMENT OF H. LANATUS

SEEDLINGS IN A SWARD

Hart and McGuire (1964) sowed H. lanatus seeds into regularly cut swards in July. They found that when the swards were cut at 100mm above the ground, instead of 50mm, there were far fewer H. lanatus seedlings present the following spring. However, such results refer only to cut swards whereas the experiment described here was in a sward grazed by cattle in the autumn. The very low establishment of H. lanatus from seed may, however, have been due to severe competition from established species during late autumn, winter and spring when the crop was left to grow for silage.

It would be interesting to compare the establishment of H. lanatus from seed in swards under other types of management. Set stocking, paddock grazing and hay, with and without artificial bare patches in the sward would perhaps be of greatest interest.

COMPARISON OF THE GROWTH

OF ~~ev~~ MASSEY BASYN AND

OXFORDSHIRE H. LANATUS

Massey Basyn is a cultivar of H. lanatus, bred in New Zealand to increase the productivity of hill land (Munro, 1961; Jacques, 1974; Jacques et al., 1974). It has yielded similar dry weights as Ruanui, Manawa and Ariki ryegrasses and lambs grazing it have made the same liveweight gains as those on Ruanui ryegrass (Watkin and Robinson, 1974) although they weighed less at birth.

During 1975 and 1976, twelve plants of Massey Basyn and twelve of 'local' H. lanatus were grown outside in pots with adequate water and nutrients, in four blocks. The growth of these plants was measured as shown in Appendix 5 (p.249). The results are given in Appendix 6 (p.250). Massey Basyn plants were taller, had wider leaves, heavier panicles and

spikelets and a greater shoot fresh weight than indigenous H. lanatus plants. They also began to flower a few days earlier. Whether such differences would be of significance in animal production can only be discovered by field experimentation.

CONCLUSIONS

- Spaced plants of H. lanatus can produce large numbers of seeds - up to 240,000.
- Seeds of H. lanatus can germinate throughout the year but those establishing early rather than late in a dry summer produce far more seed the next year.
- Between 65% and 89% of viable H. lanatus seeds germinate within a few weeks of falling onto bare, moist soil.
- Unlike L. perenne, enough H. lanatus seeds are dormant to provide a reservoir of buried viable seed under a sward.
- Holcus lanatus seedlings cannot establish well in a tall sward.
- A vegetative H. lanatus plant needs to be vernalized in order to flower.
- Tiller numbers of H. lanatus plants with more than a few hundred tillers can be quite well estimated by a regression on plant length x breadth.
- Caryopses of H. lanatus with lemmas and paleas of different colours have different ^{PERCENTAGES} \wedge of germination.
- If H. lanatus spikelets are stuck onto cotton stretched over the soil surface they germinate better than unattached spikelets.
- Massey Basyn plants were taller with wider leaves, heavier panicles and spikelets and a greater shoot fresh weight than 'local' (Oxfordshire) H. lanatus.

CHAPTER 3

SPREAD OF H. LANATUS

BY RUNNERS

INTRODUCTION

Holcus lanatus spreads vegetatively in a sward by runners (Figs. 16, p.43 , and 17, p.44). An experiment was designed to find out at what time of year they are produced and how cutting back a plant regularly or removing the apex of runners affects their growth and hence the spread of the plant.

METHOD AND MATERIALS

The plants used in this experiment were established from seed in the field during 1975 as part of the Growth Study experiment (Chapter 2, p. 8). All the plants were cut to ground level on 29 June 1976 and regrew during the summer and early autumn. On 8 November, all except nine plants, arranged in three blocks of three and of similar size, were removed from the site. The plants were allowed to grow on during the winter.

On 2 March 1977, five runners were selected at random on each plant and marked with plastic rings. The plants in each block were allocated at random to one of three treatments:

- 1 Uncut plants
- 2 Plants cut, apices of runners NOT REMOVED
- 3 Plants and apices of runners REMOVED

The removal of runner apices in treatment 3 took place on 3 March. The cutting back of plants to about 50mm from the ground took place on

FIGURE 16
Diagram of H. lanatus runner in November, 1976

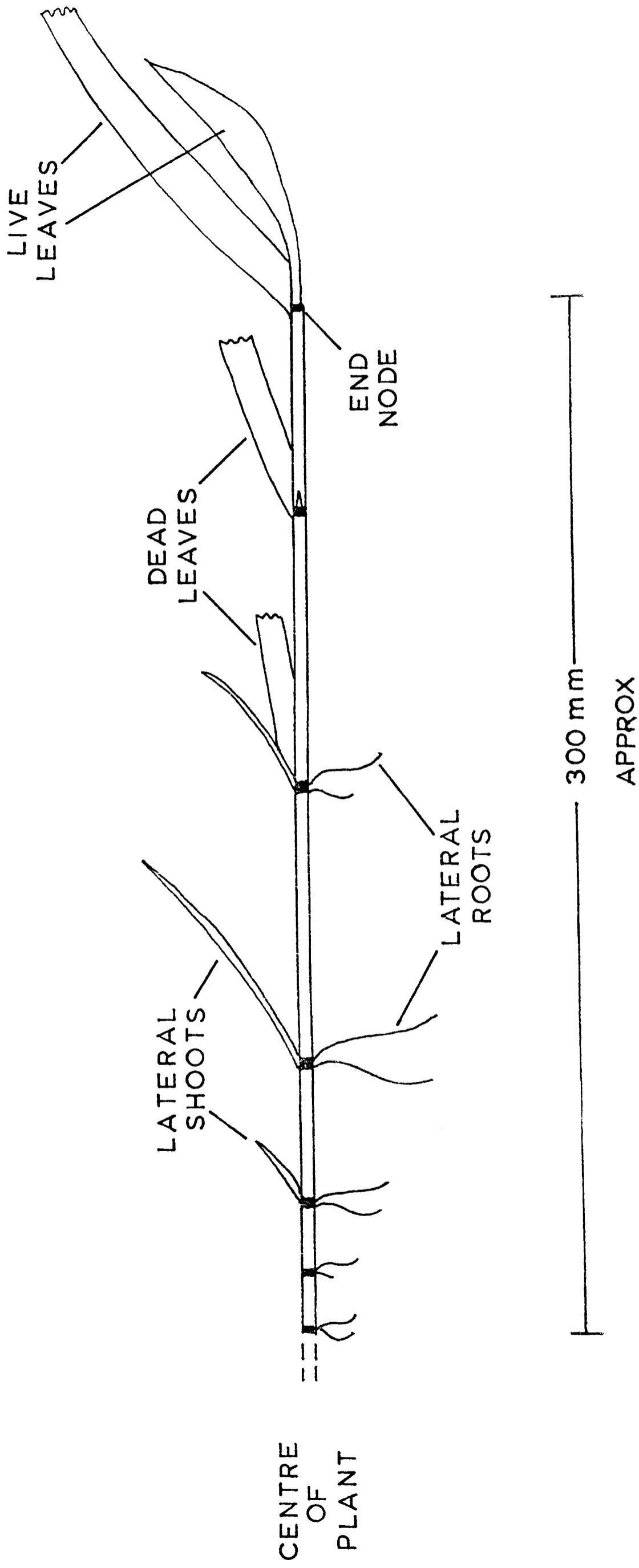


FIGURE 17

A runner of H. lanatus,
November, 1976.



3 March, 4 April, 27 April and 31 May. Shoots growing from marked runners were not cut. The plants were measured on 2 March, 18 May and 12 July.

The measurements were:-

- 1 Number of live nodes (those with shoots and/or roots) per runner
- 2 Number of live shoots per runner
- 3 Length of each live shoot FROM NODE TO LONGEST LEAF OR FLOWER TIP
- 4 Total length of runner

RESULTS

There was no significant difference between the treatments in the length of the live marked runners at any of the assessment dates (Table 7, p. 46).

Plants which were cut monthly but the tips of whose runners were uncut had significantly more live nodes per runner than plants under the other two treatments (Fig. 18A, p.47). The number of live nodes present on the runners of plants under all treatments declined significantly between May and July (Fig. 18B, p.47).

The figures for the number of live shoots per runner (Fig. 19, p. 48) and the total length of these shoots per runner (Fig. 20, p. 49) followed a similar pattern. Both were least on uncut plants and most on cut plants whose runners were uncut with the other treatment intermediate. Also, both increased with time (Figs. 19B, p.48 and 20B, p.49).

On the other hand, the mean shoot length was greatest in uncut plants (Fig. 21A, p.50) with the other two treatments having shorter shoots. The mean shoot length increased with time (Fig. 21B, p. 50).

DISCUSSION

The fact that the runners did not increase in length during the spring shows that they grew to their full length between June and winter in the previous year. This indicates that H. lanatus probably behaves in a similar

TABLE 7

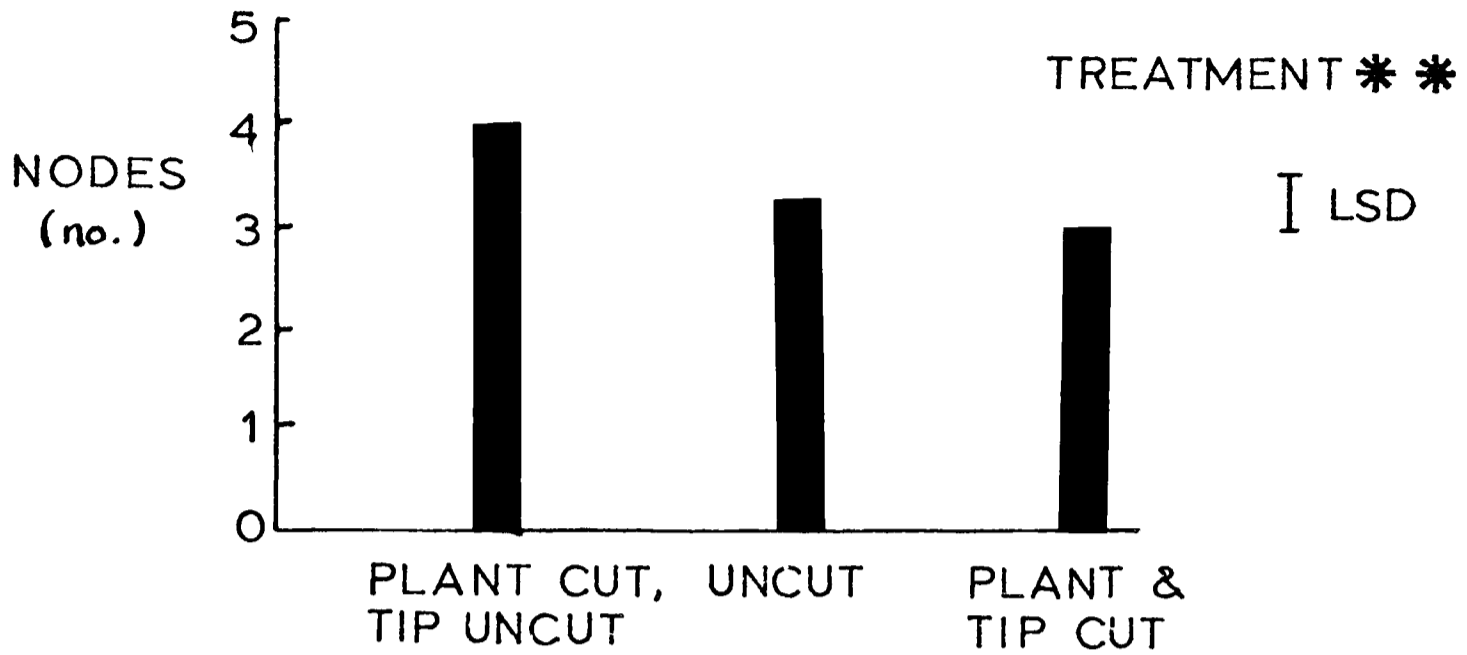
Length of live marked runners on
H. lanatus plants under 3 cutting treatments
 (Figures are means of 3 assessment dates)

TREATMENT	LENGTH OF RUNNER mm
Uncut	89.3
Plant cut, tip uncut	112.2 NSD
Plant and tip out	102.7

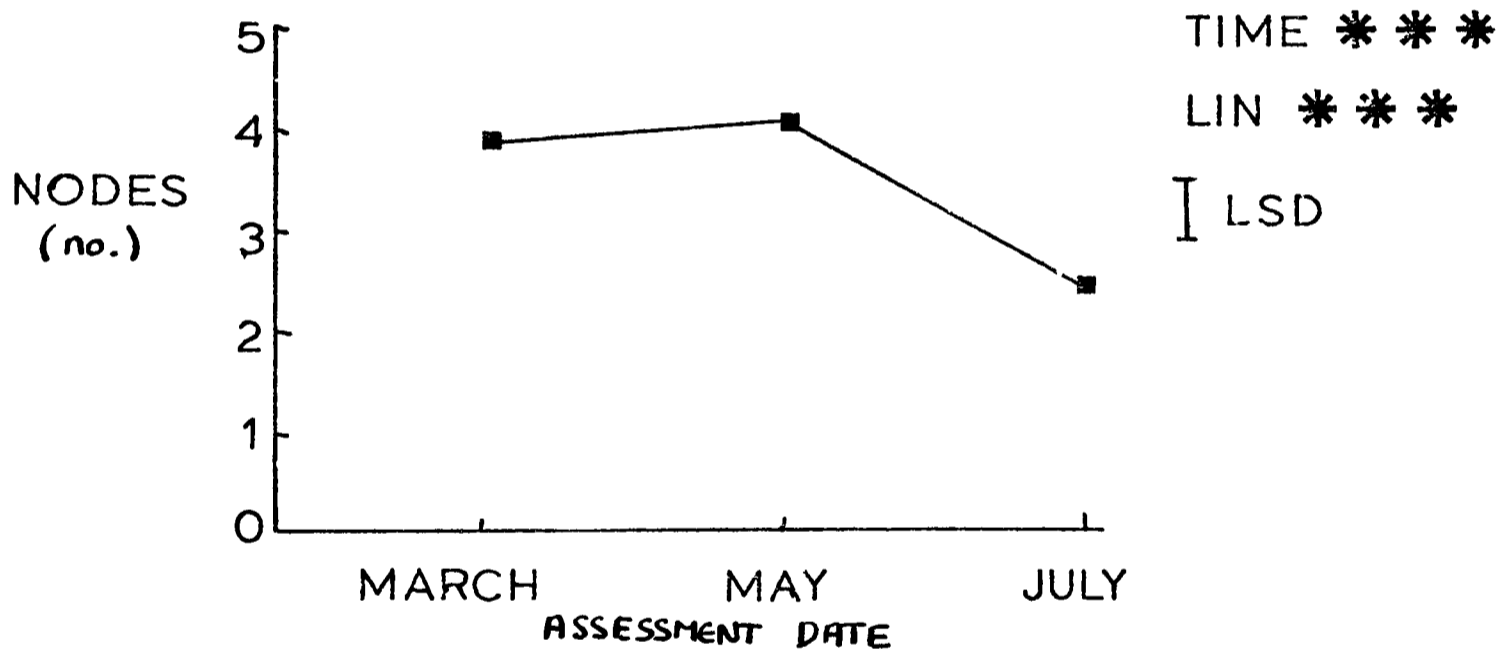
FIGURE 18

The number of live nodes per runner of H.lanatus

A. Under 3 cutting treatments (mean of 3 assessment dates)

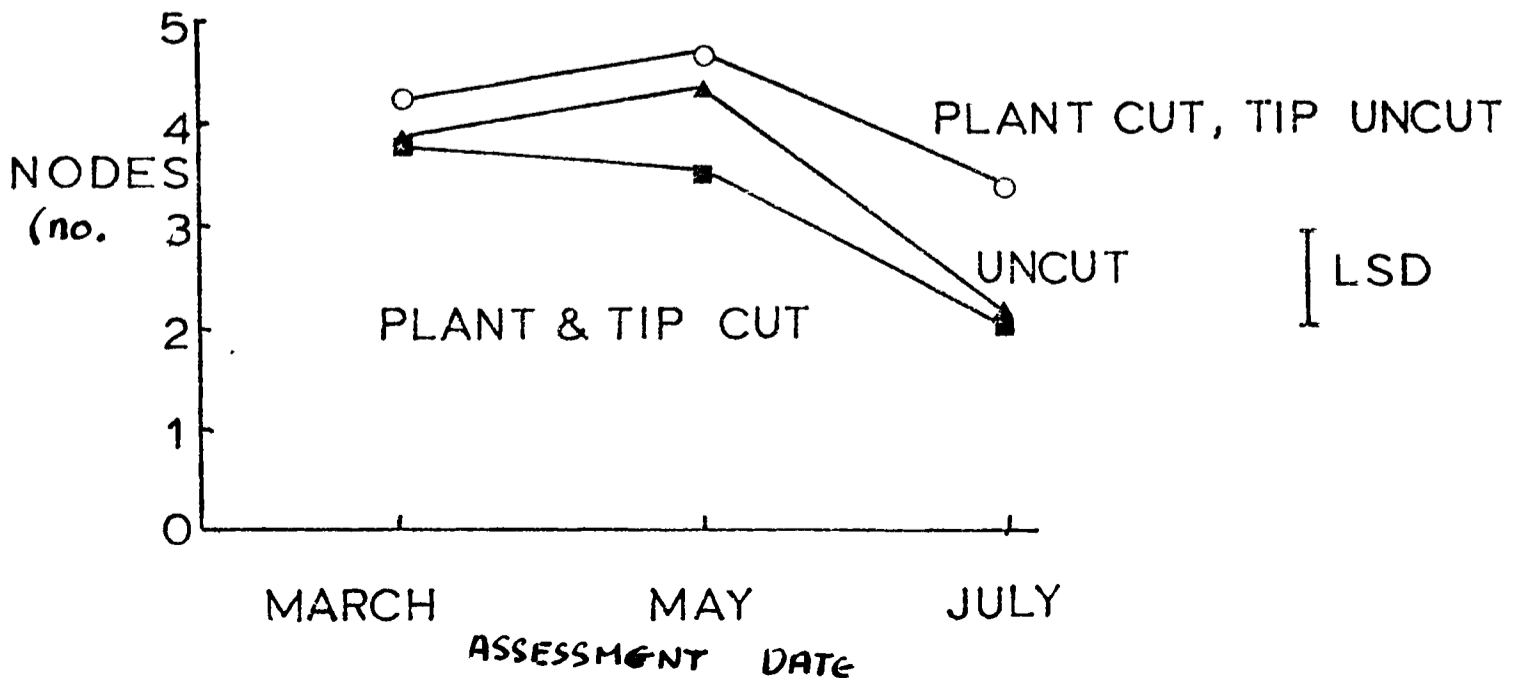


B. On 3 assessment dates (mean of 3 cutting treatments)



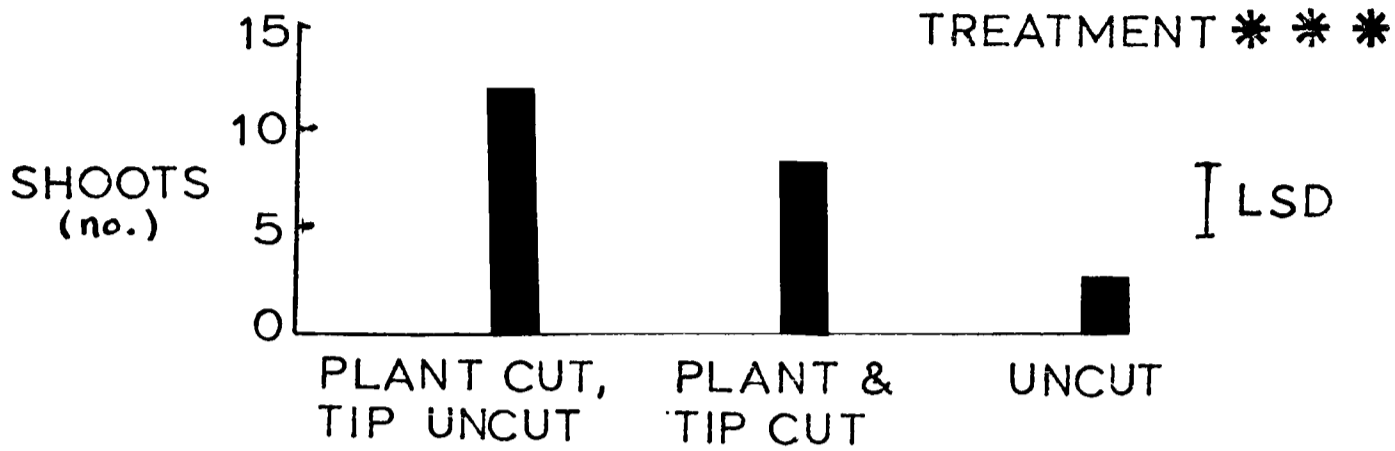
C. Interaction of 3 cutting treatments & 3 assessment dates

TREATMENT X TIME NS

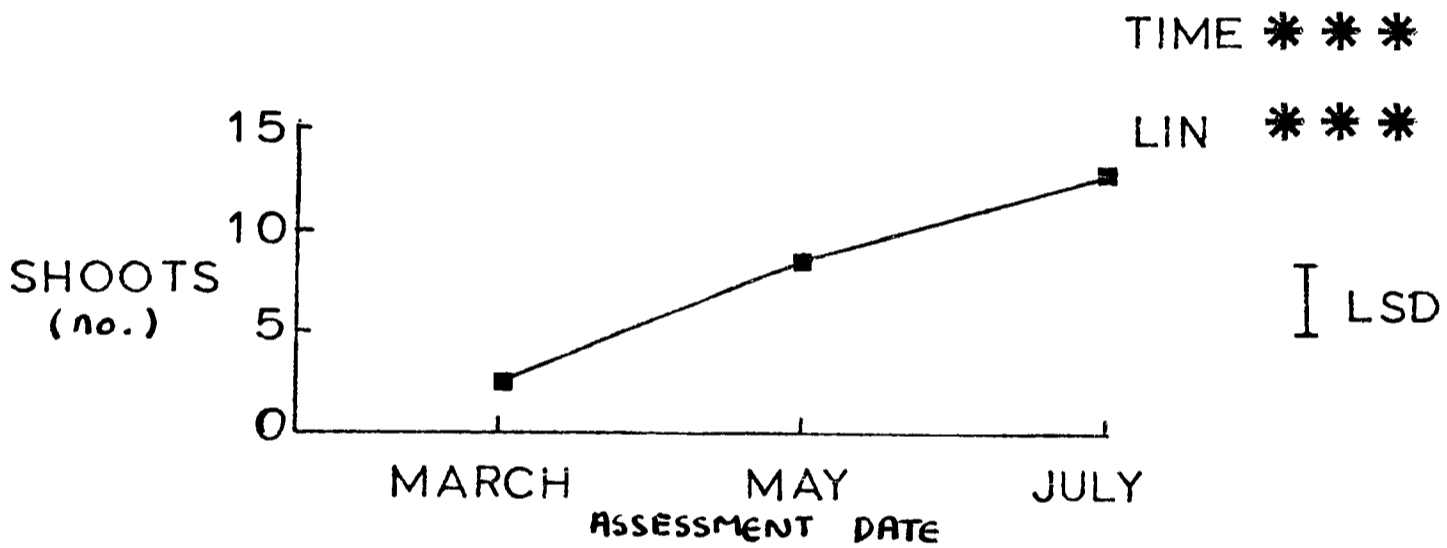


The number of live shoots per runner of H.lanatus

A. Under 3 cutting treatments (mean of 3 assessment dates)



B. On 3 assessment dates (mean of 3 cutting treatments)



C. Interaction of 3 cutting treatments & 3 assessment dates

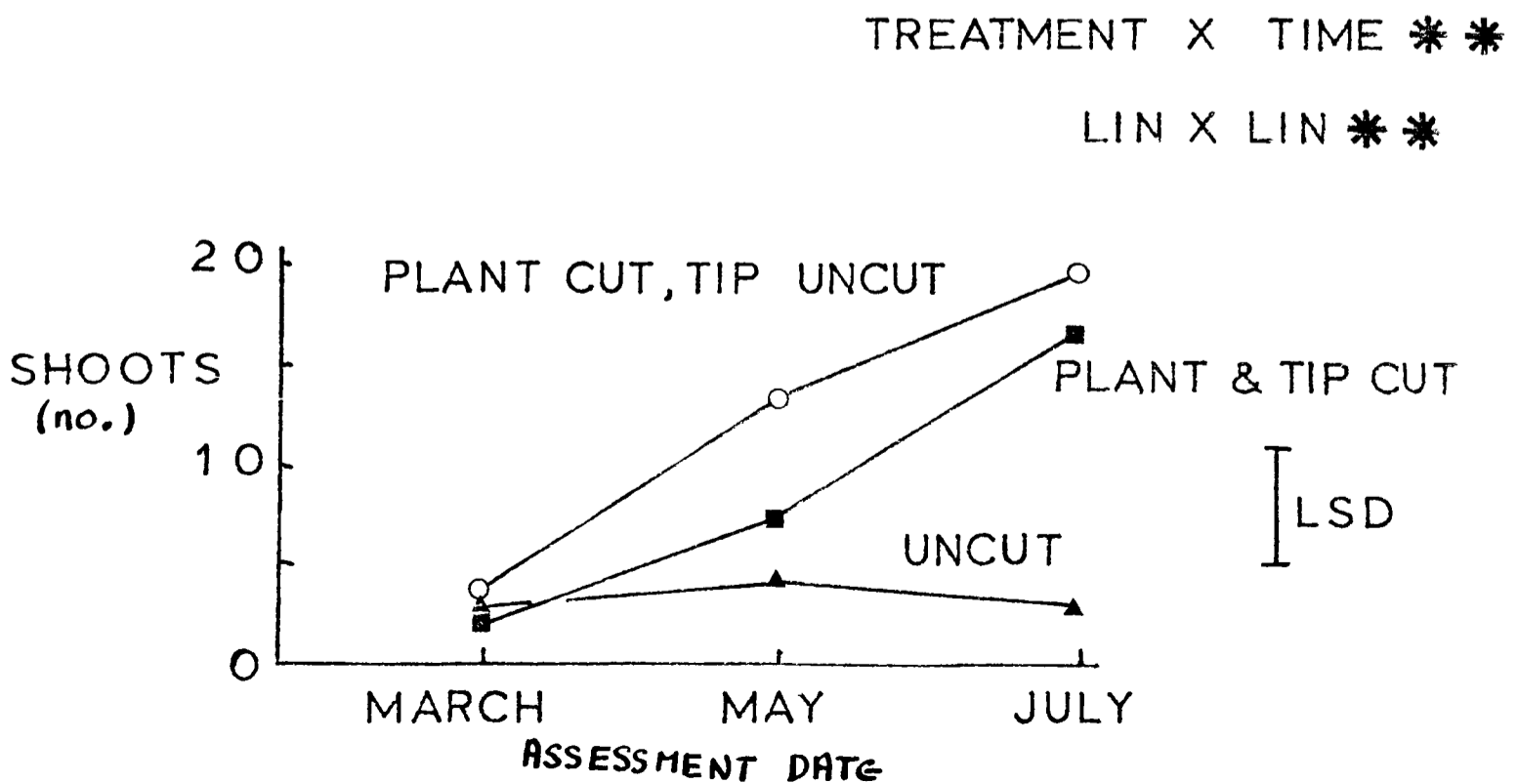
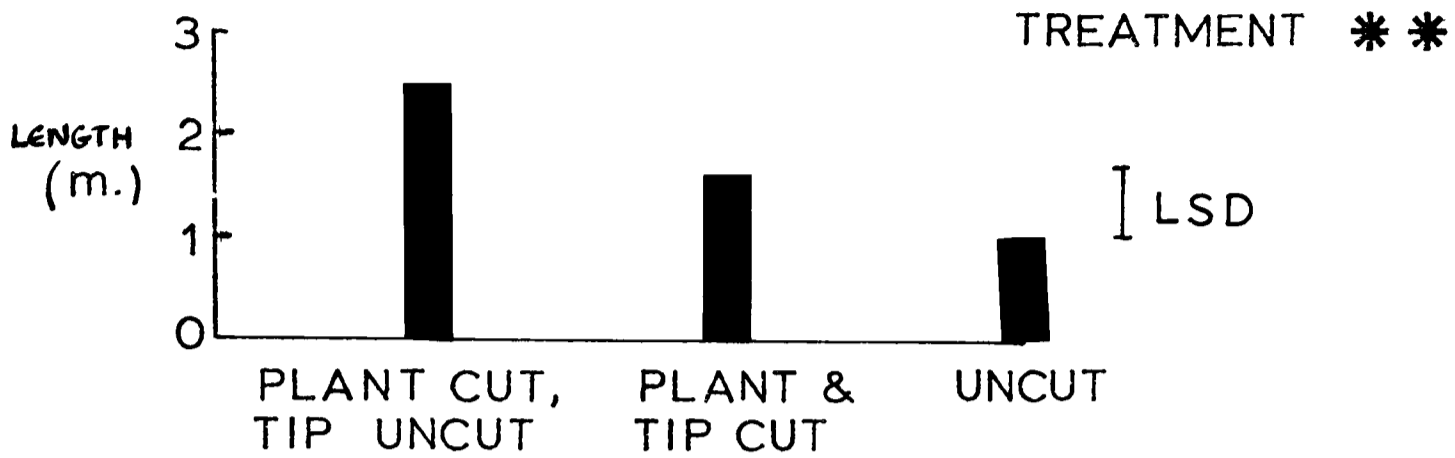


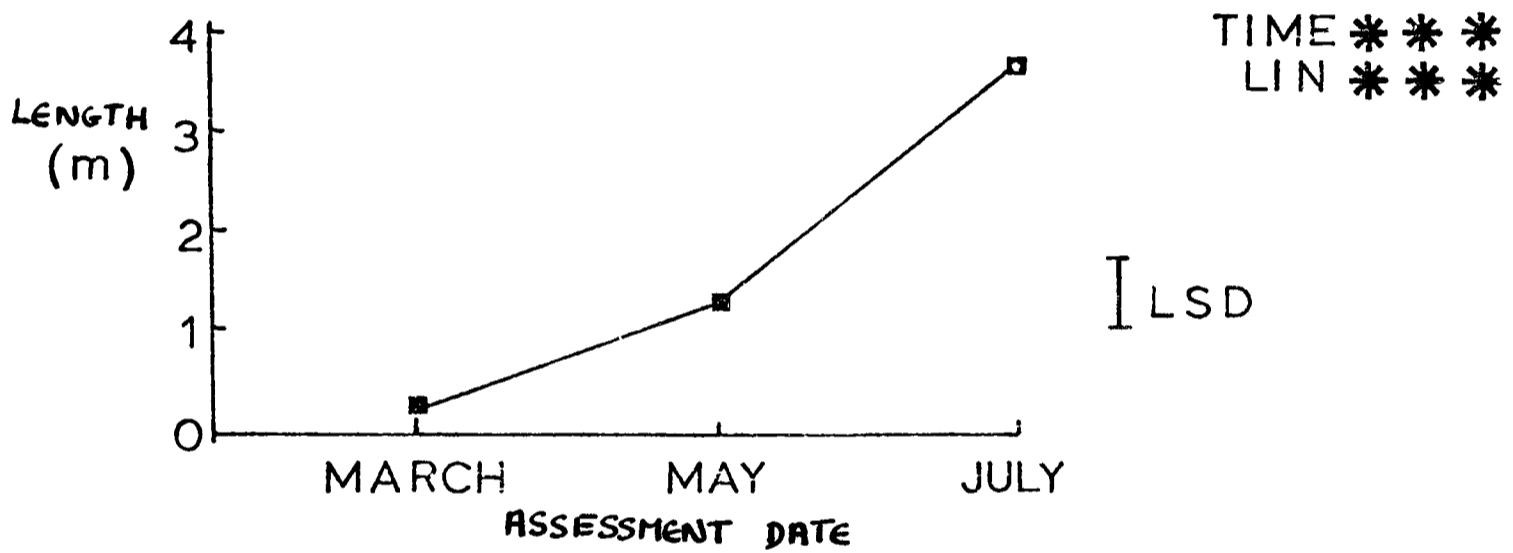
FIGURE 20

The total length of shoots per runner of H. lanatus

A. Under 3 cutting treatments (mean of 3 assessment dates)



B. On 3 assessment dates (mean of 3 cutting treatments)



C. Interaction of 3 cutting treatments & 3 assessment dates

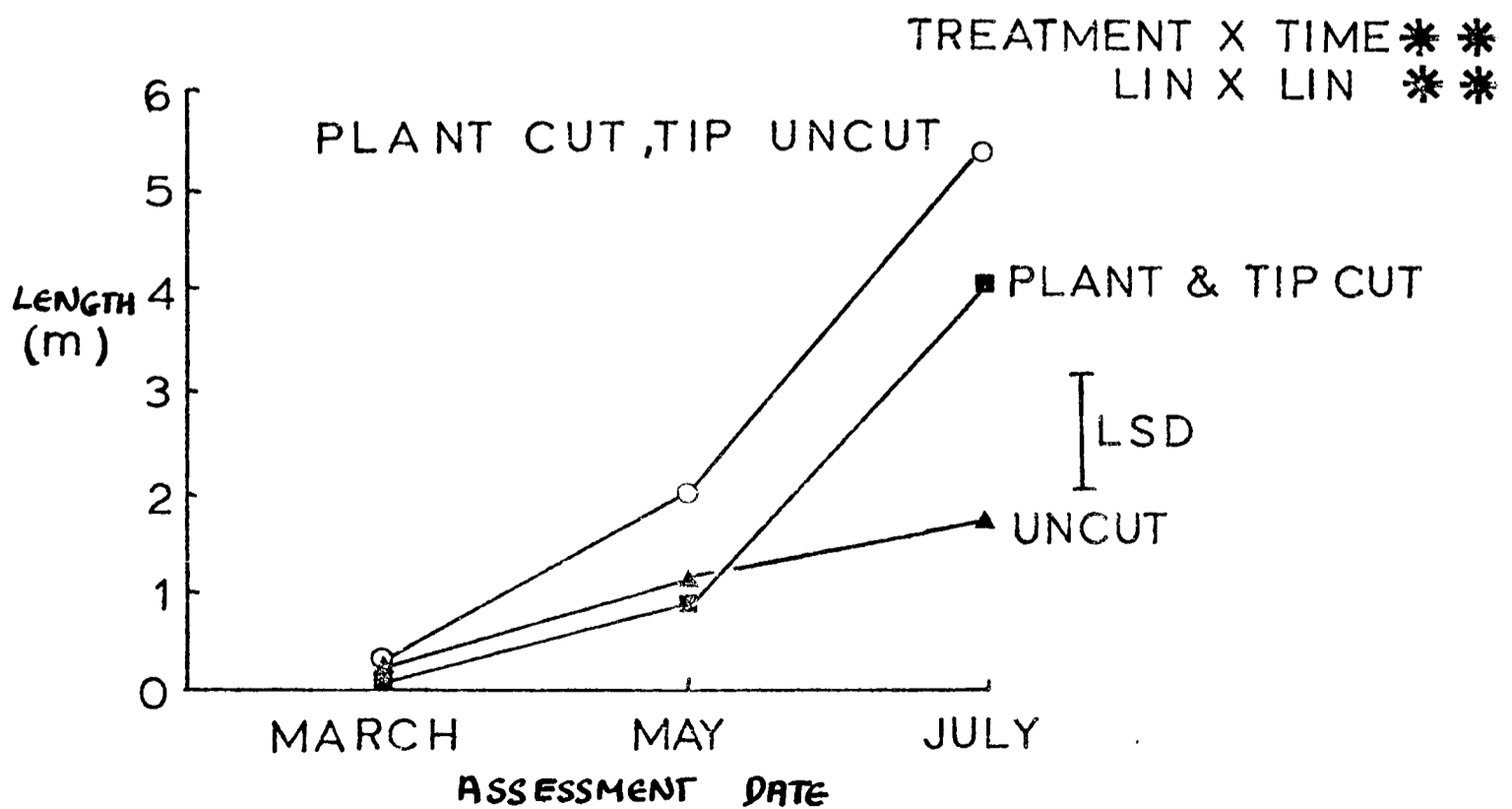
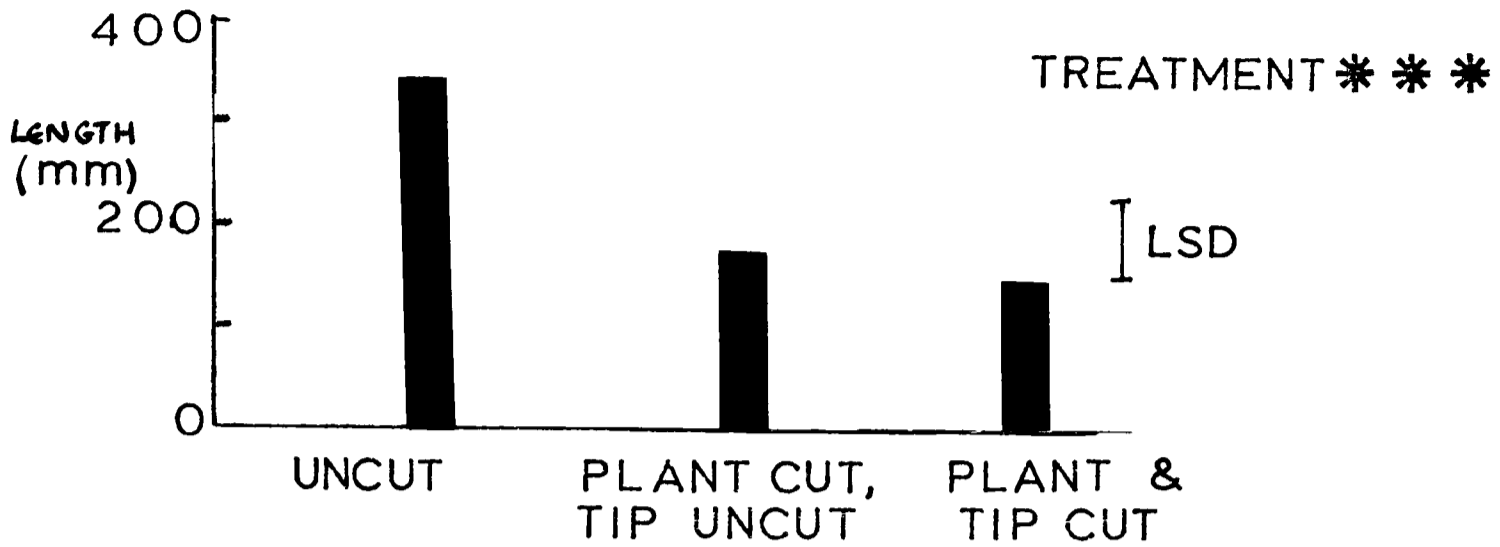


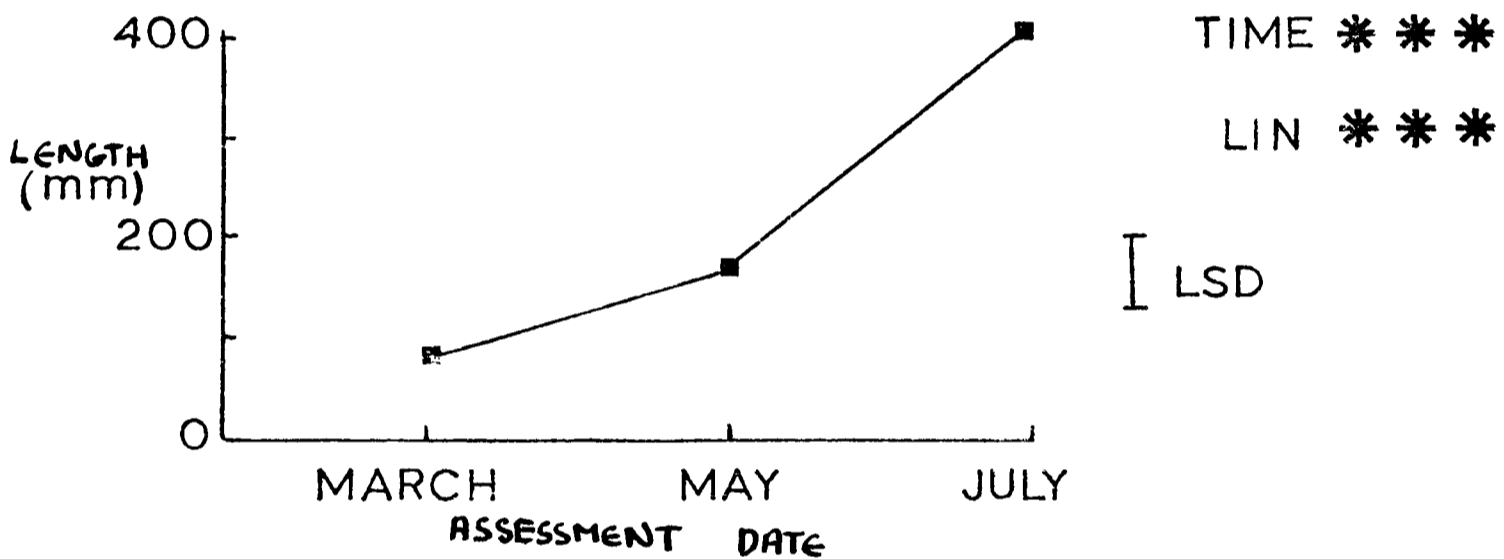
FIGURE 21

The mean length of a shoot on a runner of H.lanatus

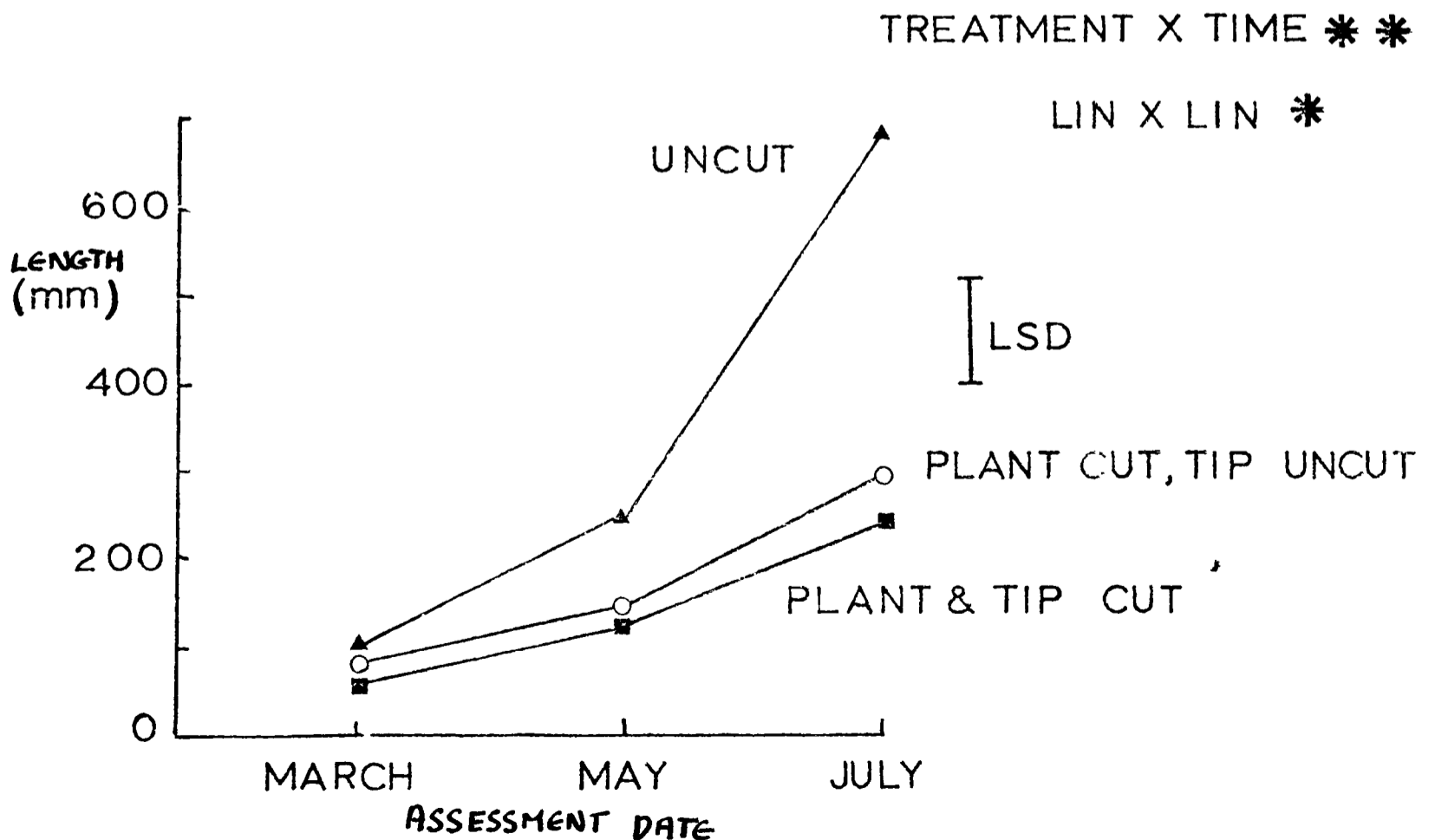
A. Under 3 cutting treatments (mean of 3 assessment dates)



B. On 3 assessment dates (mean of 3 cutting treatments)



C. Interaction of 3 cutting treatments & 3 assessment dates



manner to the strawberry plant. In Fragaria sp. long days lead to the end of flowering and to increased vegetative development, particularly of the stolons. Guttridge (1959), using Fragaria plantlets connected by stolons, showed that if one was kept under long days it inhibited flowering and promoted vegetative growth in the other, thus providing evidence for a translocatable stimulus. In H. lanatus, long days which have not been preceded by vernalization possibly induce runner formation.

Fewer nodes died on plants which were cut, but the tips of whose runners were uncut, than in the other two treatments (Fig. 18C, p. 47). In the uncut plants the greater death of nodes may be due to the shading of runners and to the competition for nutrients from the flowering culms. In the cut plants, whose runners were also cut, many nodes died near the apical end of the runner. Work with Agropyron repens has shown that the cut end of a rhizome has a deleterious effect upon the growth of shoots near it (Chancellor, 1974). Perhaps this is a similar situation.

Uncut plants had the lowest number of live shoots and the lowest total length of shoots per runner, but the highest mean shoot length. This may be partially explained by the heavy shading of vegetative shoots on runners leading to poor growth and/or death. Also, the few shoots on runners which did produce panicles became extremely long, probably exerting apical dominance over the quiescent buds. The cutting of plants allowed many more vegetative shoots on runners to survive and grow (less near cut tips of runners) but it also decreased the number of flowering shoots produced and so decreased mean shoot length.

The hypothesis that removal of the tip of a runner and, hence, of apical dominance might lead to the better growth of other, lateral roots and shoots on the runner was not confirmed. Runners tended to die back from a cut tip. The situation seems to differ from that in Agropyron repens rhizomes where all the nodes are dormant until the dominant shoot is removed (Rogan and Smith, 1976).

During the March measurements a tendency for nodes near the centre of the plant to produce only roots was noted, while those in the middle of the runner produced roots and shoots and those nodes near the apex were still dormant. This polarity is similar to that found in aerial shoots of A. repens where basal axillary buds tend to remain dormant or produce rhizomes and buds at higher levels develop into tillers (Rogan and Smith, 1975).

This experiment suggests that if H. lanatus is cut in the field to prevent flowering and make it more palatable to stock this will also enable it to spread better by runners as the plantlets will be shaded less by the parent plant and will have less competition for nutrients. However, these results apply to spaced plants and this work needs to be carried out in a closed sward.

CONCLUSIONS

On spaced plants of H. lanatus, runners formed during the autumn. Lateral shoots on runners WERE MORE NUMEROUS when the parent plants were cut monthly in spring.

CHAPTER 4

EFFECT OF DAY LENGTH, TEMPERATURE

AND TIME OF FIRST CUT ON

FLOWERING OF H. LANATUSINTRODUCTION

DAY LENGTH AND TEMPERATURE

In numerous plants floral initiation shows a definite dependence upon certain environmental conditions. Two conditions which most frequently control floral initiation are day length (photoperiodism) and low temperature (vernalization). Holcus lanatus plants from southern Europe tend to flower in the year of sowing whereas those from northern Europe flower only in the following year because they require vernalization (Böcher and Larsen, 1958). I have found no information about a day length requirement for flowering in H. lanatus but most of the other grasses in the Avenae are long day plants (Evans, 1964).

In another experiment (Chapter 5, p. 83) when H. lanatus plants were brought inside during the winter and divided up, the plants established from them did not flower. An experiment was therefore designed to find out primarily the approximate amount of cold treatment required for floral initiation. It was also designed to test whether short days could replace or complement any low temperature requirement.

TIME OF FIRST CUT

It has been observed in the field that if H. lanatus was cut at a certain time, flowering could be prevented (R.J. Haggart, pers. comm.). This experiment was designed to quantify this observation.

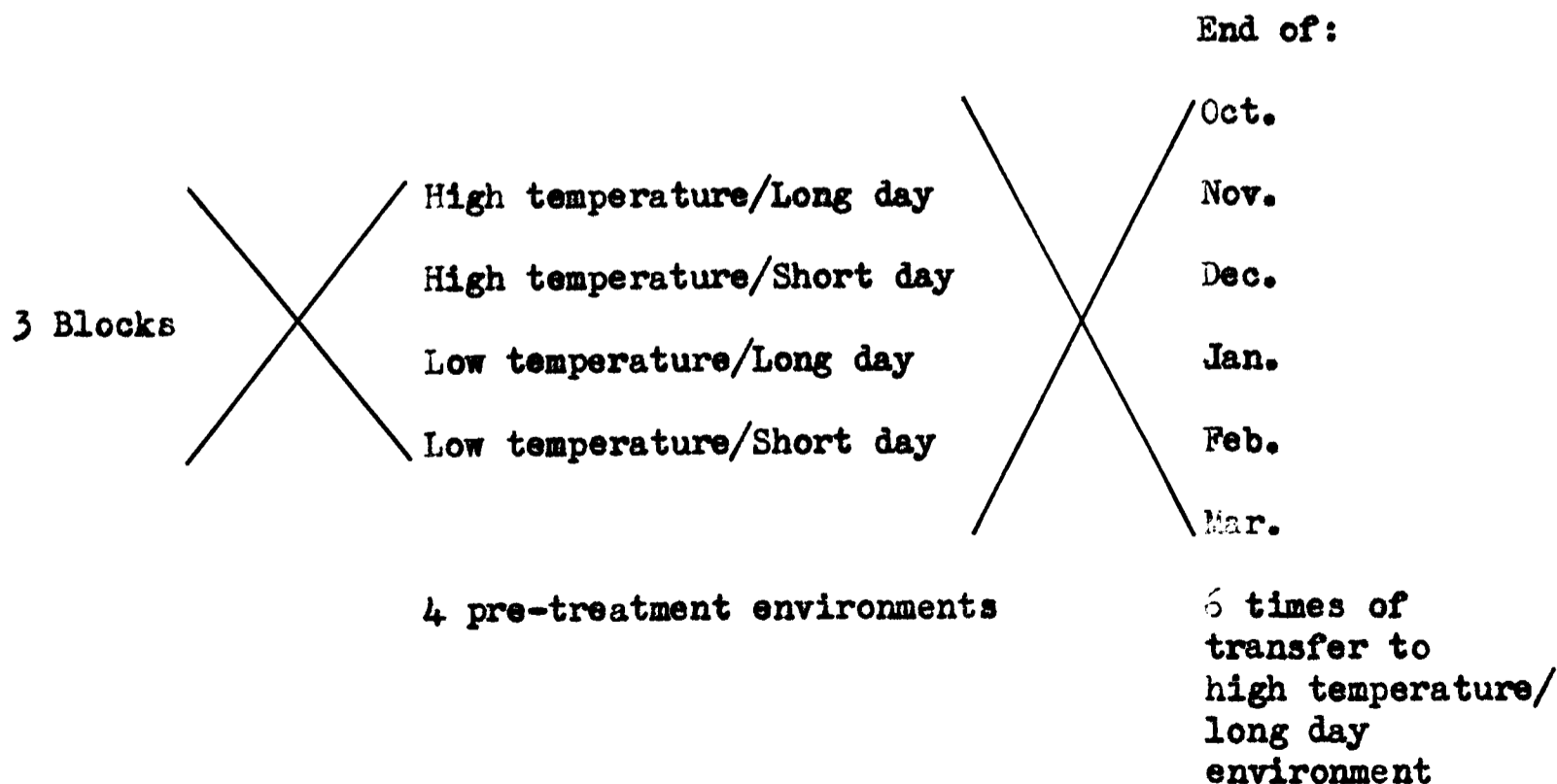
METHOD AND MATERIALS

DAY LENGTH AND TEMPERATURE

On 22 September 1976, three large plants of H. lanatus, each growing in a 250mm diameter pot were brought inside from a paved area where they had grown and flowered during the summer. They were divided into plants, each with about five tillers, and were planted in general purpose potting compost in 60mm cube pots and kept in a glasshouse. During the following week the mean minimum temperature was 12.4°C and the mean maximum temperature 18.3°C.

On 29 September, seventy two 150mm diameter plastic pots were prepared. In each, a piece of nylon mesh with 1mm diameter holes was placed over the drainage hole and covered with a 10mm deep layer of peat. The pots were filled with unsterilized sandy loam soil to which John Innes fertilizer and other compounds had been added (details in Appendix 7, p.251).

One plant of about five tillers was transplanted into each pot. The plants in each block originated from the same parent. Eighteen plants were placed in each of four different environments. Three of these (one per block) were subsequently removed from these environments at monthly intervals and placed in a long day/high temperature environment:



The four different environments were achieved as follows:

1. High temperature/long day. The plants were in a heated glasshouse under a sixteen hour day. During this time the mean weekly minimum temperature was 12.2°C and the mean weekly maximum temperature 18.3°C .
2. High temperature/short day. These plants were in a heated glasshouse, under the same temperature regime as the previous treatment. However, they were inside a specially made ventilated 'light' box. A black plastic sheet rolled across the top of the box automatically at 9.00 and rolled back to cover the box again at 17.00 each day, so the plants had an eight hour day. A fan operated all the time in the box to prevent the atmosphere becoming humid (Fig. 22B, p. 56).
3. Low temperature/short day. The plants were grown outside, on a paved area.
4. Low temperature/long day. These plants were also grown outside, at the same temperature as the previous treatment. However, they were about 300mm beneath a 100W lamp which was switched on all the time, giving a twenty four hour day (Fig. 22A, p. 56). These plants were re-randomised weekly because measurements showed that light distribution from the fixed lamp was uneven (Table 8, p. 57).

Nutrients and fungicide. All plants received a 0.5% solution of Vitafeed weekly and 5g John Innes fertilizer on 21 December (compositions in Appendix 7, p. 251) and were watered as required. On 10 October they were sprayed with a copper-based fungicide because there were rust pustules on some lower leaves.

Solarimeter readings. On 1 November 1976, solarimeter readings were taken at the level of the top of the pot in all four environments. These comparative figures are shown in Table 8 (p. 57).

View of two treatments in the day length & temperature experiment on 26 October 1976

A. Long day & low temperature



B. Short day & high temperature



TABLE 8

Comparative solarimeter readings from a range of environments at 16.30 on 11 November 1976

POSITION *	SOLARIMETER READING w/m^2
Glasshouse under fluorescent tube **	12.1
Outside under 100w lamp	5.5-40.5 ***
Paved area	0.44

* measured at soil surface

** 65/80w warm white

***range covers pots at all distances from lamp

TABLE 9

The number of days on which the minimum temperature was $5^{\circ}C$ from October 1976 to March 1977

YEAR	MONTH	NUMBER OF DAYS	CUMULATIVE NUMBER OF DAYS
1976	October	5	5
"	November	24	29
"	December	29	58
1977	January	29	87
"	February	22	109
"	March	20	129

Flowering. The number of panicles per plant was recorded on 13 April, 11 May, 8 June and 6 July 1977. The results are given as the mean of the number of panicles present on these four assessment dates (Fig. 23, p. 59).

Outside temperature. The number of days during each month from October to March when the minimum temperature was less than or equal to 5°C was noted (Table 9, p. 57).

TIME OF FIRST CUT

Twenty eight plants of H. lanatus were established in pots on 29 September 1976 in the same manner as for the day length and temperature experiment. The plants were divided into four blocks and kept outside on a paved area. All plants in blocks one and two were from one clone and those in blocks three and four from another clone. On 1 October 1976 a copper-based fungicide was applied to the plants. Vitafeed liquid fertilizer was applied weekly as a 1% solution from March onwards and the plants were watered as required.

Once a fortnight, from 14 March to 6 June 1977, one plant in each block was cut to 25mm above the soil. The number of panicles present was recorded weekly from 15 June to 8 July.

RESULTS

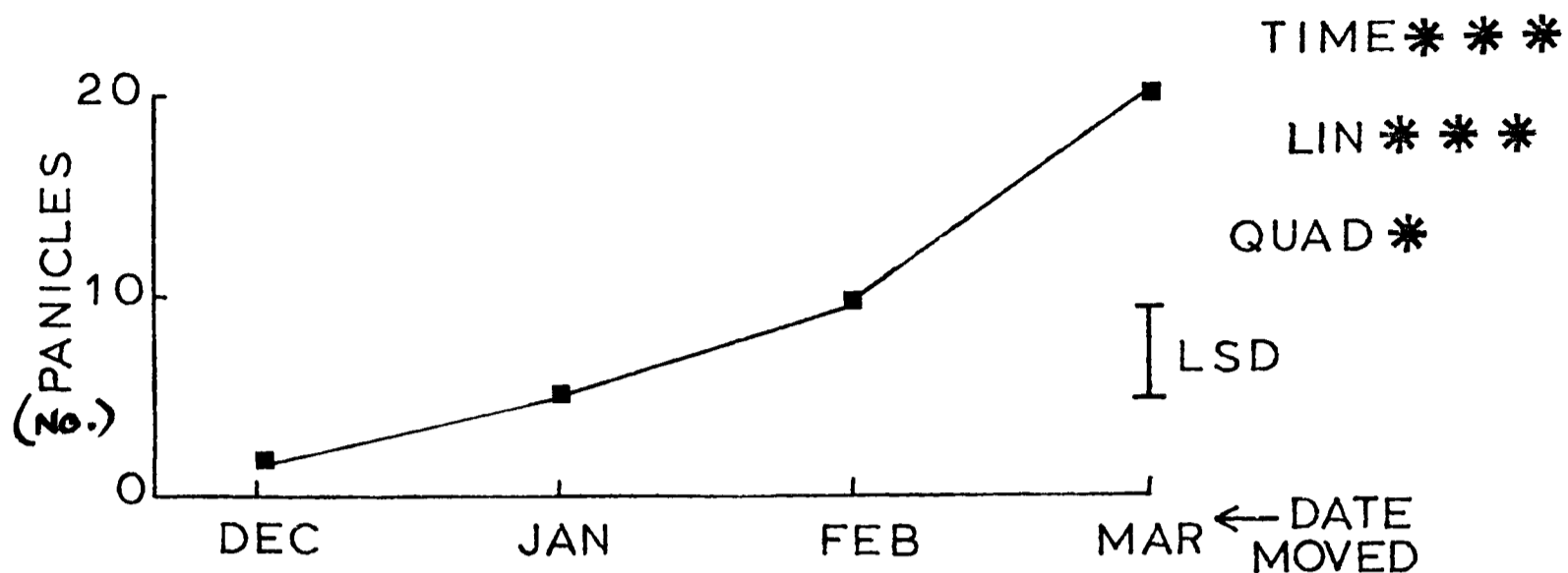
DAY LENGTH AND TEMPERATURE

The longer the plants were left in low temperature/short or long day or in high temperature/short day treatments, the more panicles they formed (Fig. 23A, p. 59). Plants which were always in a high temperature/long day environment did not produce any panicles and so were not included in the analysis.

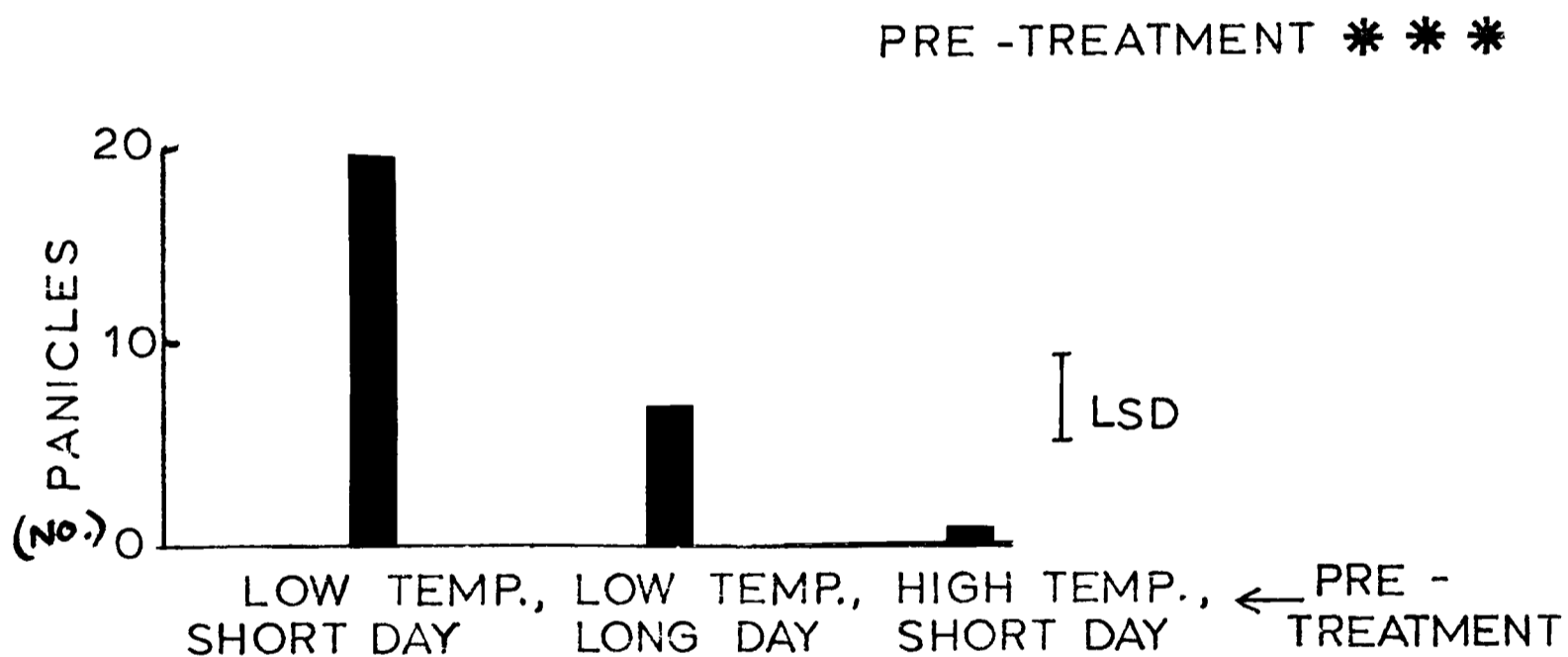
FIGURE 23

The number of panicles per plant of H.lanatus

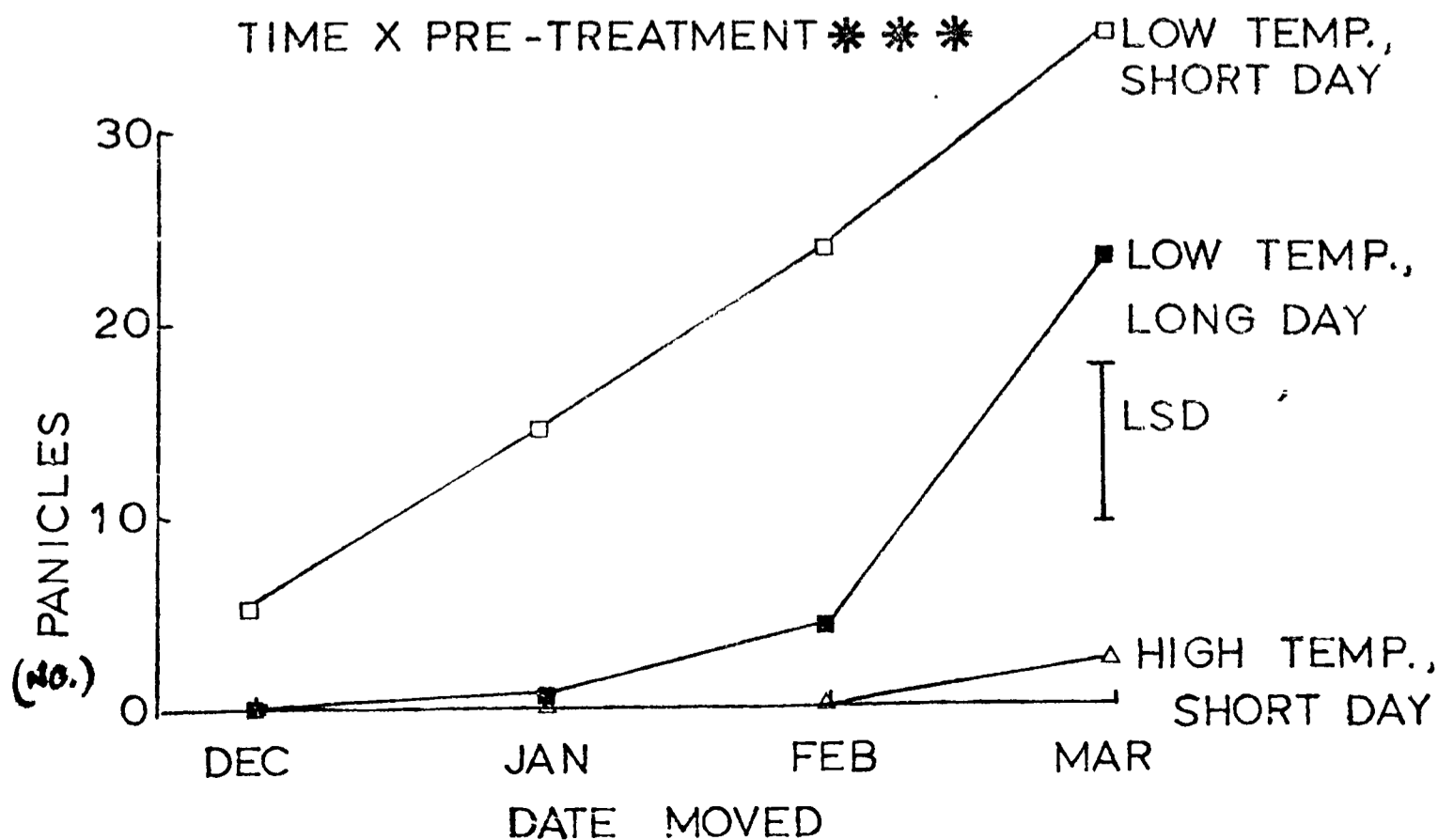
A. When plants were brought into high temperatures & long days on 4 dates (mean of 3 pre-treatments)



B. When plants were brought into high temperatures & long days from 3 pre-treatments (mean of 4 dates of removal)



C. Interaction of time & pre-treatment



The low temperature/short day treatment produced most panicles, followed by the low temperature/long day treatment. The high temperature/short day plants produced only a few panicles (Fig. 23B, p. 59). These results are shown clearly in the interaction (Fig. 23C, p. 59).

Plants brought into the high temperature/long day environment at the end of either October or November did not flower so they have been excluded from the analysis. Thus, H. lanatus plants must be exposed to at least between twenty four and twenty nine days in which the minimum temperature is below 5°C if they are to flower (Table 9, p. 57). But, when the plants were kept at high temperatures under short days for five months a small amount of flowering occurred (Fig. 23C, p. 59). There was no visible difference in panicle size between the treatments.

TIME OF FIRST CUT

Plants cut between 14 March and 9 May produced similar numbers of panicles in their regrowth (Fig. 24, p. 61). When plants were cut on 23 May, flowering was delayed and the total number of panicles was reduced, but not significantly. However, cutting on 6 June resulted in very few panicles being present in the regrowth (Fig. 24, p. 61). Instead a lush, vegetative regrowth was produced (Fig. 25, p. 62).

DISCUSSION

DAY LENGTH AND TEMPERATURE

Firstly, the drawbacks of the rather crude design of this experiment should be mentioned. The long day plants outside had a twenty four hour day whereas those inside had a sixteen hour day and the light sources used differed. Thus, the effect on flowering may have been confounded by both differences in the total light energy received and in the quality of that light. However, the results showed large differences and so, with these facts in mind, they are worthy of consideration.

FIGURE 24

The number of panicles on H.lanatus plants which were cut on one of 7 dates

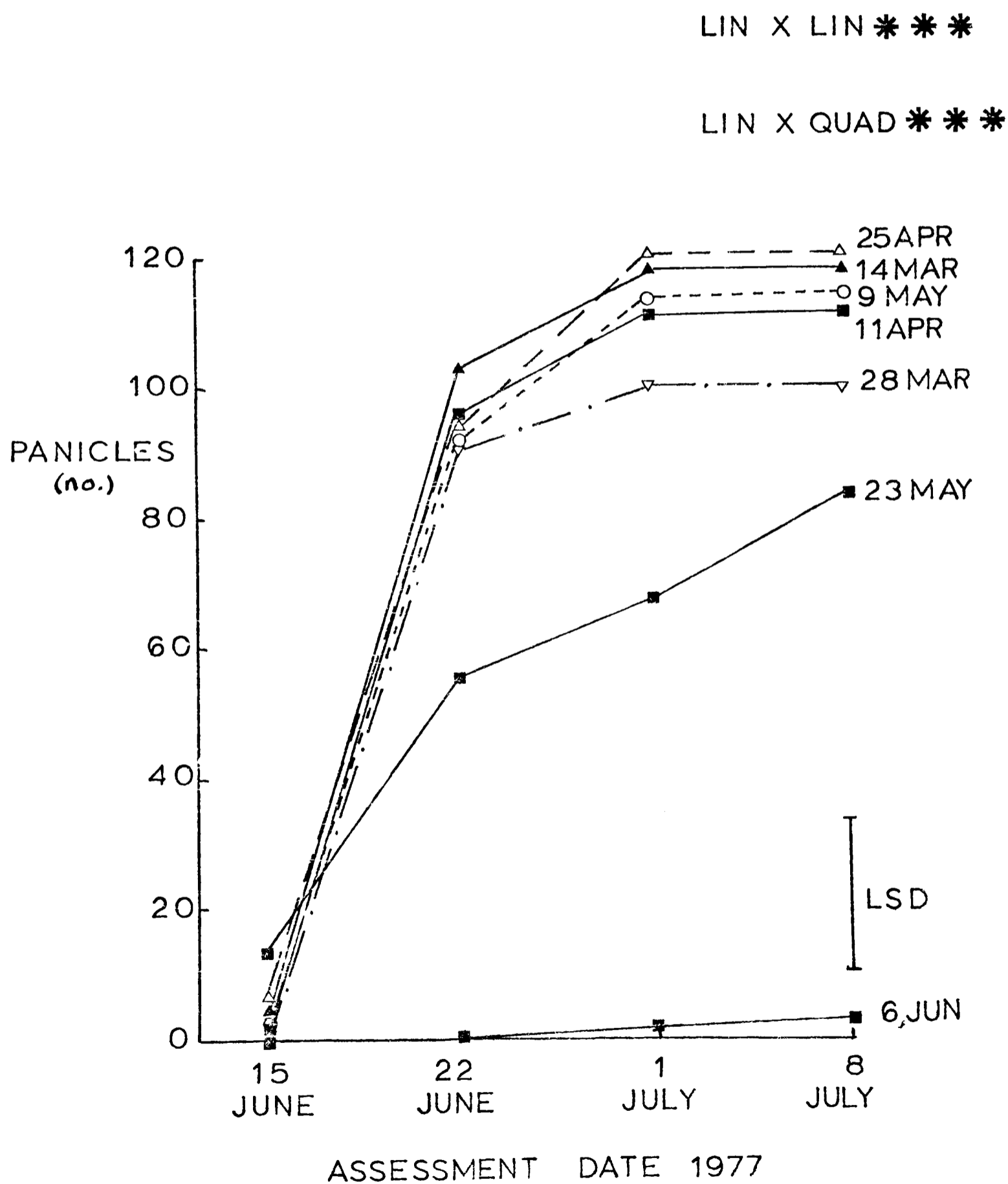
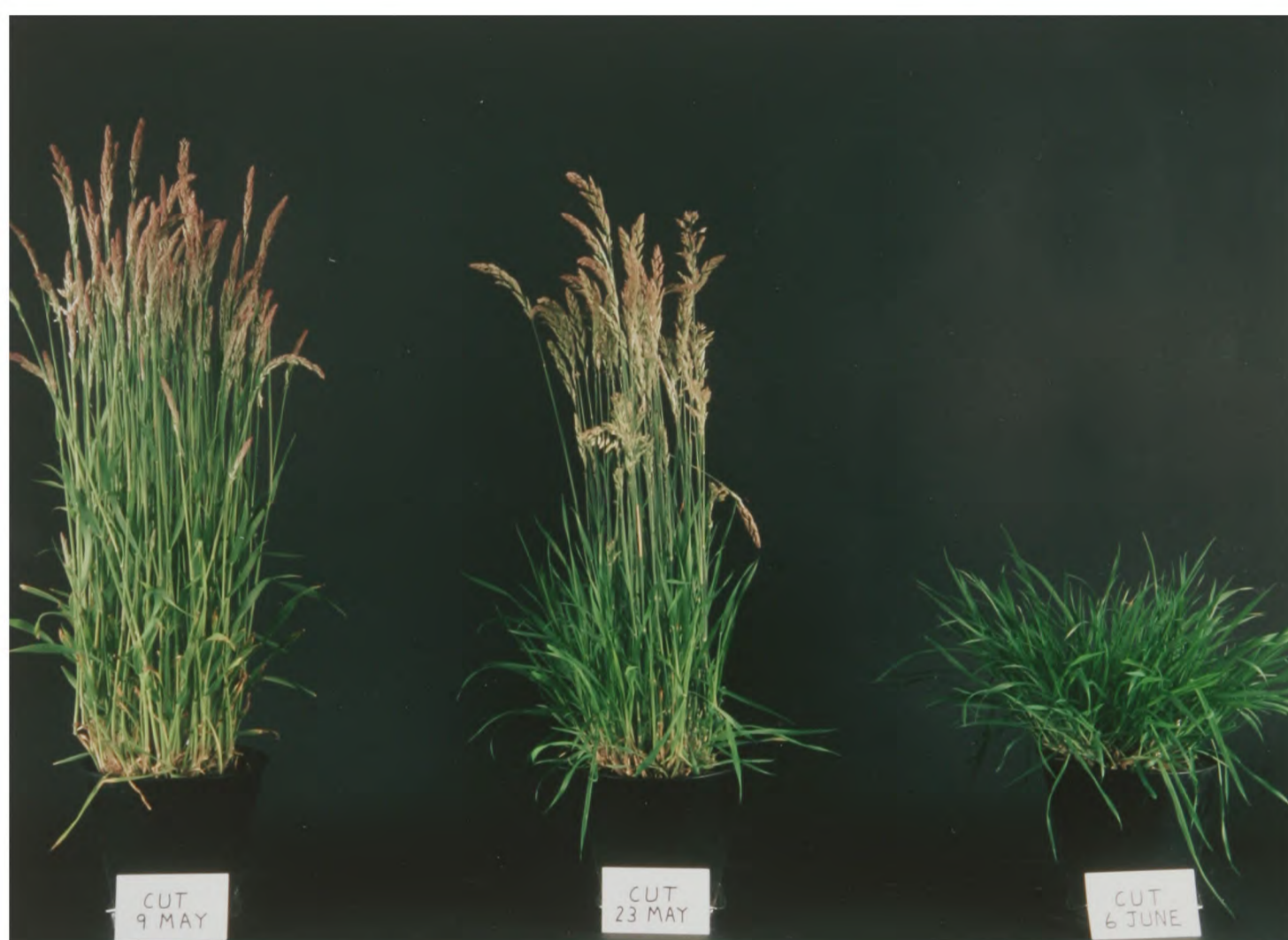


FIGURE 25

Plants of H. lanatus cut once on either 9 May, 23 May or 6 June 1977. Photograph taken 8 July 1977



The results confirm that in general, British H. lanatus plants require vernalization in order to flower (Böcher and Larsen, 1958). They also show that some plants may have failed to flower in a previous experiment because by the end of December, during a mild winter, they had not received enough cold treatment.

The cumulative effect of cold treatment on flowering, during the length of time studied, is similar to the response of Hyoscyamus niger. Lang (1951) exposed young plants to various lengths of cold treatments under short day conditions and then transferred them to warm, long days. The longer the time of exposure to cold temperatures, the greater the number of flowers produced.

Short days can enhance the effect of vernalization on the flowering of H. lanatus but this work has also shown that short days can replace vernalization to a small extent (Fig. 23C, p. 59). This effect has also been noted in Lolium perenne (Hillman, 1969). Thus, it seems that both these plants respond either as vernalizable long-day plants or as short-long-day plants, depending on the circumstances.

In H. lanatus runners tend to be produced during the autumn, i.e. after warm weather and long days (Chapter 3, p. 45). However, if the long days are preceded by cold weather, as they are in spring, flowering is induced. Vernalization seems to trigger the plant from vegetative to sexual reproduction at a time when the process can be successfully completed.

TIME OF FIRST CUT

This work used only two clones of H. lanatus and these were grown in pots. However, the results have confirmed the observation that if a sward containing H. lanatus is topped when buds are visible, but before panicles appear, a vegetative regrowth results. In the Midlands in most years the appropriate time will be about the first week in June.

The presence of H. lanatus in a Lolium perenne sward which is cut for silage in early June decreases the mean digestibility of the silage. This is because H. lanatus reaches 65D value earlier than L. perenne (Haggar, 1976a). However, the vegetative summer regrowth of H. lanatus will provide useful production at a time when L. perenne growth is declining (Haggar et al., in press).

CONCLUSIONS

DAY LENGTH AND TEMPERATURE

The Oxfordshire H. lanatus plants used in this experiment, in general, needed to be vernalized in order to flower. The minimum exposure needed for flowering was between twenty five and twenty nine days with a minimum temperature $\leq 5^{\circ}\text{C}$. The longer the cold treatment the more panicles the plants produced. Short days enhanced the effect of vernalization. To a small extent, long exposure (five months) to short days replaced vernalization.

TIME OF FIRST CUT

Holcus lanatus plants cut when in bud produced vegetative summer regrowth.

CHAPTER 5

EFFECT OF HEIGHT AND FREQUENCY
OF CUTTING ON THE GROWTH OF
H. LANATUS AND L. PERENNEINTRODUCTION

Holcus lanatus can dominate swards under infrequent cutting or grazing régimes. For example, when rabbit grazing of swards was prevented by netting (Tansley, 1939) or ceased after myxomatosis (Thomas, 1960), the amount of H. lanatus present increased. There is, however, little experimental evidence on the effect of cutting upon H. lanatus.

Holcus lanatus dominated a mixture with L. perenne which was cut either to 50mm when it reached 125mm or to 25mm when it reached 75mm, during the seeding year (Riveros, 1963). A similar result was obtained from a short term pot experiment using transplanted tillers of the two species (Froud-Williams, 1974). The aim of this work was, therefore, to study the effect of cutting height and frequency on the growth of established H. lanatus plants both in monoculture and with L. perenne over a period of several months.

The first experiment (1975) was in the glasshouse with water and nutrients non-limiting and with mesh tubes round the shoots, so that the plants had to compete fully with each other for light. The next year (1976) a similar experiment was carried out in field plots to find out whether the earlier results would be confirmed under field conditions. As H. lanatus did not flower in the 1976 experiment and growth was restricted by drought, a final field experiment was set up in 1977. In this, both vegetative H. lanatus plants and plants with a potential for flowering were used and the

plots were regularly watered. The aim of this final experiment was to find out whether some of the differences between the first two experiments were due to the flowering or non-flowering of H. lanatus, to drought in the field or to excessive shading of L. perenne plants in the glasshouse experiment due to H. lanatus shoots being held erect by the mesh.

METHOD AND MATERIALS

1975

Raising plants. On 4 and 5 February 1975 clumps of L. perenne and H. lanatus were dug up from the W.R.O. grassland. Individual tillers with shoots 50-100mm long and roots, were detached and planted separately in general purpose potting compost in 60mm cube pots in the glasshouse. Supplementary lighting provided a 16h day. The mean weekly minimum temperature was 12°C and the mean weekly maximum temperature was 24°C. The establishing plants were watered regularly, given a 1% solution of Vitafeed weekly and occasionally trimmed to about 50mm.

Glasshouse experiment. One hundred and eight plastic pots, each 250mm in diameter were used in this experiment. A piece of nylon mesh with 1mm diameter holes was placed over the drainage hole in each pot and covered with a 25mm deep layer of gravel. The pots were filled to within about 25mm of the rim with a medium loam soil into which John Innes fertilizer and other compounds had been mixed (Appendix 7, p.251).



On 25 and 26 March six established plants were transplanted into each prepared pot. These were either all L. perenne, all H. lanatus or three of each species. There were thirty six pots of each type. On 4 April any dead plants were replaced and the level of soil in each pot was adjusted to exactly 25mm below the rim by adding a layer of sterilized medium loam soil.

All plants were sprayed with a copper-based fungicide because some H. lanatus plants had rust pustules on their lower leaves.

Throughout the twenty four weeks of the experiment the pots were watered regularly and were supplied with a 1% solution of Vitafeed weekly. In addition, 10g of John Innes fertilizer was applied to each pot at the mid point of the experiment. The mean weekly minimum temperature was 11.7°C and the mean weekly maximum temperature was 19.2°C . On 30 May all plants were sprayed with 'Milgo' fungicide to control mildew which was on one L. perenne plant.

All plants were trimmed to about 50mm above the soil surface on 10 April and any weed seedlings removed. On 21 April an adjustable height windbreak made of plastic mesh with 6mm x 9mm holes was fastened round each pot to a height of 300mm (Fig. 26, p. 68). On 29 April, day 1 of the experiment, plants were cut to their appropriate heights for the first time. This was the only cut from which trimmings were discarded.

The experiment contained four randomised blocks each of:

3 heights of cut		3 frequencies of cut		3 species compositions
25, 50, 100 mm		2, 4, 6 wks		<u>L. perenne,</u> <u>H. lanatus,</u> 50:50 mixture

The dates of harvests are shown in Table 10 (p. 69). The grass cut off from each pot was sorted by species and the dry weights were recorded.

Before each harvest, the presence or absence of panicles ^{AND FLOWER BUDS, I.E. ALL INITIATED INFLORESCENCES} in each pot

was noted. After the final harvest, the stubble remaining in the pots was cut off at ground level, separated and its dry weight was recorded.

1976

Raising plants. On 17 December 1975, clumps of H. lanatus and L. perenne were dug up from the W.R.O. grassland. Plants were established from these in the same way as for the 1975 experiment. However, in this case, the mean

Overall view of 1975 cutting experiment



TABLE 10

Harvest dates in 1975 and 1976

HEIGHT OF CUT mm	25	50	100	25	50	100	25	50	100
INTERVAL OF CUT wk	2			4			6		
YIELD PERIOD									
29 April-22 July	13 May (1st)			27 May (1st)			10 June (1st)		
	27 May (2nd)								
	10 June (3rd)								
	24 June (4th)			24 June (2nd)					
	8 July (5th)								
	22 July (6th)			22 July (3rd)			22 July (2nd)		
23 July-14 October	5 Aug (7th)								
	19 Aug (8th)			19 Aug (4th)					
	2 Sep (9th)						2 Sep (3rd)		
	16 Sep (10th)			16 Sep (5th)					
	30 Sep (11th)								
	14 Oct (12th)			14 Oct (6th)			14 Oct (4th)		

TABLE 11

Harvest dates in 1977

HEIGHT OF CUT mm	50	100	50	100
INTERVAL OF CUT wk	3		6	
DATES	18 May (1st)		8 June (1st)	
	8 June (2nd)			
	29 June (3rd)			
	20 July (4th)		20 July (2nd)	

weekly minimum temperature was 9.9°C and the mean weekly maximum temperature was 18.3°C .

Field experiment. This was arranged in three randomised blocks each of twenty seven plots. Each plot was 0.5m square. The treatments were the same as for the 1975^{POT} experiment, but with two plants being transplanted into each plot. On 26 March, cv S23 L. perenne seed was also sown in a band 100mm wide round the edge of each plot at about 15 kg/ha. A dressing of 15:15:22 fertilizer at 375 kg/ha was applied then and after every harvest. The dates of harvests are shown in Table 10 (p. 69). The plants were watered by hand during dry weather .

At each harvest flowering was noted, the plants were cut to their appropriate heights and the dry weights of the harvested material were recorded. After the final harvest the stubble was cut at ground level, separated and the dry weight recorded.

1977

Raising plants. On 14 September 1976 three large plants of H. lanatus which had originated from the W.R.O. grassland and had been growing in pots outside during the summer, were each divided into two halves. Each half was transplanted into a 250mm diameter pot containing medium loam soil. One set of three pots was left outside and the other set was brought into a heated glasshouse during the winter. All six plants received a 1% solution of Vitafeed weekly and were watered as required.

On 16 and 17 February 1977, plants were established both from these plants and from clumps of L. perenne freshly dug up from the W.R.O. grassland, in the same way as for the previous two experiments. However, in this case, the mean weekly minimum temperature was 10.9°C and the mean weekly maximum temperature was 21.2°C .

Field experiment. This was laid out in three randomised blocks each of twenty plots. Each plot was 0.5m square.

The treatments within each block were:

2 heights of cut	×	2 frequencies of cut	×	5 species compositions
50, 100mm		3, 6 wks		1. <u>L. perenne</u>
				2. <u>H. lanatus</u> (VERNALISED)
				3. <u>H. lanatus</u> (non-VERNALISED)
				4. <u>L. perenne</u> + <u>H. lanatus</u> (VERNALISED)
				5. <u>L. perenne</u> + <u>H. lanatus</u> (non-VERNALISED)

On 13 April 1977, four established plants were transplanted into the centre of each plot. These were either all L. perenne, all H. lanatus or two of each species as appropriate. The H. lanatus (flowering) plants originated from plants kept outside during the winter whereas the non-flowering ones originated from those kept in the glasshouse. On 15 April cv RVP L. multiflorum seed was sown in a band 100mm wide round the edge of each plot and on the pathways at about 15 kg/ha. Fertilizer was applied as in 1976. The harvest dates are shown in Table 11 (p. 69). The plants were watered regularly by hand during dry weather. Assessments were made in the same way as for 1976.

RESULTS

SHOOT DRY WEIGHTS - 1975 POT EXPERIMENT

The cumulative shoot dry weights of the first twelve weeks, last twelve weeks and all twenty four weeks of the experiment follow very similar patterns so only the yields for all twenty four weeks will be considered (Fig. 27, p. 72).

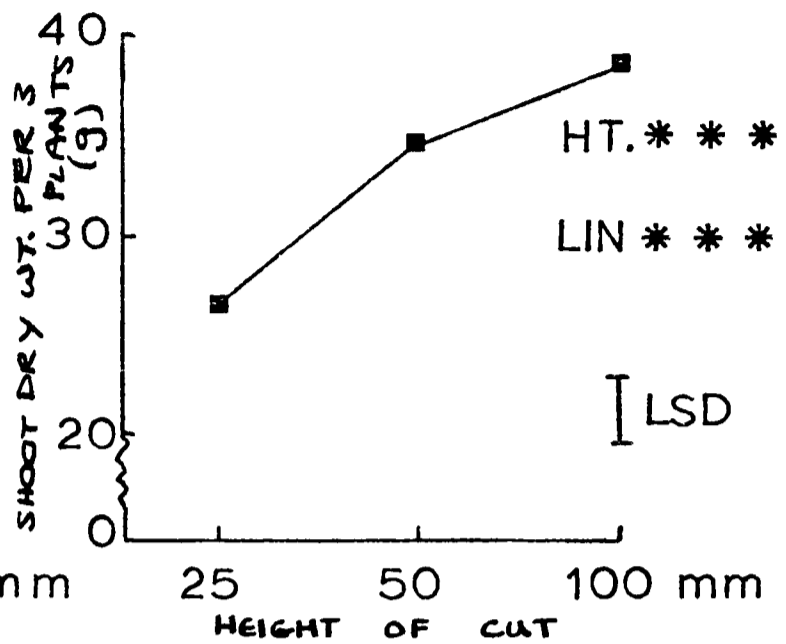
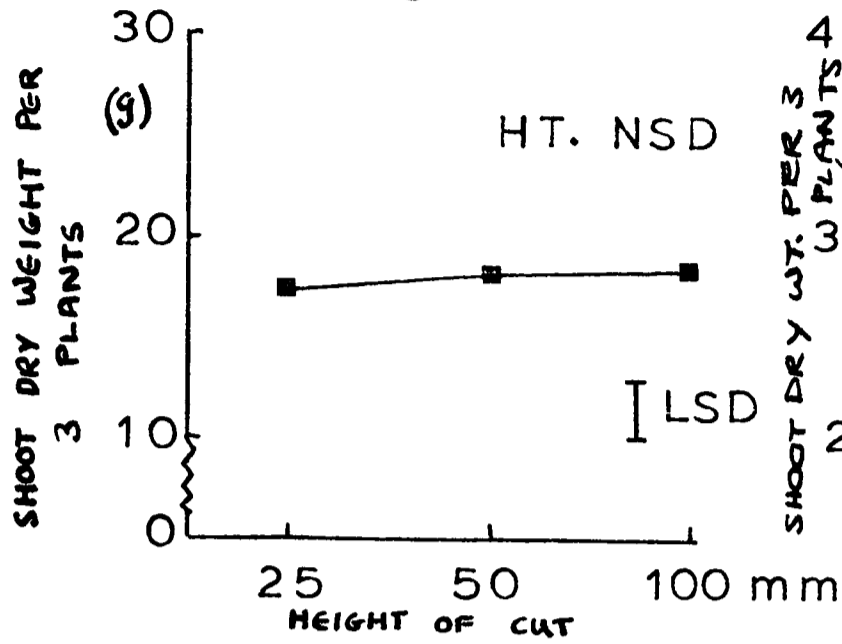
Cumulative shoot dry weights over 24 weeks of H.lanatus & L.perenne in 1975

Figures in A & B are means of pure & mixed cultures

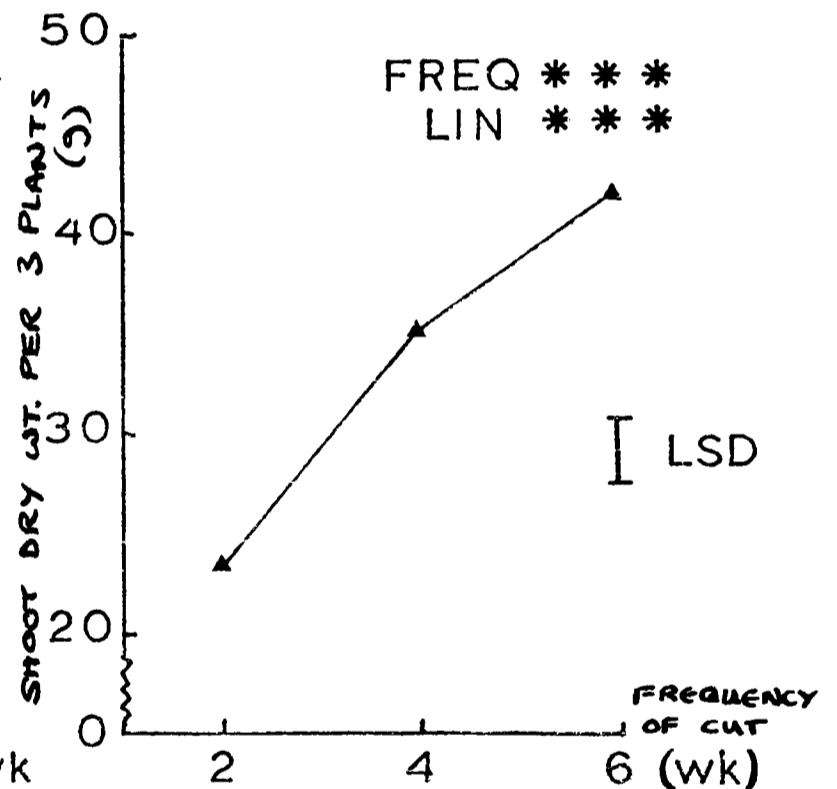
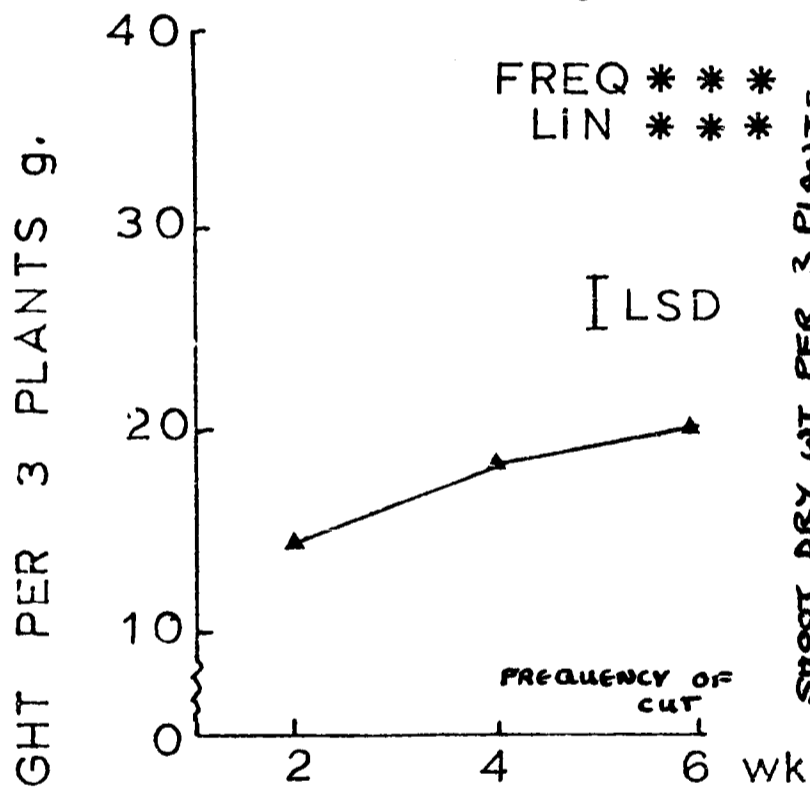
L. perenne

H.lanatus

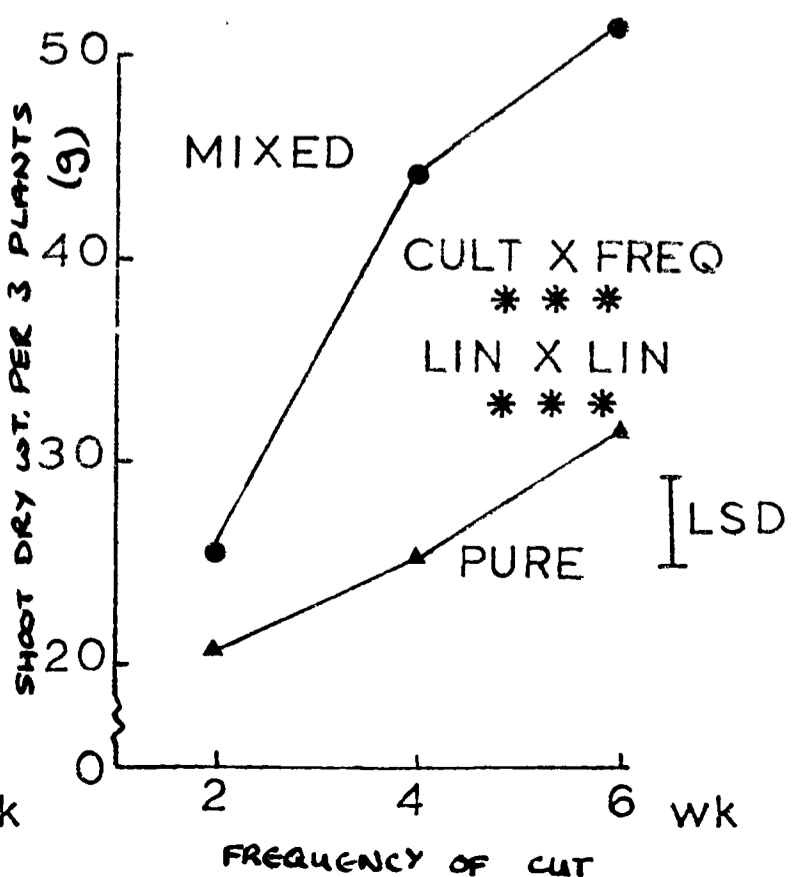
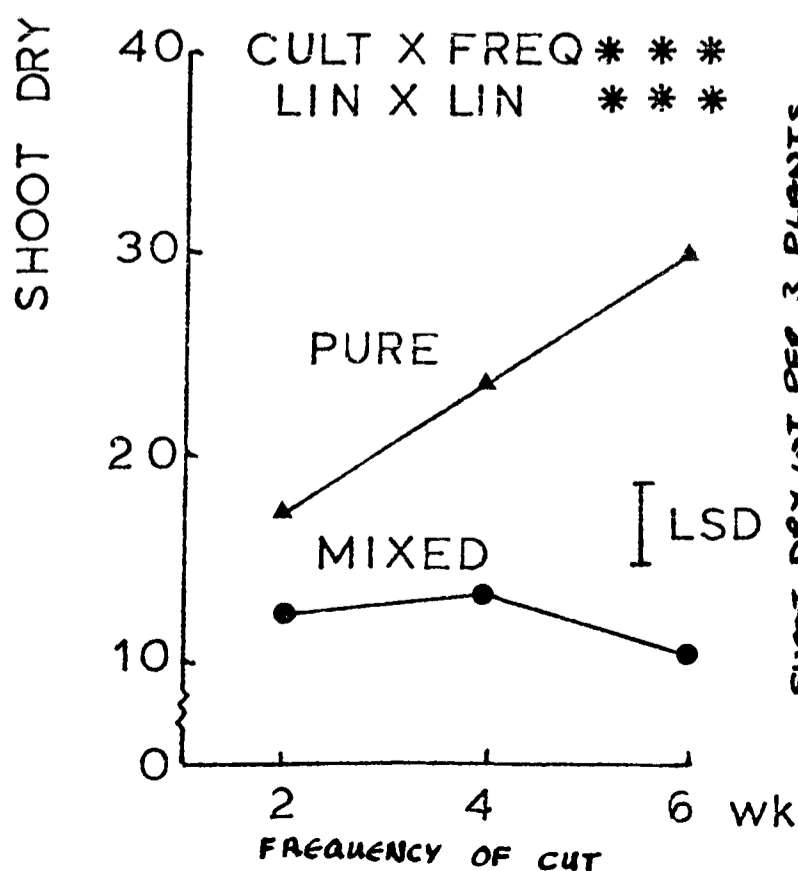
A. Effect of height of cut



B. Effect of frequency of cut



C. Interaction between culture & frequency of cut



Height of cut. There was no significant difference between the yields of L. perenne at different cutting heights. Whereas, there was a highly significant linear trend of increased yields at greater cutting heights with H. lanatus (Fig. 27A, p. 72).

Frequency of cut. Both species showed a highly significant linear trend of increased yields with less frequent cutting. However, the response of H. lanatus was more pronounced than that of L. perenne (Fig. 27B, p. 72).

Culture x frequency interactions. Both grasses had a highly significant interaction. Holcus lanatus had a greater yield per plant in mixed than in pure culture whereas the reverse was true for L. perenne (Fig. 27C, p. 72).

CULTURE X HEIGHT INTERACTIONS THESE WERE NOT SIGNIFICANT.

Relative replacement rates. The data from this experiment was used to calculate the relative replacement rate of L. perenne by H. lanatus in mixture at each harvest for all combinations of height and frequency of cutting. The method used was that of De Wit and Van den Bergh (1965):

The relative replacement rate of H. lanatus (H) with respect to L. perenne (L) between harvests 1 and 2 is:

$${}^2_1 \rho_{HL} = \frac{{}^2 r_H / {}^1 r_H}{{}^2 r_L / {}^1 r_L}$$

in which ${}^1 r_L$ and ${}^1 r_H$ are the shoot dry weights at harvest 1 and ${}^2 r_H$ and ${}^2 r_L$ are the shoot dry weights at harvest 2. And:

$${}^1 r_H = \frac{\text{yield of } \underline{H. lanatus} \text{ in mixture, harvest 1}}{\text{yield of } \underline{H. lanatus} \text{ in monoculture, harvest 1}}$$

$${}^1 r_L = \frac{\text{yield of } \underline{L. perenne} \text{ in mixture, harvest 1}}{\text{yield of } \underline{L. perenne} \text{ in monoculture, harvest 1}}$$

These ratios from the first harvest of each treatment were used as the reference ones to which all later harvests were compared. The relative replacement rates of H. lanatus with respect to time have been plotted on a logarithmic scale in Figures 28 (p. 75) and 29 (p. 76). These lines are called 'course lines'. They show that H. lanatus replaced L. perenne in all treatments but slowest when cut at 25mm. When the mixtures were cut at monthly intervals, H. lanatus ^{INITIALLY} made consistent rapid gains.

STUBBLE DRY WEIGHTS - 1975

In Figure 30 (p. 77) the stubble dry weights of each species are presented for the three cutting heights. The amount of L. perenne present was not affected by the frequency of cutting, except when it was cut at 100mm. Then, the stubble dry weight/plant increased with less frequent cutting in pure culture but decreased in mixture.

The greater the interval between cuts the larger was the dry weight of H. lanatus stubble present (Fig. 30, p. 77). This was significant at 25 and 100mm cutting heights. When the grass was cut at 50mm the stubble dry weight/plant increased with less frequent cutting in pure culture but reached a peak at monthly cuts in mixture.

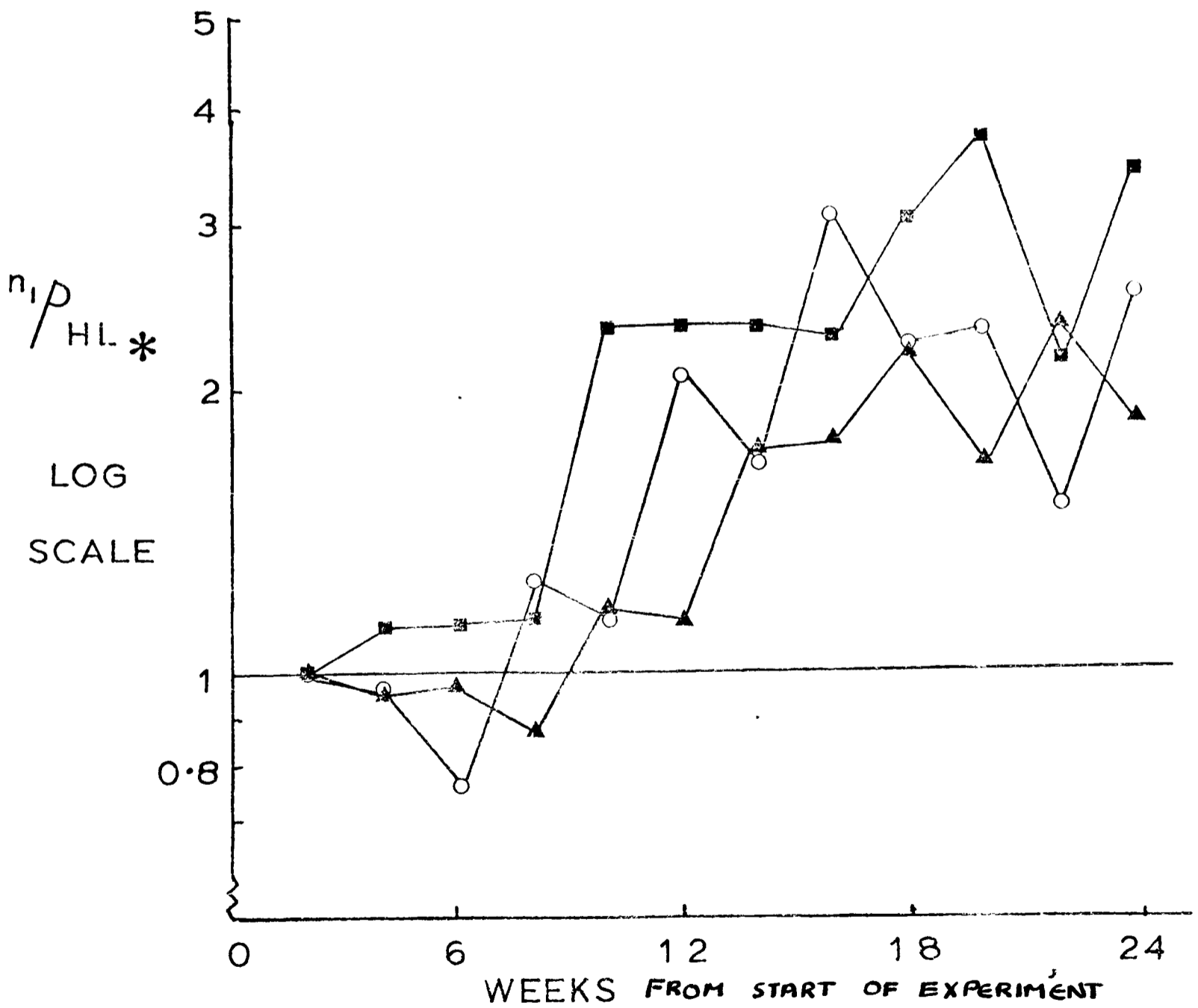
The figures in Table 12 (p. 78) show that H. lanatus always had more stubble/plant in mixed than in pure culture whereas the reverse was true for L. perenne. The effect of height of cutting on the percentage of H. lanatus in mixture is shown in Figure 31 (p. 79). This was examined on a percentage basis since the higher the cutting level, the greater the potential amount of stubble. As height of cutting increased, the percentage of H. lanatus in the mixture increased linearly.

PANICLES AND FLOWER BUDS - 1975

The figures in Table 13 (p. 78) and Figure 32 (p. 80) deal only with the first twelve weeks of the experiment, for hardly any flowering occurred after this time. In general, more L. perenne plants flowered than

FIGURE 28

Course lines for H.lanatus with respect to L.perenne when cut at 3 heights (Figures are means of 3 frequencies of cut)

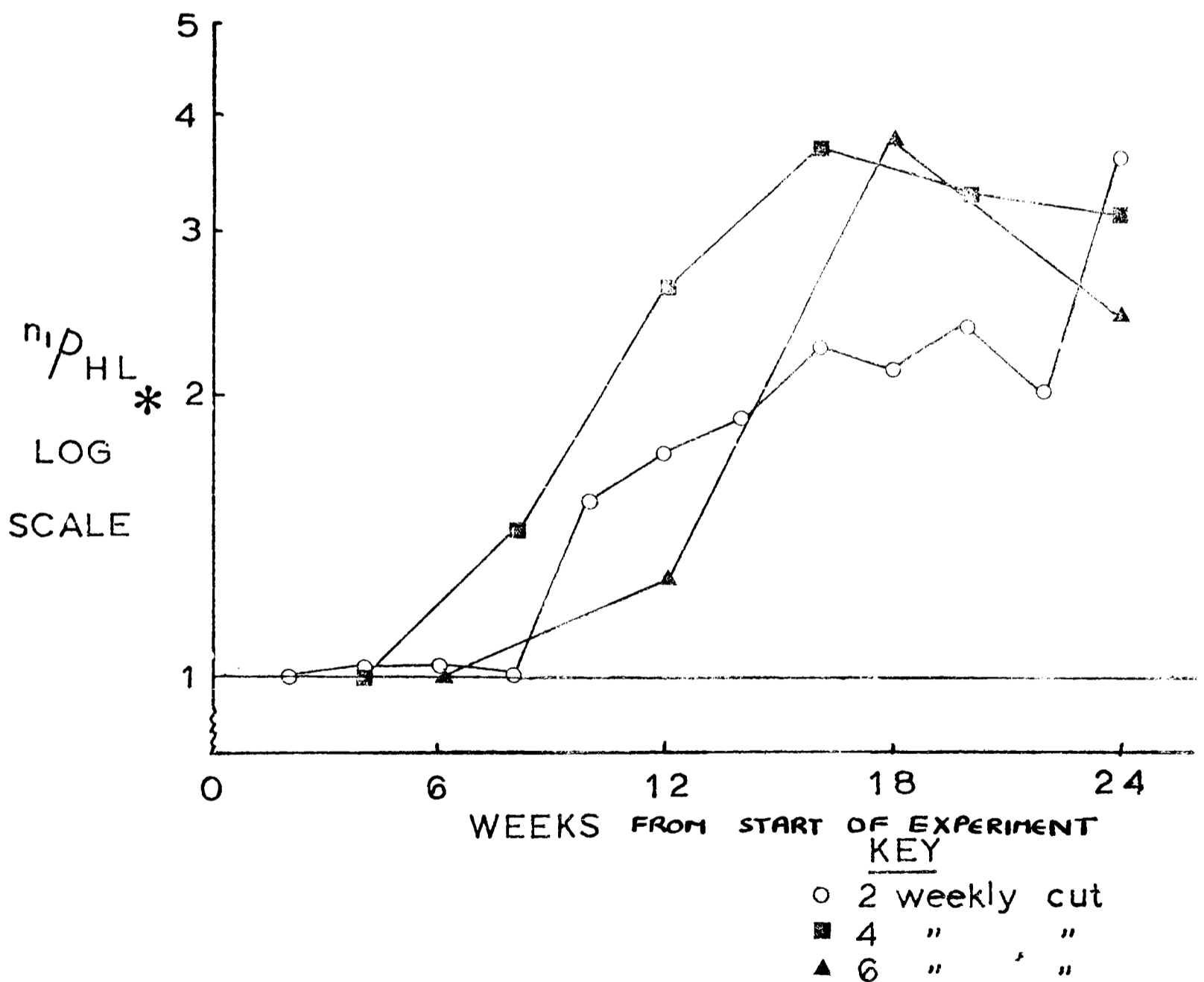


* $\frac{n_1 \rho}{HL}$ = Relative replacement rate of L.perenne by H.lanatus

KEY
 o cut at 100 mm
 ■ " " 50 "
 ▲ " " 25 "

FIGURE 29

Course lines for H.lanatus with respect to L.perenne when cut at 3 frequencies (Figures are means of 3 heights of cut)



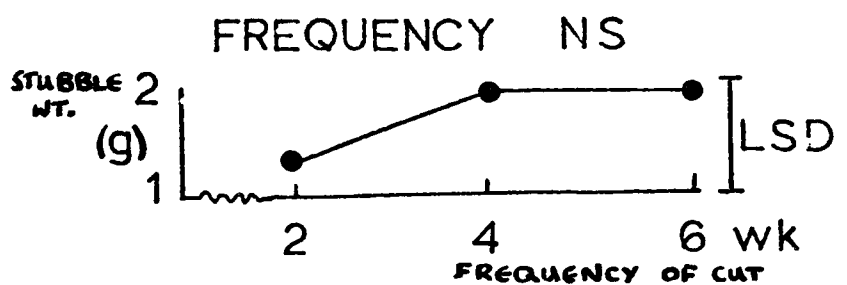
* $\frac{n_1 \rho}{HL}$ = Relative replacement rate of L.perenne by H.lanatus

FIGURE 30

Stubble dry weight (g./3 pots) of H.lanatus & L.perenne at 3 heights & 3 frequencies of cut in 1975. Except for interactions, figures are means of pure & mixed cultures

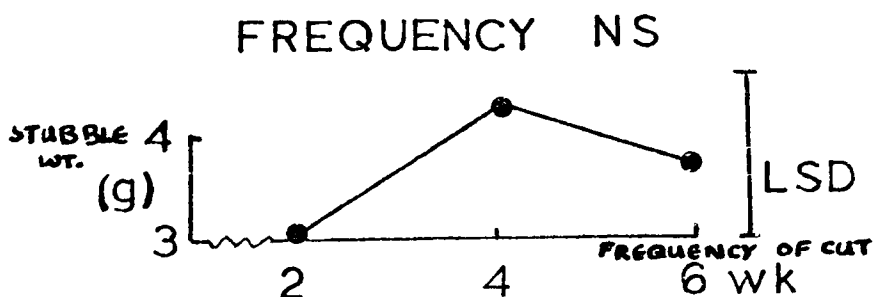
L.perenne

A. CUT AT 25 mm



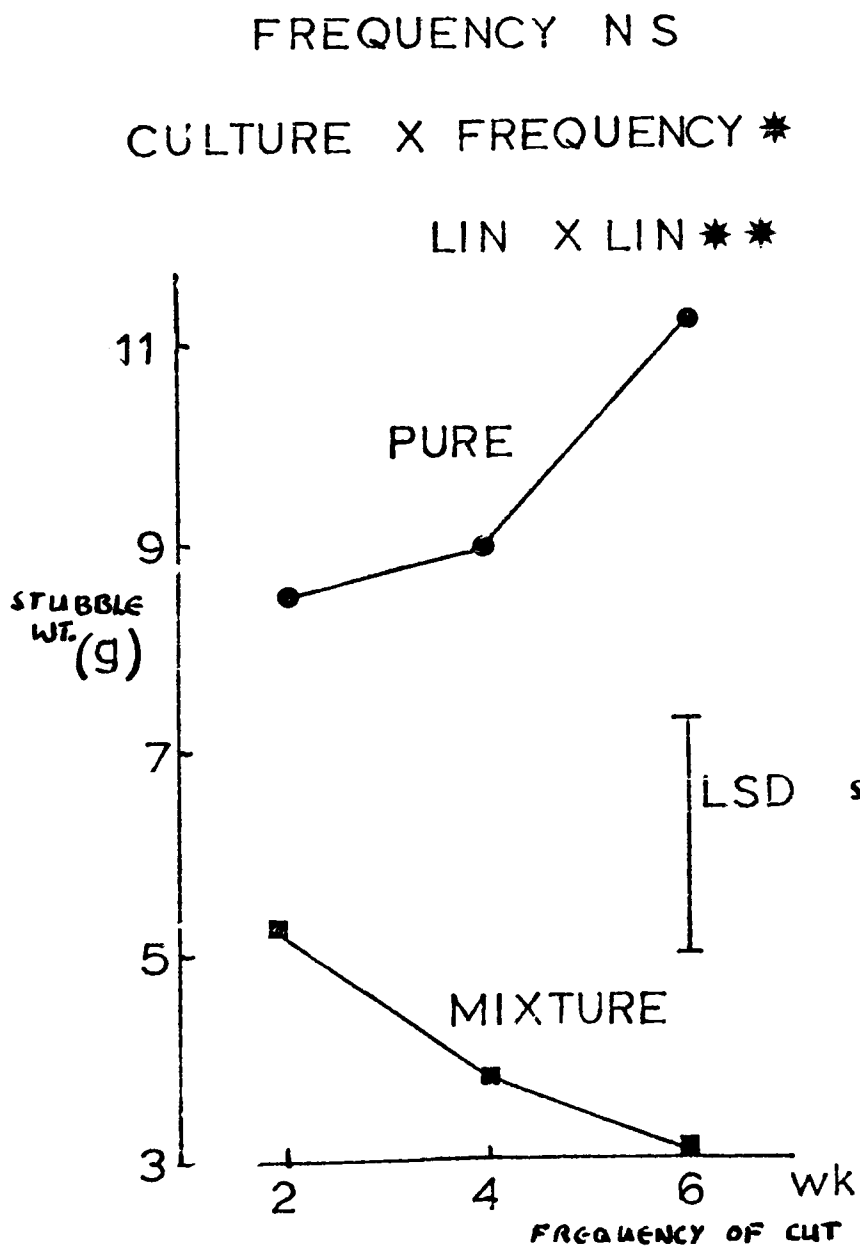
CULTURE X FREQUENCY NS

B. CUT AT 50 mm



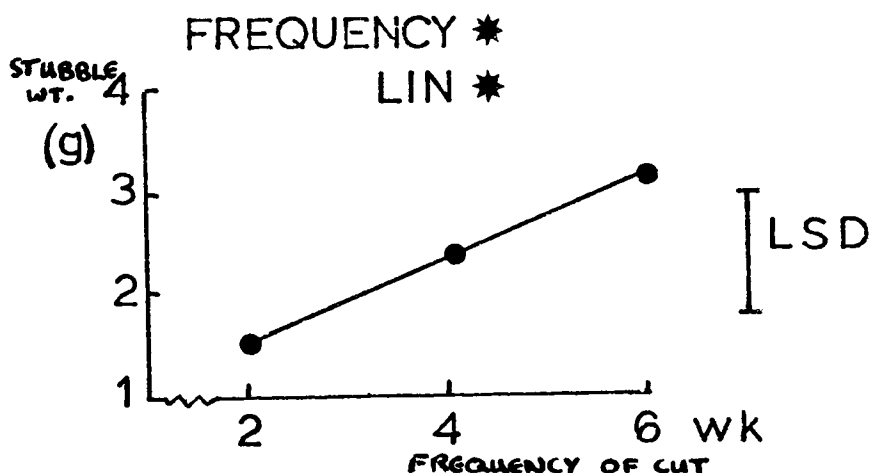
CULTURE X FREQUENCY NS

C. CUT AT 100 mm



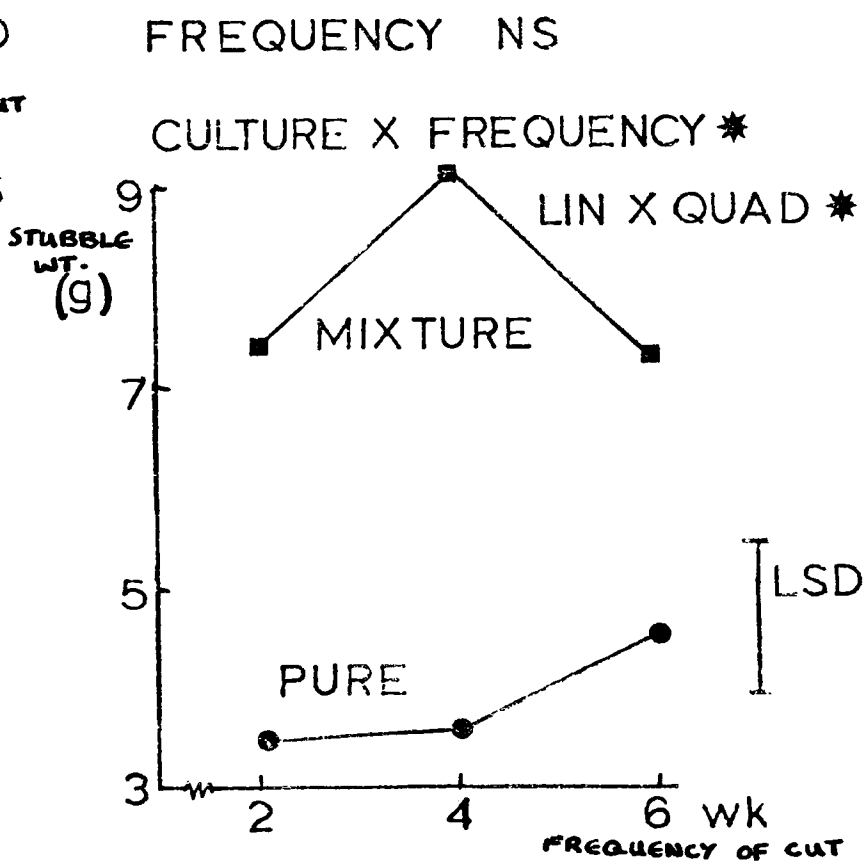
H.lanatus

A. CUT AT 25 mm

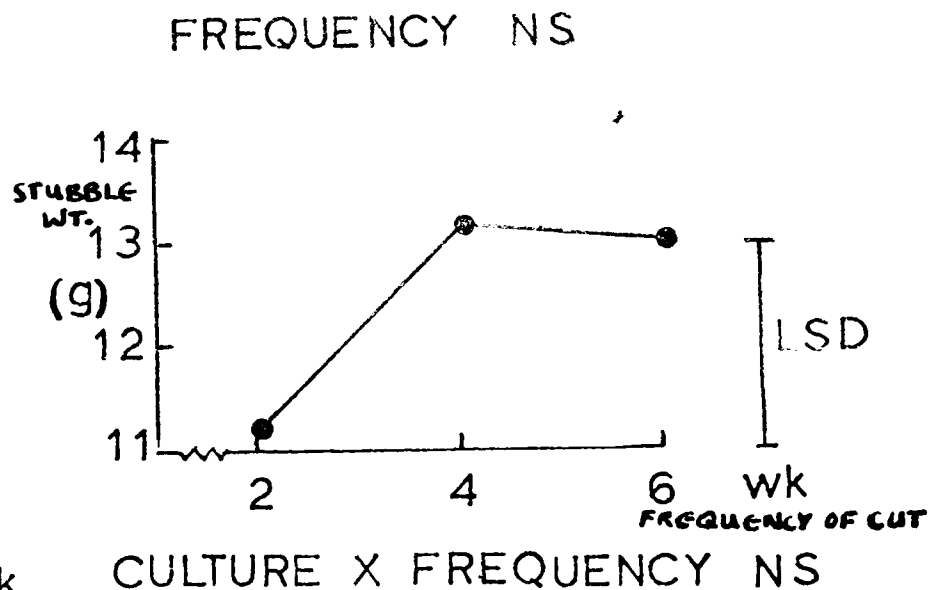


CULTURE X FREQUENCY NS

B. CUT AT 50 mm



C. CUT AT 100 mm



CULTURE X FREQUENCY NS

TABLE 12

The stubble dry weight (g.) of H. lanatus and L. perenne in pure versus mixed culture at 3 heights of cut.

Figures are means of 3 frequencies of cut

HEIGHT OF CUT mm	25	50	100
<u>L. perenne</u>			
Pure	1.9	4.8	9.6
Significance	NSD	**	***
Mixed	1.6	2.6	4.0
<u>H. lanatus</u>			
Pure	1.6	3.9	9.1
Significance	**	***	***
Mixed	3.2	8.0	15.9

TABLE 13

The SCORE of panicles of H. lanatus and L. perenne, grown in pure culture, over the first 12 weeks. Figures are the means of 3 heights of cut

FREQUENCY OF CUT (WK.)	<u>L. PERENNE</u>	<u>H. LANATUS</u>	SIGNIFICANCE OF DIFFERENCE
2	1.6	0	***
4	1.9	0.8	***
6	4.5	4.2	NSD

FIGURE 31

STUBBLE FORMED BY
 Percentage of H. lanatus in mixed culture at 3
 heights of cut in 1975. Figures are means of 3
 frequencies of cut.

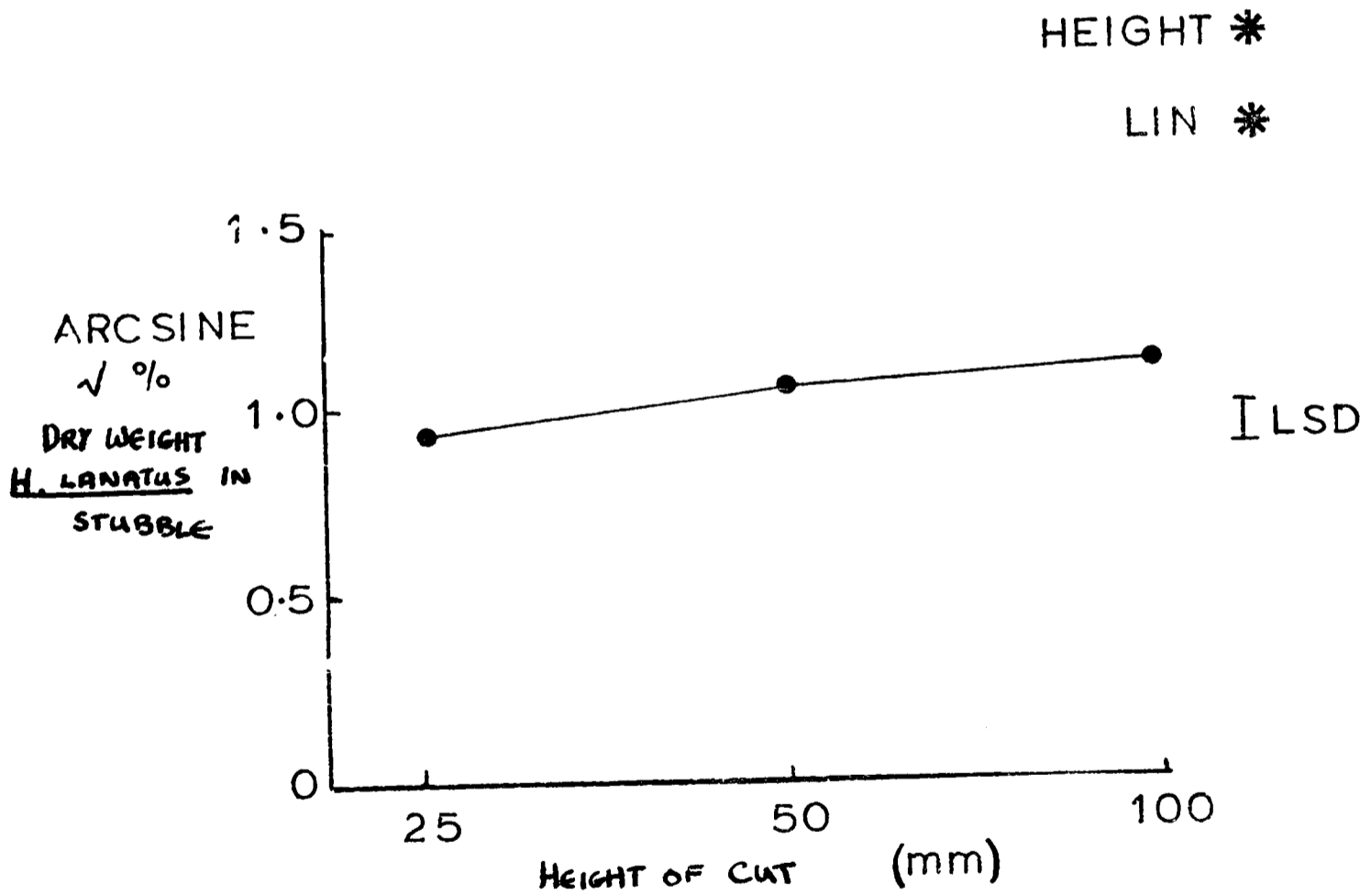


FIGURE 32

Cumulative presence of panicles or panicles/ buds of H.lanatus AND FLOWER & L.perenne at 3 heights of cutting over 12 weeks in 1975.

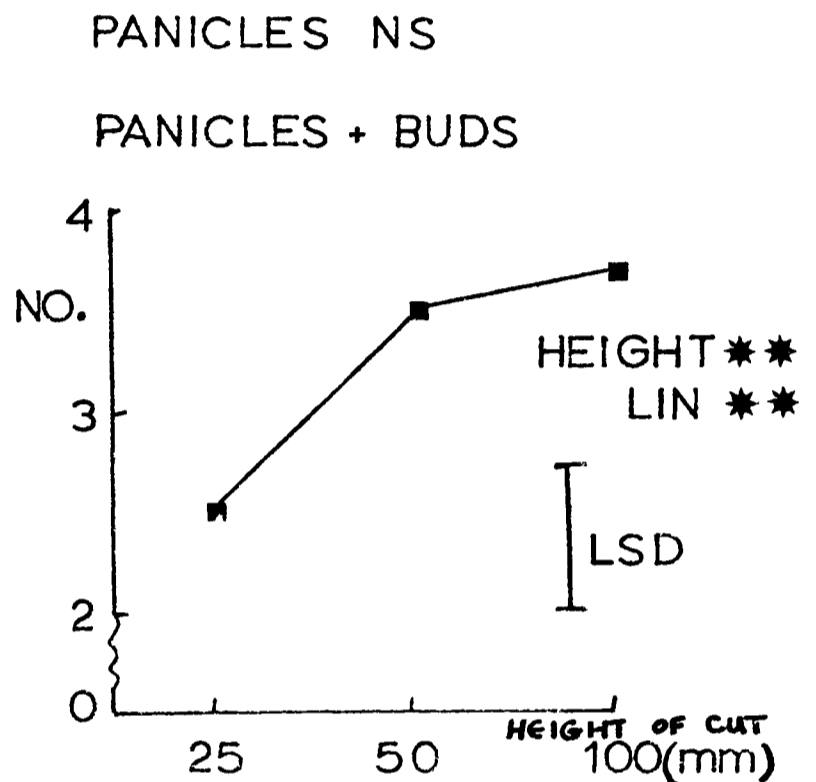
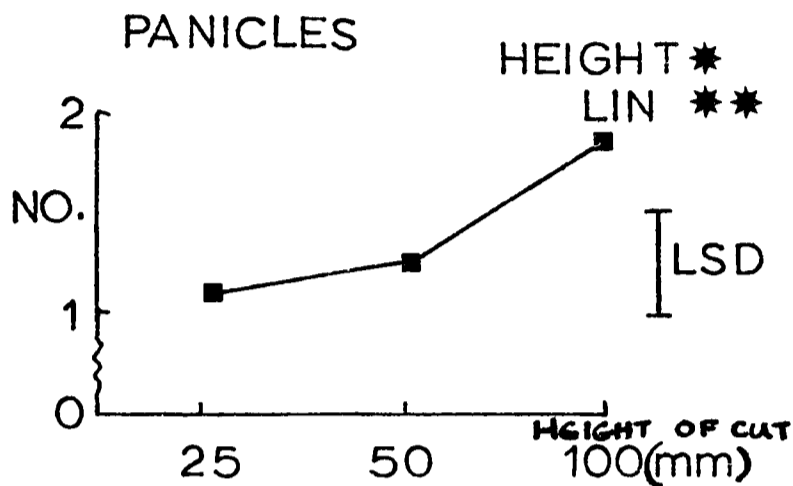
Figures are means of pure & mixed cultures

L.perenne

H.lanatus

A. CUT EVERY 2 WEEKS

A. CUT EVERY 2 WEEKS



PANICLES + BUDS NS

B. CUT EVERY 4 WEEKS

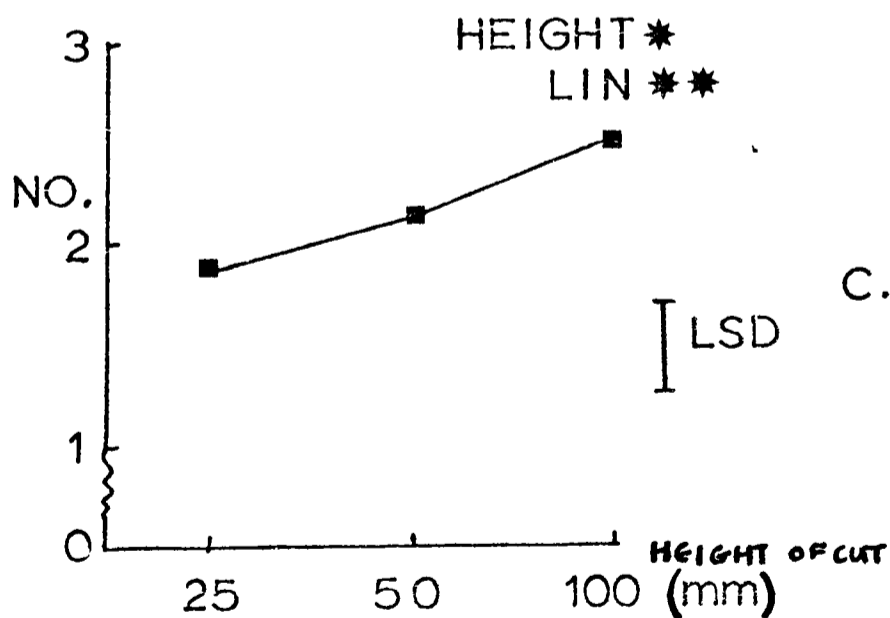
B. CUT EVERY 4 WEEKS

PANICLES NS

PANICLES NS

PANICLES + BUDS

PANICLES + BUDS NS



C. CUT EVERY 6 WEEKS

PANICLES NS

PANICLES + BUDS NS

C. CUT EVERY 6 WEEKS

PANICLES NS

PANICLES + BUDS NS

did H. lanatus plants (Table 13, p. 78).

H. lanatus. When H. lanatus plants were cut every two weeks no panicles were produced. However, the number of H. lanatus plants which had flower buds, increased with height of cutting at this frequency (Fig. 32A, p. 80). When H. lanatus plants were cut every month or six weeks the height of cut did not affect the number of plants with panicles and/or flower buds (Fig. 32B and C, p. 80).

L. perenne. When L. perenne was cut monthly there was no difference between the heights of cutting with respect to the number of plants bearing panicles. However, the number of plants with panicles and/or flower buds increased with height of cutting (Fig. 32B, p. 80). At the six week interval there was no significant difference between the cutting treatments (Fig. 32C, p. 80).

FIELD EXPERIMENT

SHOOT DRY WEIGHTS - 1976

The cumulative shoot dry weights for the twenty four weeks of the experiment are given in Figure 33 (p. 82).

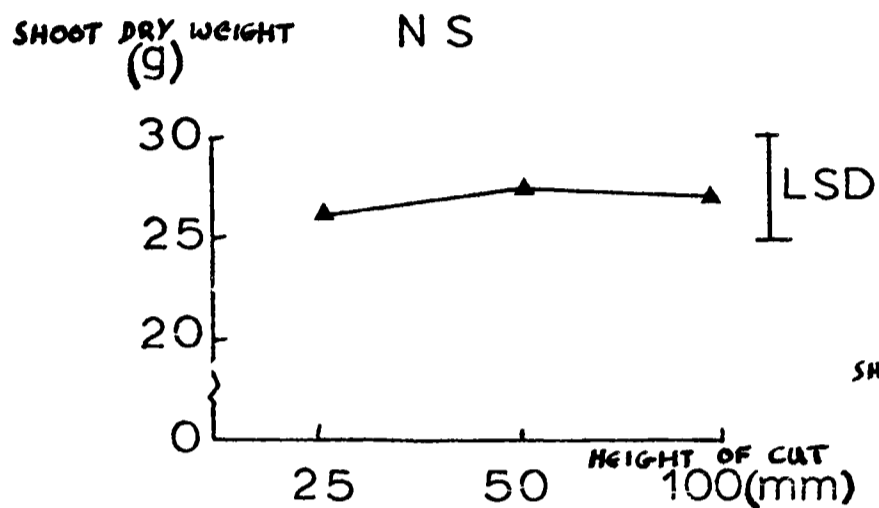
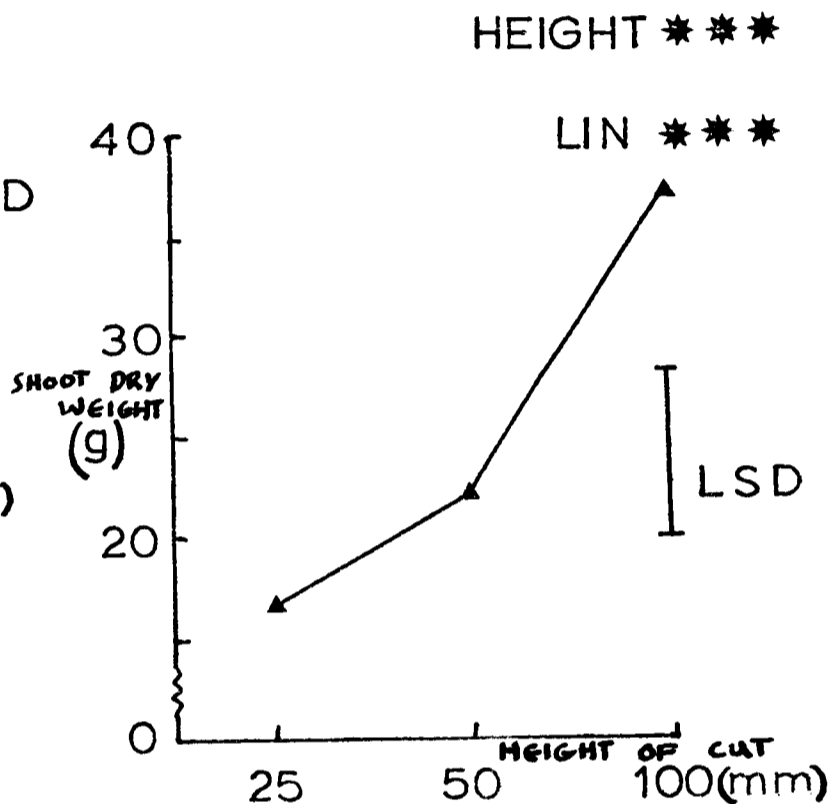
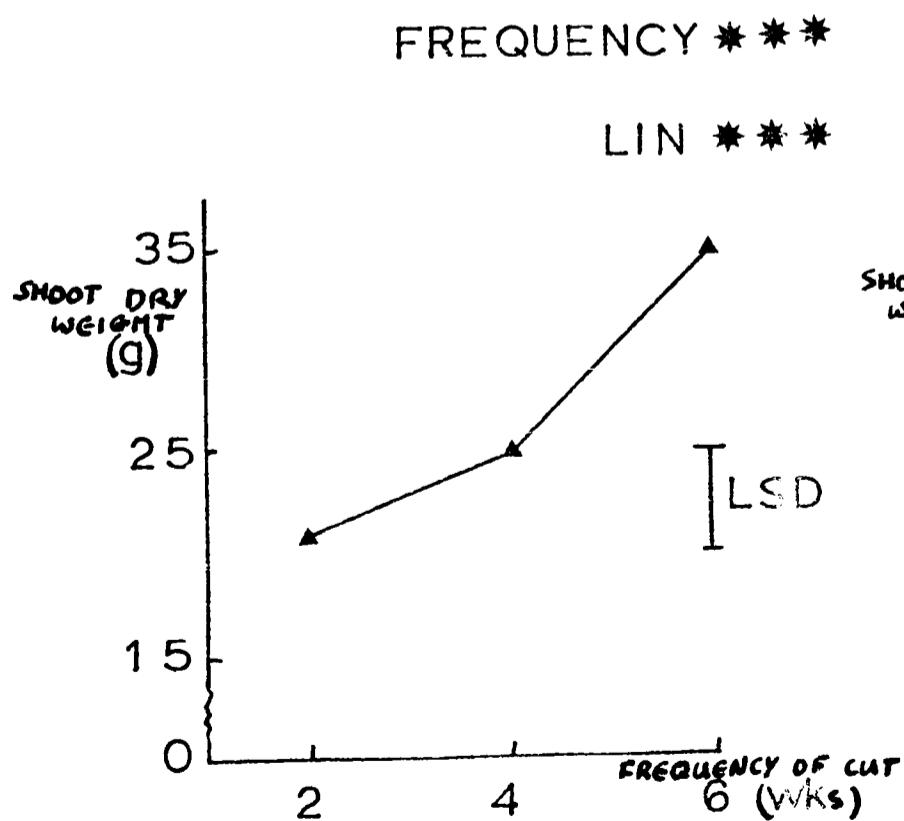
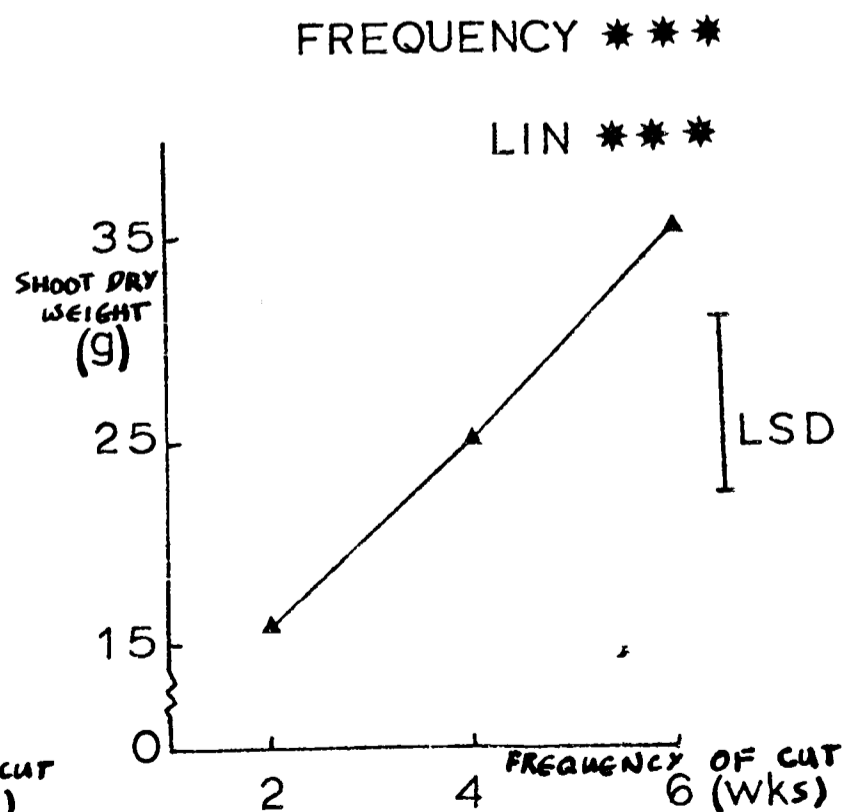
Height of cut. The height of cut did not significantly affect the yield of L. perenne but the greater the height at which H. lanatus was cut, the greater its yield (Fig. 33A, p. 82). At 25mm and 50mm, L. perenne yielded more than H. lanatus but at 100mm cutting height this was reversed.

Frequency of cut. Both species showed a highly significant linear trend of increasing yield with less frequent cutting (Fig. 33B, p. 82).

Culture x frequency interactions. There were no significant interactions.

FIGURE 33

Cumulative shoot dry weights of H.lanatus & L.perenne over 24 weeks in 1976. Figures are means of pure & mixed cultures

L.perenneA. Effect of height of cutH.lanatusA. Effect of height of cutB. Effect of frequencyB. Effect of frequency

STUBBLE DRY WEIGHTS - 1976

The stubble dry weights of both species are presented in Figure 34 (p. 84) for the three heights of cutting. The amount of L. perenne stubble present was unaffected by the frequency of cutting. When H. lanatus had been cut at 100mm there was more stubble present when it had been cut infrequently (Fig. 34C, p. 84). This also occurred when H. lanatus had been cut at 25mm but only when it was grown in pure culture (Fig. 34A, p. 84).

The effect of height of cutting on the percentage of H. lanatus in the stubble is shown in Figure 35 (p. 85). The proportion of H. lanatus stubble in mixed culture increased linearly with increasing height of cut.

PANICLES AND FLOWER BUDS - 1976

Only L. perenne plants flowered in this experiment. The presence of panicles and flower buds on L. perenne at three frequencies of cutting is shown in Figure 36 (p. 86). When the grass was cut every two weeks more plants produced panicles or flower buds as the height of cutting was increased (Fig. 36A, p. 86). When L. perenne was cut every month or six weeks, more plants produced panicles when growing in pure than in mixed culture (Fig. 36B and C, p. 86).

FIELD EXPERIMENT - 1977

At the third harvest (29 June) two features were noted. Firstly, that many L. perenne plants were stunted, possibly due to virus infection, and had not grown since they were first cut and, secondly, that H. lanatus plants which had been treated with the aim of allowing them to flower were not going to flower. The experiment was, therefore, abandoned and no results are presented.

FIGURE 34

Stubble dry weights (g./3 pots) of H.lanatus & L.perenne at 3 heights & 3 frequencies of cutting in 1976.

L.perenne

H.lanatus

A. CUT AT 25 mm

A. CUT AT 25 mm

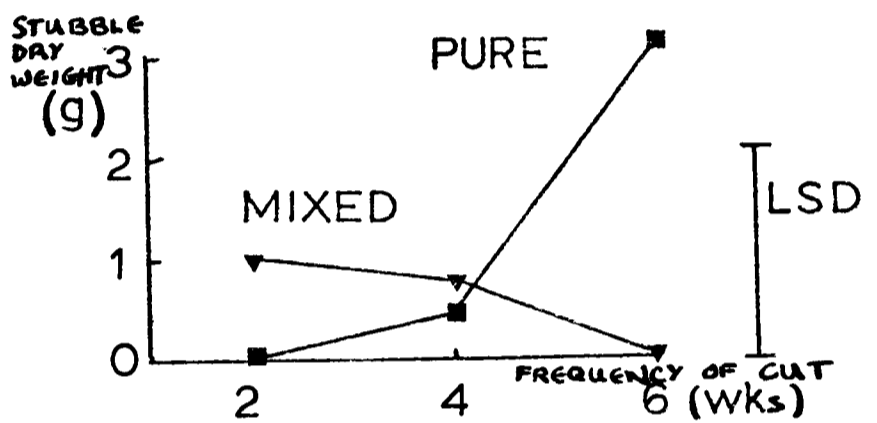
FREQUENCY N S

FREQUENCY N S

CULTURE X FREQUENCY N S

CULTURE X FREQUENCY *

LIN X LIN *



B. CUT AT 50 mm

B. CUT AT 50 mm

FREQUENCY N S

FREQUENCY N S

CULTURE X FREQUENCY N S

CULTURE X FREQUENCY N S

C. CUT AT 100 mm

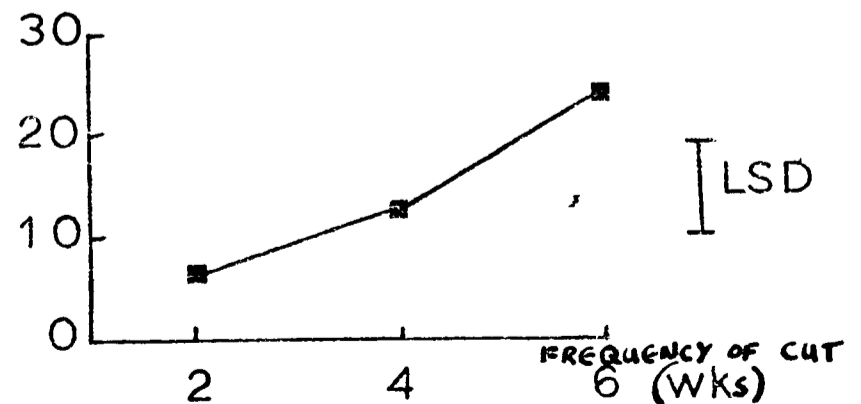
C. CUT AT 100 mm

FREQUENCY N S

FREQUENCY **

CULTURE X FREQUENCY N S

STUBBLE DRY WEIGHT (g) (mean of pure & mixed) LIN **



CULTURE X FREQUENCY N S

FIGURE 35

STUBBLE FORMED BY
Percentage of H. lanatus

in mixed culture at 3

heights of cut in 1976. Figures are means of 3 frequencies
of cut

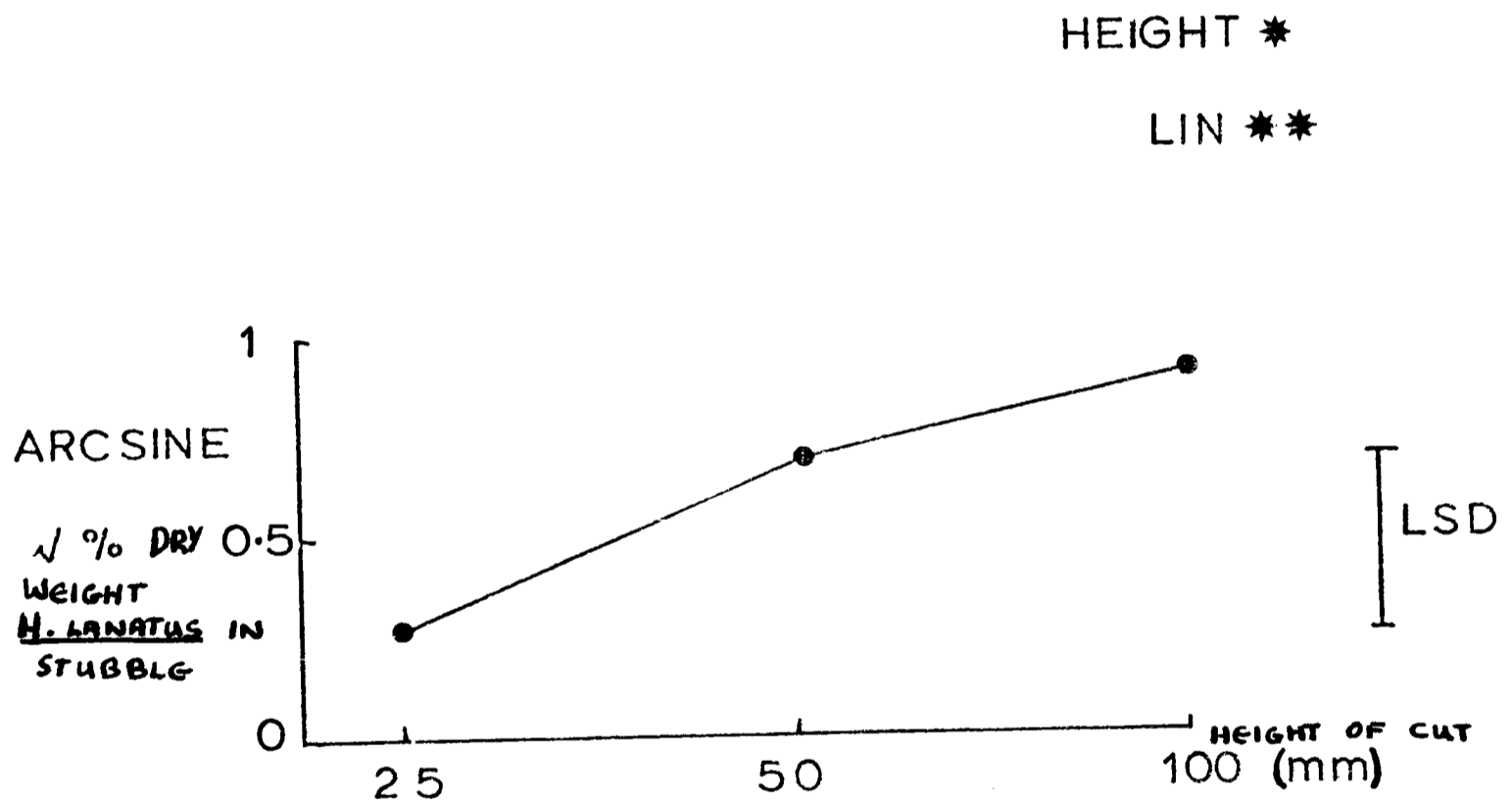


FIGURE 36

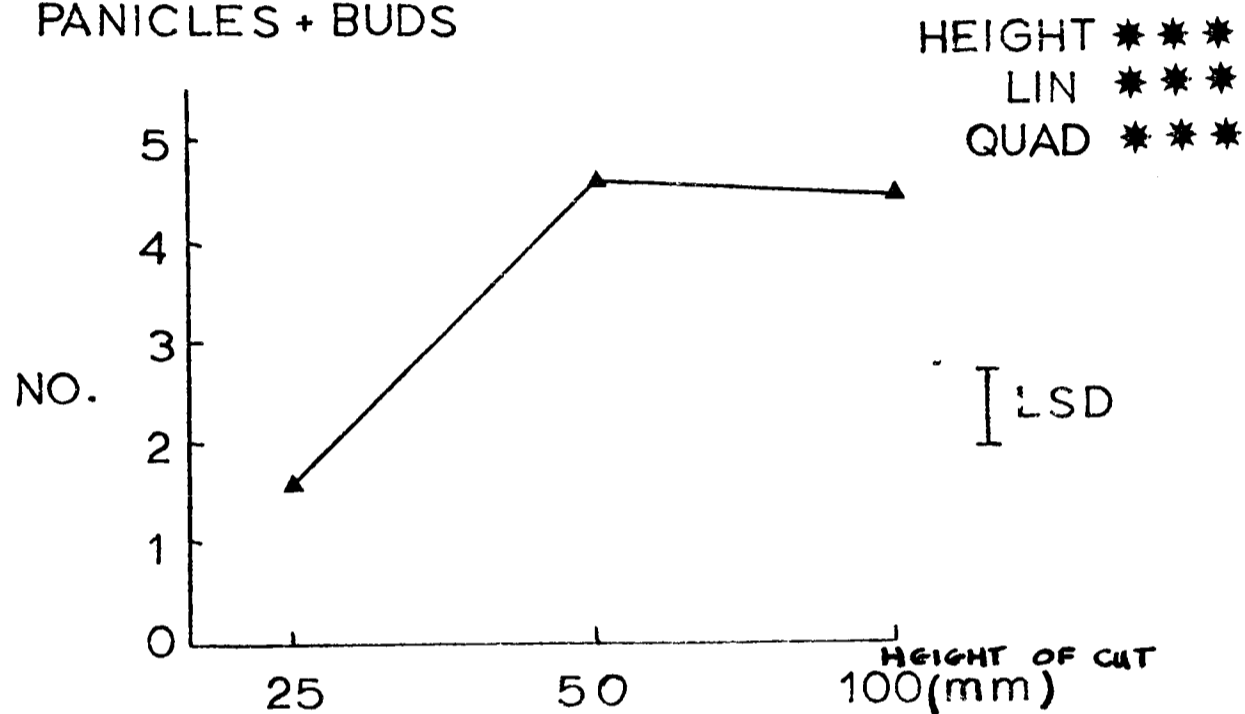
Cumulative presence of panicles or panicles ^{AND FLOWER} buds of L.perenne at 3 heights of cutting over 12 weeks in 1976.

Figures are means of pure & mixed cultures

A. CUT EVERY 2 WEEKS

PANICLES N S

PANICLES + BUDS



B. CUT EVERY 4 WEEKS

PANICLES

PURE 2.2 MIXED 1.7 CULTURE *

PANICLES + BUDS N S

C. CUT EVERY 6 WEEKS

PANICLES

PURE 1.9 MIXED 1.3 CULTURE *

PANICLES + BUDS N S

DISCUSSION

INTRODUCTION

Numerous experiments have been carried out to study the effect of height and frequency of defoliation on the dry matter yield of grassland. In general, higher yields have been recorded with less frequent defoliation (Woodman and Norman, 1932). Many people have found that low cutting increased herbage yields of mixed swards as compared with high cutting (Robinson and Sprague, 1947; Robinson, Sprague and Lueck, 1952; Burger, Jacobs and Hittle, 1958; Reid, 1959). However, both Roberts and Hunt (1936) and Brougham (1959) found that high cutting was preferable to low cutting. It seems that the results obtained depend upon the grass species present (Stapledon, 1924; Miles, 1960; Langville and Warren, 1961; Reid, 1962; Black and Alexander, 1967), fertilizer nitrogen (Reid, 1959; Holliday and Wilman, 1965; Binnie, Harrington and Murdoch, 1974; Frame, 1975), soil moisture (Jäntti and Kramer, 1956; Appadurai and Holmes, 1964) and on the presence of clover (Reid, 1959; 1962; 1966; 1967; 1968).

It has been suggested (Brougham, 1958) that maximum productivity is obtained from a sward when all incoming light is intercepted and it has been shown that a lower initial rate of regrowth may occur when swards are cut shorter and light interception is low (Brougham, 1956).

EFFECT OF HEIGHT AND FREQUENCY

OF CUTTING ON DRY WEIGHT

This work has shown that both L. perenne and H. lanatus gave greater yields of shoot dry weight with longer intervals between cuts. This confirms the findings of Ennik (1965). Also, the yield of H. lanatus increased with greater heights of cutting, but the yield of L. perenne was unaffected (p. 89 , line 7).

EFFECT OF HEIGHT OF CUTTING ON FLOWERING

Height of cutting also had an effect upon the flowering of the two species. In the glasshouse experiment, H. lanatus plants did not produce any panicles when cut every two weeks but the number of plants which produced flower buds increased linearly with increasing height of cutting. Under the same conditions the number of L. perenne plants which produced panicles increased with increasing height of cutting, but, when the numbers of flower buds and panicles were combined, there was no significant difference. This indicates that a low height of cutting delays flowering when applied frequently. When the monthly cutting of L. perenne is considered, the number of plants producing panicles or flower buds increased with height of cutting indicating that a low height of cutting may reduce or delay panicle production.

TOLERANCE OF LOW CUTTING BY L. PERENNE

Many H. lanatus plants died in the field in the 1976 experiment when they were subjected to frequent, low defoliation. Lolium perenne plants were not so badly affected. This is in agreement with the work of Sithamparanathan (1963) who found that H. lanatus plants had only half the root dry weight of L. perenne plants when both species had been cut frequently and close to the soil surface. Brougham (1957) even found that a frequent, low cutting treatment increased the tiller density of L. perenne in a sward. Variation in response to defoliation pressures by different grasses has been related to the number and position of tiller sites (Stapledon, 1924; Jackson, 1974). The photosynthetic efficiency of the stubble and the level of plant reserves have also been implicated (Brougham, 1957).

A study of the reserves in L. perenne has shown the importance of fructosan (Norman, 1936) which is stored in the 'stem' bases (Norman and Richardson, 1937). This suggests that if L. perenne is cut even as low as 25mm these reserves should not be greatly affected. Indeed, Sullivan and Sprague (1943) have shown that for L. perenne, frequency of cutting has a greater effect than does height of cutting on yield. The results of the experiments described here support this finding. Possibly, H. lanatus is less able to tolerate low defoliation because its reserves are not concentrated in the 'stem' bases like those of L. perenne.

This suggests that if a mixed sward is undergrazed or allowed to grow on for hay production, H. lanatus will tend to dominate L. perenne. Whereas, if a sward is intensively grazed with perhaps an early silage cut, H. lanatus will not have such an advantage.

HOLCUS LANATUS DOMINATION

OF MIXTURES

In the glasshouse experiment, when neither water nor nutrients was limiting, H. lanatus dominated mixtures with L. perenne under all except the most severe treatments. Holcus lanatus had a greater shoot and stubble dry weight yield per plant when grown in mixture whereas L. perenne had a greater shoot and stubble dry weight in monoculture. Also, the response of increased stubble weight per plant of L. perenne with less frequent cutting at 100mm only occurred in monoculture and not when grown with H. lanatus. In the 1976 field experiment, more L. perenne plants produced panicles in pure than in mixed culture.

The work of Riveros (1963) has shown that H. lanatus can intercept more light than L. perenne and in my first experiment, H. lanatus was clearly shading L. perenne in most treatments. Such almost completely closed canopy systems have been reported by Chadhokar and Humphreys (1973) and Robson (1973). Such intense shading is likely to cause a fall in tiller production

(Langer, Ryle and Jewiss, 1964). Within a period of six weeks the rate of respiration in the dark of a seedling sward of L. perenne has been found to increase seven-fold (Robson, 1973). Plants with a majority of leaves under low light were found to be unable to compensate from the photosynthesis of better placed leaves since the rate of photosynthesis was adversely affected (Woledge, 1972). Also, a reduction in light level caused more photosynthate to go to the main terminal meristem instead of the other tillers and roots in Lolium temulentum (Ryle and Powell, 1976). Thus, shade can cause the death of tillers and whole plants.

The fact that H. lanatus readily dominated L. perenne under infrequent cutting confirms field observations. Holcus lanatus and other unsown species readily invade infrequently defoliated L. perenne swards. But, in the 1976 field experiment H. lanatus did not dominate mixtures with L. perenne to the same extent as in the glasshouse experiment. This may have been because the foliage in the glasshouse experiment was held erect by tubes of mesh whereas in the field it could flop sideways - causing less shading of the L. perenne. Also, the H. lanatus plants in the 1976 experiment did not flower probably because they had not been vernalized. So, their growth habit was again less erect and shading.

Charles (pers. comm.) found that L. perenne dominated H. lanatus after a series of three cuts at monthly intervals. His work was carried out on young plants germinated from seed in boxes so it appears that H. lanatus is not so aggressive in the seedling stage as it can be as an established plant.

Another possible reason why H. lanatus did not dominate L. perenne in the 1976 field experiment may be that there was a drought whereas water was non-limiting in the glasshouse experiment. Although the plants were watered regularly by hand this did not prevent water stress. It was noticeable that H. lanatus plants appeared wilted more often than L. perenne plants. Work

by Appadurai and Holmes (1964) has shown that interactions may occur between soil moisture and the height at which grasses are cut.

1977 Field experiment. This experiment failed to resolve the question of why H. lanatus had not dominated L. perenne as much in the 1976 field experiment as it had done in the 1975 glasshouse experiment. This was because none of the H. lanatus plants flowered. However, other plants of H. lanatus, also brought into the glasshouse from outside in February, did flower (Chapter 4, p. 59). It seems likely, therefore, that the plants in this experiment were devernalized either by being divided up at that time or by being transplanted into the field in the spring. In the field they were subjected to frost and shorter days than they had been in the heated glasshouse with a 16h day.

There are many cases of high temperature causing devernalization in plants (Schwabe, 1955; van de Pol, 1972). This cannot be the explanation in this case. Transfer to short days and low light intensity has caused devernalization in Sinapis alba (Bagnard, Bernier and Arnal, 1972). This may be the explanation here. However, the reason may lie in other stresses associated with transplanting outside such as water stress or defoliation.

CONCLUSIONS

The higher H. lanatus plants were cut, the greater their shoot dry weight but height of cutting did not affect the yield of L. perenne. This suggests that H. lanatus would tend to dominate L. perenne in an infrequently defoliated sward. Less frequent cutting increased the total shoot dry weight of both species. Stubble yields generally followed shoot dry weights.

In a glasshouse experiment, H. lanatus dominated a 50:50 mixture with L. perenne, but it did not do so in the field. This may have been due to water stress, less shading of L. perenne by H. lanatus or because H. lanatus

did not flower in the field experiment. More research is needed to discover the reason for this devernalization. Both frequent and low cutting restricted the flowering of both species in the glasshouse experiment.

CHAPTER 6

FIELD ESTABLISHMENT, WEED INGRESS

AND RESPONSE TO TREADING OF

H. LANATUS AND L. PERENNEINTRODUCTION

ESTABLISHMENT AND WEED INGRESS

Previous experiments (Chapter 2, p. 4) have studied the establishment of H. lanatus from spaced seeds in bare soil and from seed spread onto established swards. This experiment was designed to observe THE establishment ^{OF H. LANATUS} in a newly sown sward both in monoculture and in mixture with L. perenne. The major weeds which invaded these swards were also to be noted.

EFFECT OF TREADING ON SWARDS

Treading can have a marked effect on sward yields (Edmond, 1958; 1964) and composition (Brown and Evans, 1973) both directly on the plants and through the soil. However, in one trial, Charles (1972) found that the effect of treading within one grazing season varied from a reduction in yield or no significant effect, to an increase in yield following treading in a dry period.

Indirect effects. Cattle grazing, compared with cutting, increases soil bulk density (Richards, 1973). Such soil compaction reduces aeration (Steinbrenner, 1951), water penetration (Alderfer and Robinson, 1947) and root growth (Gupta, 1933).

Direct effects. Edmond (1966) observed that the leaves of trodden grasses were crushed and bruised on hard dry soil, buried in soft wet soil and covered with a film of mud in puddled and slurried soil. These effects either turn a sward into a standing hay crop in warm dry weather or restrict transpiration and gaseous diffusion when leaves are buried or sealed with mud.

EFFECT OF TREADING ON H. LANATUS

AND L. PERENNE

Edmond studied the effect of animal treading on a range of grassland species in work reviewed by Brown and Evans (1973). His results in New Zealand showed that treading decreased the yield of H. lanatus more than that of L. perenne and that it reduced the number of panicles produced by H. lanatus but increased the number produced by L. perenne (Edmond, 1964). Possible reasons for these differences are that the crowns of L. perenne plants are buried, unlike those of H. lanatus and so are cushioned from animal hooves by the soil (Sears, 1956). In addition, L. perenne leaves have a much greater tensile strength (Evans, 1967). It has also been found that H. lanatus is very susceptible to human trampling (Burden and Randerson, 1972). This experiment was designed to study the effect of different levels of treading on the yields of L. perenne and H. lanatus in monocultures and mixtures.

METHOD AND MATERIALS

On 24 April 1975 an area, 9m x 48m, on a three-year-old ryegrass sward on a sandy-loam soil at WRO, was marked out and sprayed with glyphosate at 3 kg a.i./ha to kill the sward. During May the area was rotavated and rolled. On 11 June, 250 kg/ha of 13:13:20 (N.P.K.) granular fertilizer was applied. The experiment consisted of three randomised blocks each containing nine plots (3m x 2m) arranged in three rows of three. In between each block

and at the ends of the experiment were areas where the cattle could be herded from one lane to the other and settle down to a walk before entering plots (Fig. 37, p. 96). On 11 June the plots were marked out, seed was broadcast as appropriate (Table 14, p. 97) and raked in by hand.

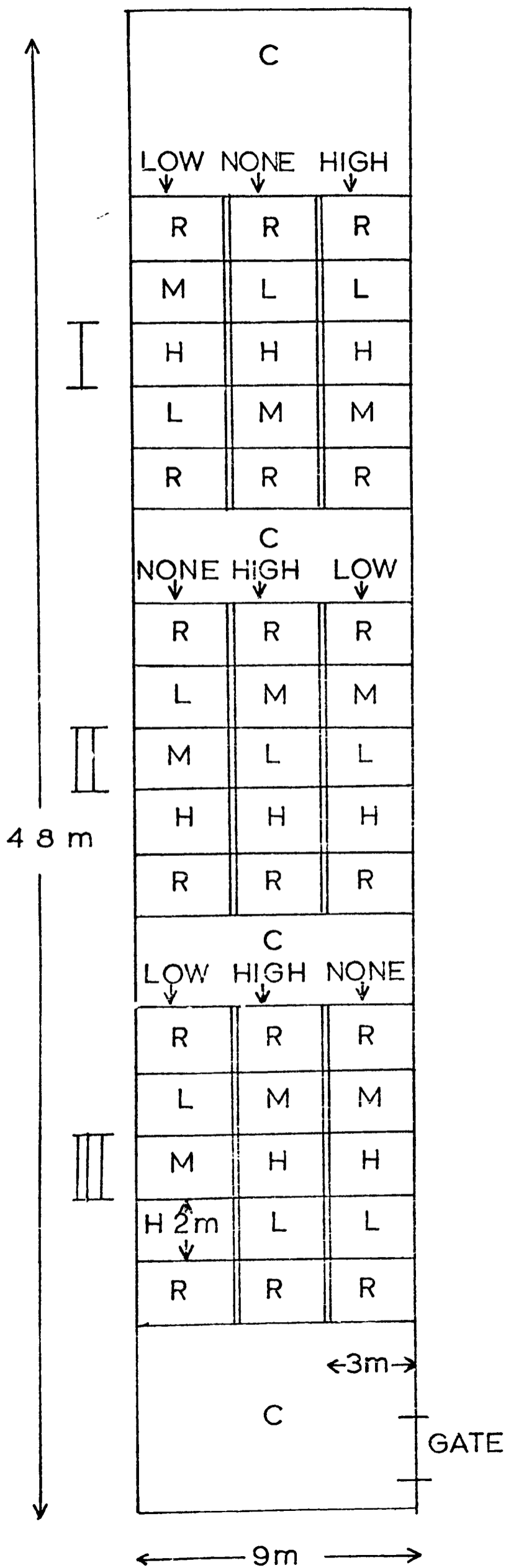
On 7 August the establishment of H. lanatus and L. perenne and of the main unsown species was noted and 2,4-DB was applied at 2.24 kg a.i./ha to kill most broadleaved weeds without damaging any clover present. On 12 August docks (Rumex spp.) were spot sprayed with MCPA. By 6 October it was found necessary to apply mecoprop at 2.5 kg a.i./ha to kill the rampant chickweed (Stellaria media). On 18 March 1976, 250 kg/ha of 13:13:20 granular fertilizer was applied. Although H. lanatus had established well in monoculture there was very little in the 'mixture' plots. So, five plants, each of about twenty tillers, which had been established in the glasshouse, were transplanted into the central square metre of each of these plots and watered regularly during two weeks.

During early May the farm staff erected a barbed wire fence with one gate round the edge of the experiment. Fencing posts were also placed in the ground at 6m intervals along the boundaries between the 'lanes'. On 14 May the area was cut to about 25mm above ground level using a Mayfield mower and the grass was removed.

On 17 May two strands of rope were used to separate the 'lanes' while seven cattle (each weighing 360-400 kg) were walked up and down the experiment at about 6 km/h to impose the three treading treatments (Table 15, p. 97). Appendix 8, (p. 252) shows how these were calculated. On 30 June one 450mm square quadrat was placed in the centre of each plot. The herbage which had regrown within the area was cut to about 25mm above the soil surface. The samples were sorted into H. lanatus, L. perenne, Poa annua and broadleaved species and their dry weights were recorded. A series of three treadings, each followed by a harvest, was made and the dates of the

FIGURE 37

Plan of treading experiment



KEY

L	<u>L.perenne</u>
H	<u>H.lanatus</u>
M	<u>L.perenne</u> + <u>H.lanatus</u>
C	Collecting & crossing over area
R	Running in area
NONE LOW HIGH	Treading levels

TABLE 14

Seeds sown in the treading experiment

PLOT TYPE	SPECIES	kg/ha
Monoculture ryegrass	S23 <u>Lolium perenne</u>	16.8
Monoculture Yorkshire fog	'local' <u>Holcus lanatus</u>	16.8
Mixture	S23 <u>L. perenne</u>	8.4
	'local' <u>H. lanatus</u>	8.4

TABLE 15

Levels of treading in the treading experiment

LEVEL	HOW IMPOSED (no. of passages of 7 cattle)	STOCKING RATE cattle/ha/dy
None	None	0
Low	8	2.8
High	24	8.4

operations are given in Table 16 (p. 99). By the final treading the cattle weighed about 500 kg each (Fig. 38, p. 100).

RESULTS

ESTABLISHMENT

Establishment of the sown species was best on the L. perenne monoculture plots. Establishment by H. lanatus in monoculture was not as great but was adequate. However, L. perenne dominated the mixed plots and very few H. lanatus plants became established in them.

INVASION BY POA ANNUA AND BROAD-LEAVED WEEDS

By 7 August there were large numbers of weeds in the plots. There was no obvious difference in their distribution related to the species sown on the plots. There were several dock plants (Rumex spp.) which were well established and probably originated from old tap roots. Other major weeds were, chickweed (Stellaria media), knotgrass (Polygonum aviculare), groundsel (Senecio vulgaris) and Poa annua. Herbicides were applied to control the broad-leaved weeds (p. 95).

At the first harvest the shoot dry weight of P. annua from H. lanatus plots was much greater than from L. perenne plots, with the mixed plots being intermediate (Table 17, p. 99). However, at the next two harvests there was no significant difference in the amount of P. annua in these plots. The amounts of broad-leaved weeds present at the harvests were so small that they were not analysed.

TABLE 16

Dates on which treatments were carried out in 1976

HARVEST NUMBER	CUT ALL OVER (25mm)	FERTILIZED (250 kg/ha 13:13:20)	TRODDEN (7 CATTLE)	SAMPLED (25mm)
Harvest 1	14 May.	18 Mar.	17 May.	30 Jun.
Harvest 2	1 Jul.	14 Jul.	2 Aug.	13 Oct.
Harvest 3	14 Oct.	26 Oct.	15 Nov.	5 Apr. (1977)

TABLE 17

Amount of Poa annua present at Harvest 1

	PLOT		
	<u>L. perenne</u>	Mixed	<u>H. lanatus</u>
Shoot dry weight <u>Poa annua</u> g/quadrat	2.4	7.5	21.1

Cattle on the treading experiment, 15 November 1976



EFFECT OF TREADING AND CULTURE UPON
SHOOT DRY WEIGHT

The effect of treading upon the shoot dry weights of H. lanatus and L. perenne at the first harvest is shown in Figure 39 (p.102). Treading made no significant difference to the yield of L. perenne, whereas the high level significantly decreased the yield of H. lanatus. In harvests two and three there was no significant effect of treading on yield. Neither was there any significant difference in the amount of P. annua present at different treading rates at any of the harvests.

Figure 40 (p.103) shows the consistent differences between the yields of H. lanatus and L. perenne at the three harvests. Lolium perenne still dominated the mixed plots.

DISCUSSION

ESTABLISHMENT

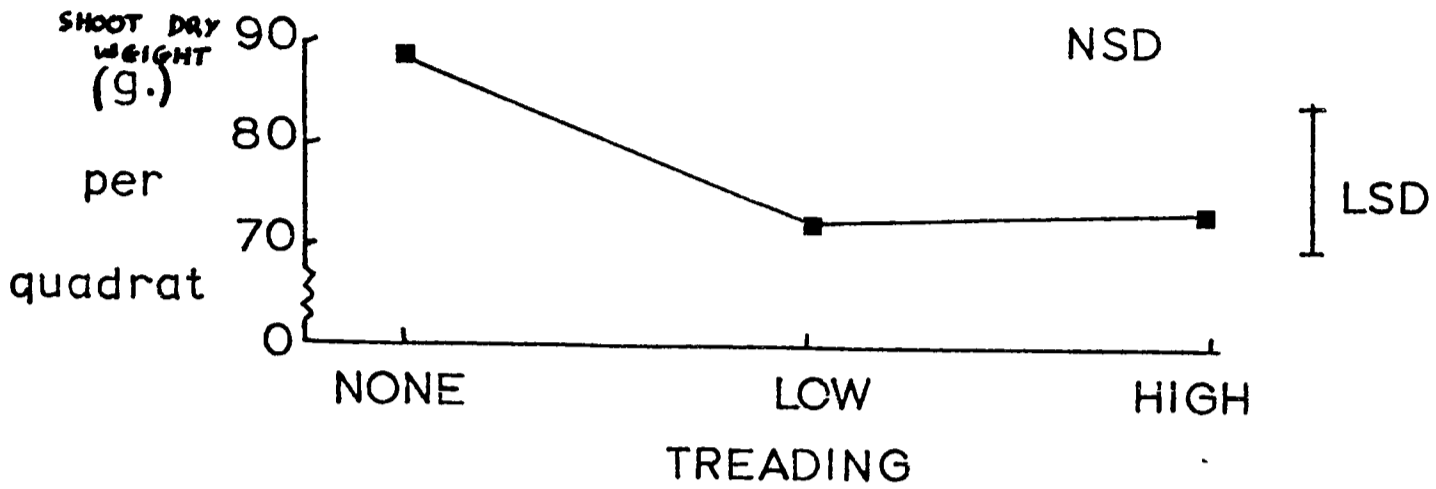
The relatively poor establishment of H. lanatus and good establishment of L. perenne in mixture was reflected in the yields of the grasses at subsequent harvests. Perhaps, L. perenne seedlings established more rapidly than those of H. lanatus, shading them and competing successfully with them for water and nutrients. Another possible explanation may be found in allelopathic effects. Newman and Rovira (1975) showed that L. perenne grew more slowly when receiving leachate from its own species than from H. lanatus. Whereas, H. lanatus grew faster when receiving leachate from itself than from L. perenne.

These results are in agreement with the work of Charles (pers. comm.) who found that L. perenne seedlings dominated H. lanatus seedlings in a mixture sown in boxes. Also, H. lanatus is not usually present in large amounts in newly sown lowland swards (Morrison and Idle, 1972).

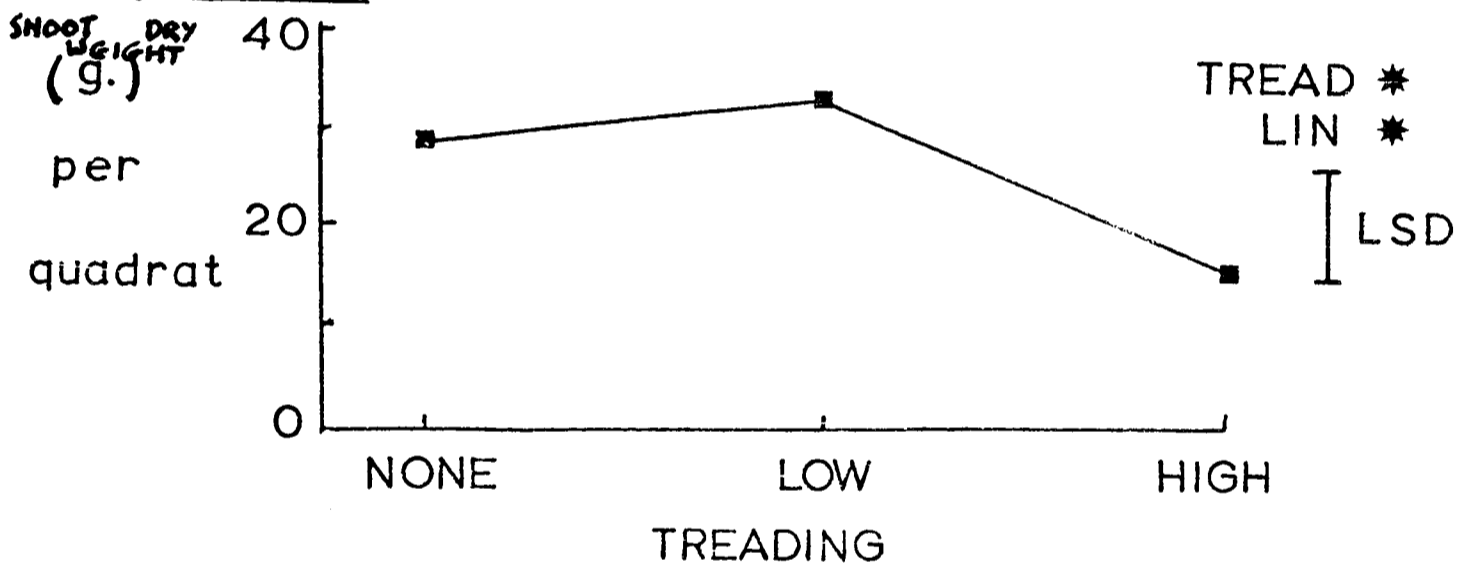
FIGURE 39

The shoot dry weight of H.lanatus & L.perenne under 3 levels of treading at Harvest 1 (30 June 1976)

A. L.perenne, mean of pure & mixed cultures



B. H.lanatus mean of pure & mixed cultures



C. H.lanatus & L.perenne monocultures

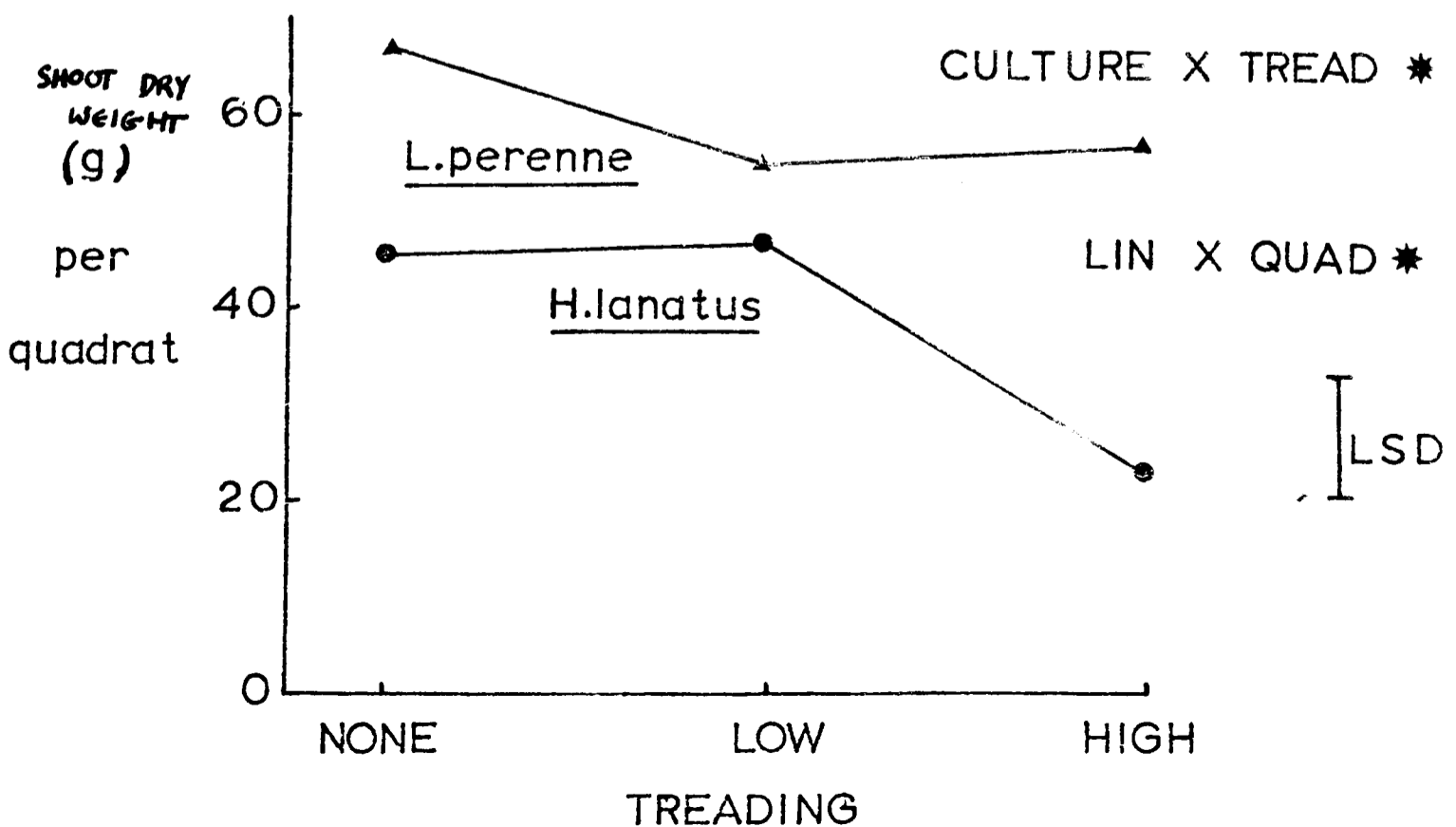
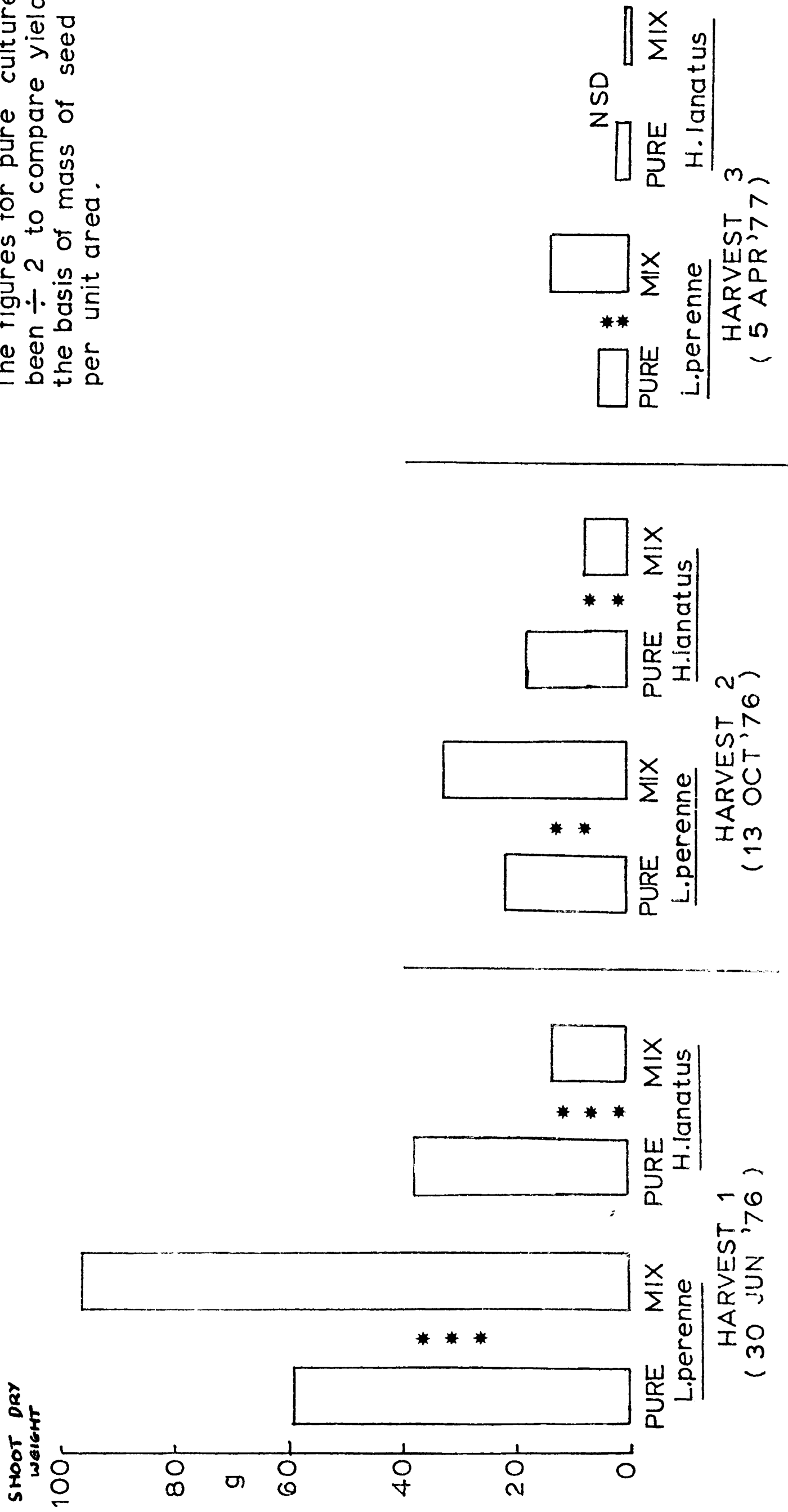


FIGURE 40

The shoot dry weight (g) of H.ianatus & L.perenne in pure & mixed culture at 3 harvests.
 Figures are means of 3 treading rates.

NOTE

The figures for pure cultures have been $\div 2$ to compare yields on the basis of mass of seed sown per unit area.



INVASION BY POA ANNUA

The rapid invasion of these newly sown swards by P. annua is typical of the behaviour of this species (Wells, 1974). A pilot survey of grassland in south east England showed that P. annua and Poa trivialis were the main weeds occurring in young swards. They reached a peak in nine to twenty-year-old swards, accounting for up to 20% of the sward and then declined in older swards. Other grasses such as Agrostis spp., Holcus lanatus and Festuca spp. usually replaced the Poa spp. (Morrison and Idle, 1972).

At the first harvest in this experiment more P. annua was present in H. lanatus plots (probably because the sward was less dense) and level of treading had no significant effect. This agrees with the work of Edmond (1964) who found that, in untrodden plots, there was only half the amount of P. annua in H. lanatus than in L. perenne plots. However, when the plots were heavily trodden he found four times more P. annua in H. lanatus than in L. perenne plots.

Possibly all H. lanatus plots were under drought stress in this experiment and so P. annua invaded them all at a high level, whereas in the New Zealand experiment, under wetter conditions, the more treading damage, the greater the space for P. annua. Most P. annua plants, being shallow rooting, died during the drought and new plants were only present as small seedlings by the final harvest. These results follow the peaks of P. annua seedling invasion of a sward which have been found to be May and September (Oswald and Haggar, 1975).

EFFECT OF TREADING ON SHOOT DRY WEIGHT

OF H. LANATUS AND L. PERENNE

The severe effect of treading upon the yield of H. lanatus, whilst not affecting L. perenne at the first harvest, confirms the work of Edmond (1964). There were no significant treading effects at the next two harvests. This might indicate that the crushing of leaves due to treading in dry conditions

damages H. lanatus more than the soil compaction and covering with mud that occur during treading in wet conditions. However, the results are confounded by the restrictions to growth due firstly to the drought and secondly to the winter. But, Edmond (1958) also found that the first treading of a series had the greatest effect.

CONCLUSIONS

Holcus lanatus does not establish well in a newly sown sward if it is in mixture with L. perenne. Heavy treading of a mixed sward can decrease the amount of H. lanatus present with little effect on L. perenne. However, L. perenne plants do not spread rapidly vegetatively and there are usually few L. perenne seeds in the soil (Chippindale and Milton, 1934) so, any bare patches produced will probably be filled by other species, e.g. P. annua and H. lanatus.

CHAPTER 7

EFFECT OF HEIGHT OF WATER TABLE ON THE
GROWTH OF H. LANATUS AND L. PERENNEINTRODUCTION

Various authors have noted that H. lanatus is frequently associated with wet sites (Armstrong, 1945; Burbidge, 1966; Grant and Brock, 1974). A pilot survey of grassland in south-east England indicated a tendency for H. lanatus both to invade swards earlier and to spread more rapidly on heavy, badly drained sites (Morrison and Idle, 1972). However, these findings may well be confounded with other factors such as low pH or low stocking rate.

The experiments, over two years, reported here, aimed to compare the growth of H. lanatus with that of L. perenne in soil subject to various levels of water table and in free-draining conditions. They were designed to discover whether H. lanatus yields better, or shows any adaptations which may enable it to survive better than L. perenne under high water table conditions.

METHOD AND MATERIALS

1975 EXPERIMENT

The containers used in this experiment were polypropylene water cisterns, 305mm deep, 430mm long and 305mm wide. A hole was drilled in the middle of one side of twenty seven cisterns, into which a two-holed rubber bung was fixed with weatherproof adhesive. An L-shaped piece of glass tubing was fitted into one of the holes in each bung so that the water level inside each cistern would be visible. The other hole formed the connection to the water supply. Nine other cisterns each had three 10mm diameter holes drilled into

the bottom of them. They were placed on two bricks and were not connected to the water supply. These were the free-draining treatments. The cisterns connected to the water supply were adjusted to produce 'low', 'medium' and 'high' water tables:

TABLE 18

TREATMENT	DEPTH OF WATER TABLE BELOW SOIL SURFACE (mm)
Low	210
Medium	110
High	50

To achieve these levels, cisterns were placed on breeze blocks and/or bricks. Fine adjustments were made after the system had equilibrated, using thin pieces of wood. An overflow hole was drilled in one side of these cisterns, just above their respective heights of water table, to provide rapid drainage of excess water during heavy rain. All holes were covered with 1mm diameter nylon mesh to prevent excessive soil loss.

The thirty six cisterns were arranged in three randomised blocks so that each block contained three cisterns of each of the four water table treatments. The main water supply tank was covered to keep out debris and it was connected to a standpipe via a ballvalve. Its exit pipe was connected to a system of black P.V.C. tubing which fed into the bung in each cistern. The connections were covered with black plastic to minimize algal growth.

Gravel was placed in the bottom of all the cisterns to a depth of about 25mm. They were then filled with unsterilized, medium loam soil to which fertilizer and other compounds had been added (Appendix 7, p.251). The system was set up on 12 June 1975 and allowed to equilibrate until 20 June when the final adjustments were made.

The H. lanatus and L. perenne plants used in this experiment were from tillers taken from the W.R.O. grassland on 4 and 5 February 1975 and established in potting compost in 60mm cubic plastic containers in the glasshouse with a 16h day, regular watering and a weekly 1% solution of Vitafeed (Appendix 7, p. 251). The mean weekly maximum temperature was 24°C and the mean weekly minimum temperature was 12°C. Six well-established plants were transplanted into each container on 23 June 1975, two days after the required water levels had been established. These plants were either all H. lanatus, all L. perenne or three of each, as required.

1976 EXPERIMENT

The equipment, soil and fertilizers used in this experiment were the same as in 1975. However, one of the aims was to compare the response of flowering and non-flowering H. lanatus. So, only free-draining, medium and high water tables were used so that each of them could contain L. perenne in monoculture, H. lanatus (flowering) in monoculture, L. perenne and H. lanatus (flowering) in mixture and, for separate analysis, H. lanatus (non-flowering) in monoculture.

The plants used in this experiment were established in the same way as in the previous experiment. However, the tillers were collected on 22 and 23 December 1975 and the mean weekly maximum temperature in the glasshouse was 18.3°C and the mean weekly minimum temperature was 9.9°C. The plants were transplanted into the containers on 17 March, with the exception of the 'non-flowering' H. lanatus plants which were not transplanted until 22 June. The water levels were satisfactorily established by 7 May.

TENSIOMETERS

1975. Tensiometers were set up to estimate the degree of water stress in the free-draining treatments. A properly working batch of six was set up on 2 July - one each in six of the nine free-draining treatments. Details of

these tensiometers are given by Webster (1966). The tensiometers were read every weekday and topped up regularly with distilled water.

1976. Tensiometers were used between 2 June and 30 August.

OBSERVATIONS

Details of the observations made in both years are given in Table 19 (p.110). An overall view of the experiment is shown in Figure 41 (p.111).

Incidental observation. During June 1975, seedlings of Chamaenerion angustifolium (Rosebay Willowherb) were observed in many of the high water table containers but in none of the other treatments. They were removed. The occurrence of seedlings of this species only in the high water table treatment agrees with findings of Myerscough and Whitehead (1966). They found not only that more seeds of this species germinated in wet soil, but also that germination was more rapid in wet soil compared to soil below field capacity.

RESULTS

TENSIOMETER READINGS

1975. Each reading was converted into soil water tension (T) using the formula:

$$T = 12.6M - 13.6R - H \quad (\text{Webster, 1966})$$

In which, M = level of mercury in capillary tube

R = level of mercury in reservoir

H = depth, below zero of the scale, of the highest part of the porous pot exposed to the soil.

The daily soil water tensions are shown in Figure 42 (p.112). From this graph the pot capacity of the soil was about 25 mbar.

TABLE 19

Details of the observations made during the watertable experiments in 1975 and 1976

DATE	OBSERVATION	HOW OBSERVED
7 Jul.-11 Dec. '75 & 2 Jun.-30 Aug. '76	Tensiometer readings	Read daily
12 Aug, 15 Sep. & 8 Oct. 1975 22 Jun. 20 Jul. & 24 Aug. 1976	Shoot dry weight <u>L. perenne</u> & <u>H. lanatus</u>	Cut plants 50 mm above soil. Sorted mixtures. Recorded dry weight per 3 plants
12 Aug. 15 Sep. & 8 Oct. 1975	Surface roots <u>H. lanatus</u>	Scored on 0-10 scale for pure & mixed cultures
20 Jul. 1976	Surface roots <u>H. lanatus</u>	Scored on 0-10 scale for pure 'non-flowering' cultures
12 Aug. 15 Sep. & 8 Oct. 1975	Adventitious roots <u>H. lanatus</u>	Counted number visible per plant in pure and mixed cultures
30 Aug. 1976	Adventitious roots <u>H. lanatus</u>	Counted number round edge of clump for pure 'non-flowering' cultures
1 Aug. 1976	Root dry weight <u>L. perenne</u> and <u>H. lanatus</u>	4 soil cores taken, each 50 mm deep & 65 mm diameter, vertically down each monoculture pot. Roots washed out & dry weight noted
15 Sep. 1975	% N in shoots of <u>L. perenne</u> and <u>H. lanatus</u>	Shoot material from monocultures dried, ground and analysed for total N by chemistry section
8 Oct. 1975	Number and % of live tillers and total number of tillers per plant of <u>H. lanatus</u>	Counted number of live tillers per plant in pure & mixed cultures. Scored amount of live tillers on 0-10 scale, hence estimated total tiller numbers
4 Sep. 1975 24 Aug. 1976	Angle of <u>H. lanatus</u> and <u>L. perenne</u> foliage	Using large protractor estimated % foliage in 0°-30°, 30°-60° & 60°-90° ranges. Hence calculated mean angle of foliage
20 Jul & 24 Aug. 1976	Number of <u>L. perenne</u> panicles and buds	Counted number per plant
Jun. 1975	Presence of <u>Chamaenerion angustifolium</u> seedlings	Noted in which treatments they occurred

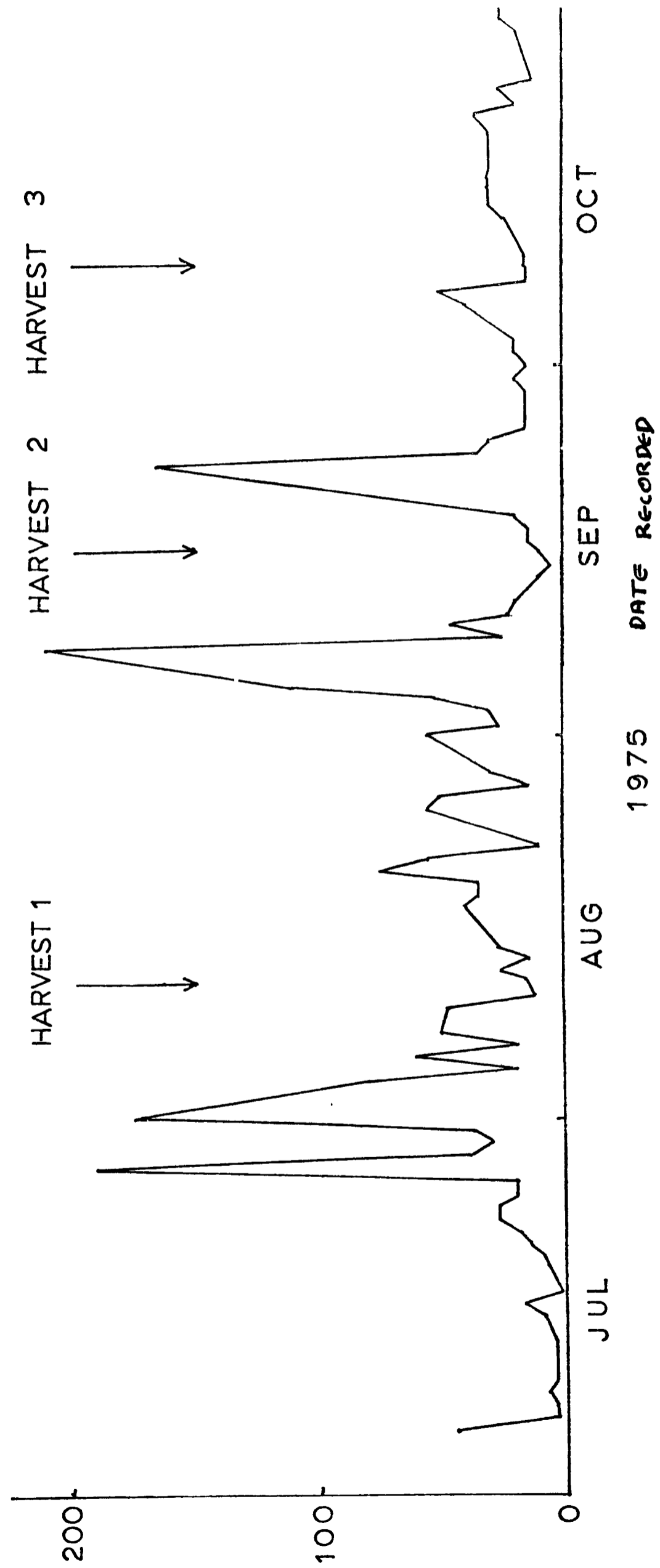
Overall view of water table experiment, February 1976



FIGURE 42

GEOMETRIC MEAN OF SOIL WATER TENSION mbar.

Soil water tension of free - draining treatment in 1975



1976. The results are shown in Figure 43 (p. 114).

SHOOT DRY WEIGHT OF H. LANATUS

AND L. PERENNE

1975. At the first harvest in 1975, the highest yields of H. lanatus and L. perenne were obtained from the low water table treatment (Fig. 44A, p. 115). This contrasts with the subsequent harvests in which the free-draining treatment provided optimum conditions and yields decreased with increasing height of water table (Fig. 44B and C, p. 115). The mean yield of H. lanatus from the four water table treatments was significantly greater than that of L. perenne at the first harvest but the reverse was found at the next two harvests. When the total yield from all three harvests was considered, there was no significant difference between the species in monocultures:

TABLE 20

SPECIES	HARVEST YIELDS(g)			TOTAL YIELD(g)
	1	2	3	
<u>L. perenne</u>	23.8	21.3	9.3	54.4
<u>H. lanatus</u>	31.8	16.1	7.1	55.0
Significance	*	* * *	*	NSD

Within each species there was no significant difference between yields in monoculture or mixture at any of the three harvests.

1976. At the first harvest the yield of both species decreased as the height of water table increased but L. perenne always yielded more than H. lanatus (Fig. 45, p. 116). However, considering the mean of the three water treatments, H. lanatus had a significantly greater yield per plant in

FIGURE 43

Soil water tension of free - draining treatment in 1976.

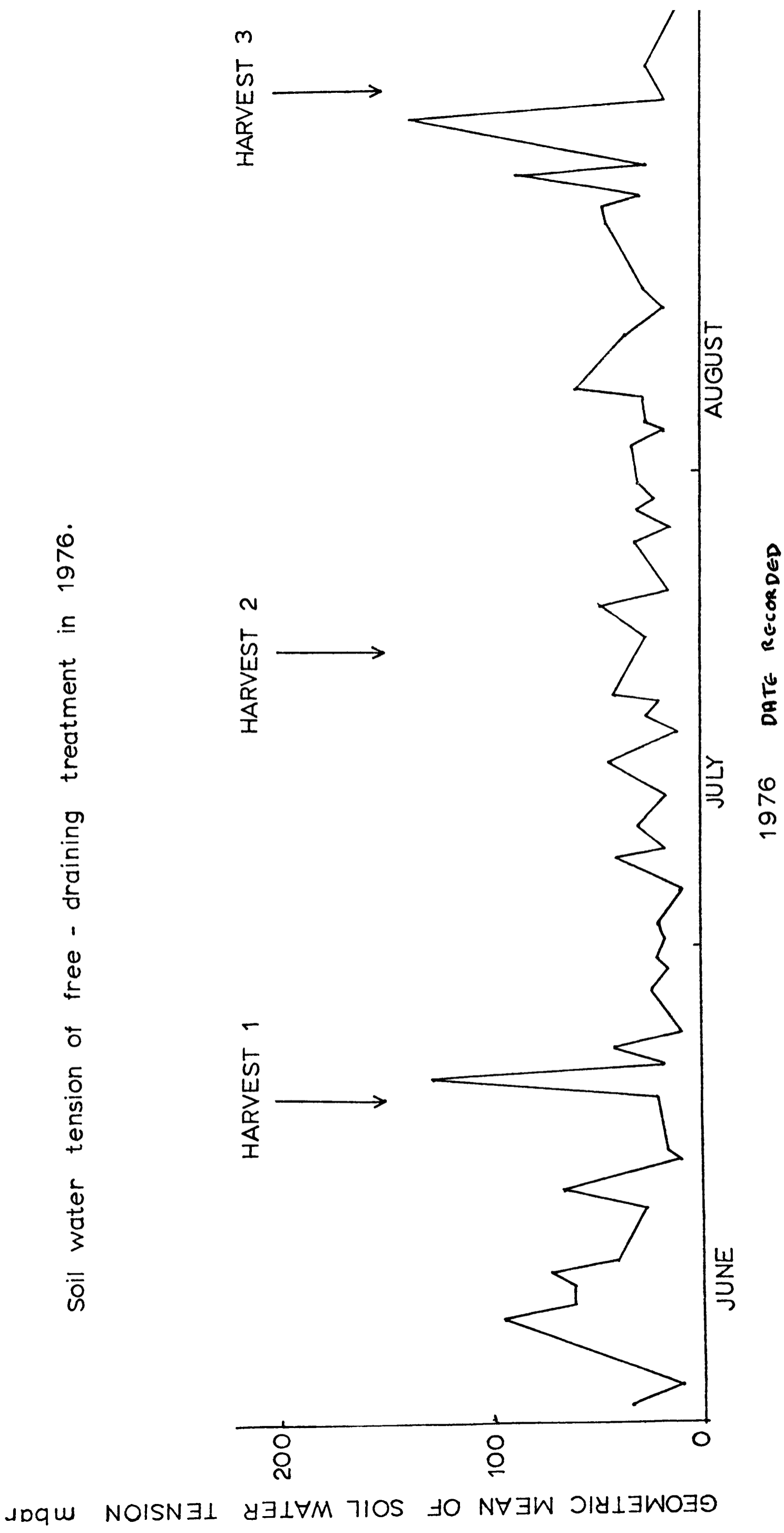


FIGURE 44

Shoot dry weights of H.lanatus & L.perenne in 4 water table treatments at 3 harvests in 1975.

(Figures are means of pure & mixed cultures)

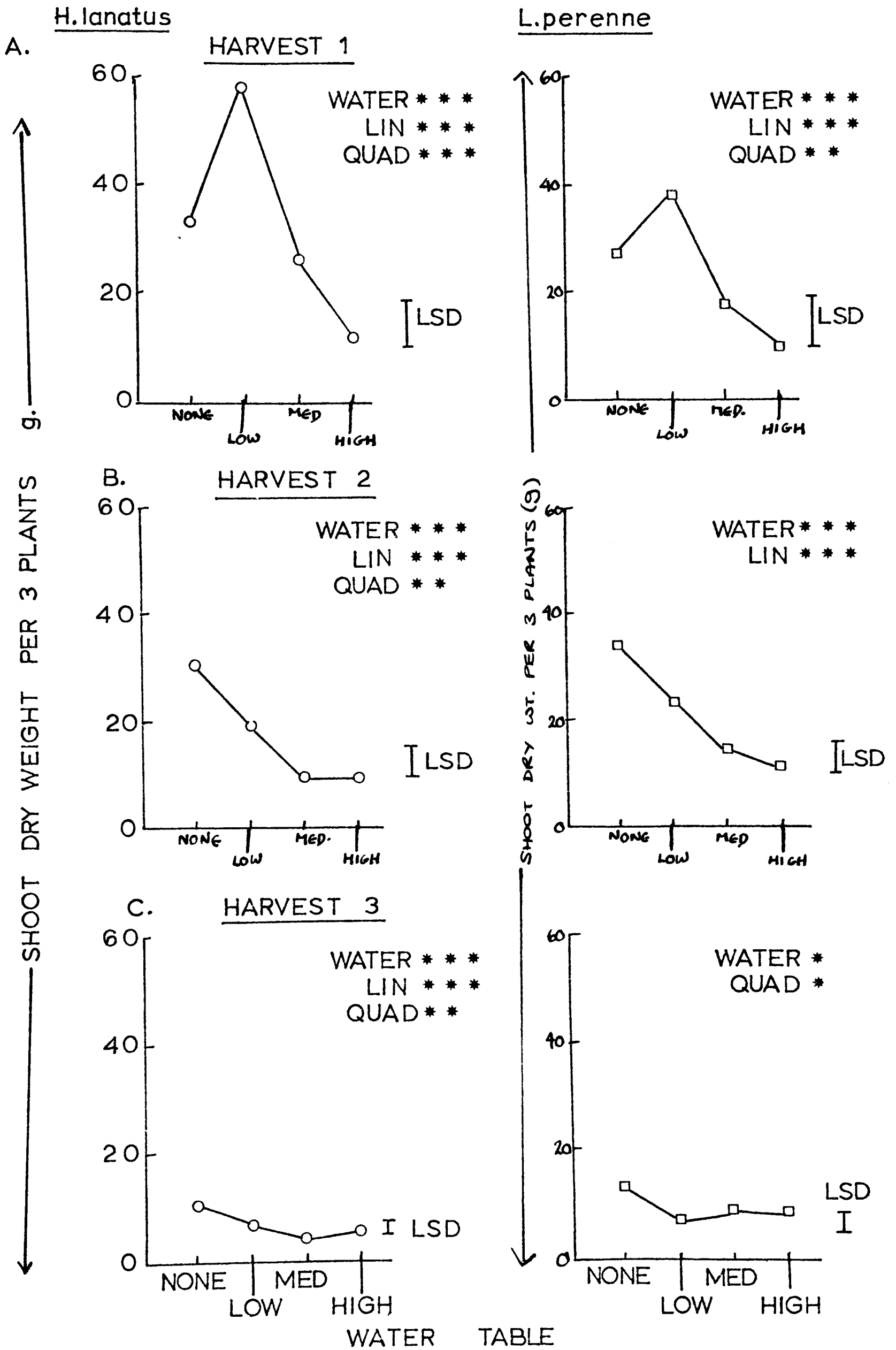
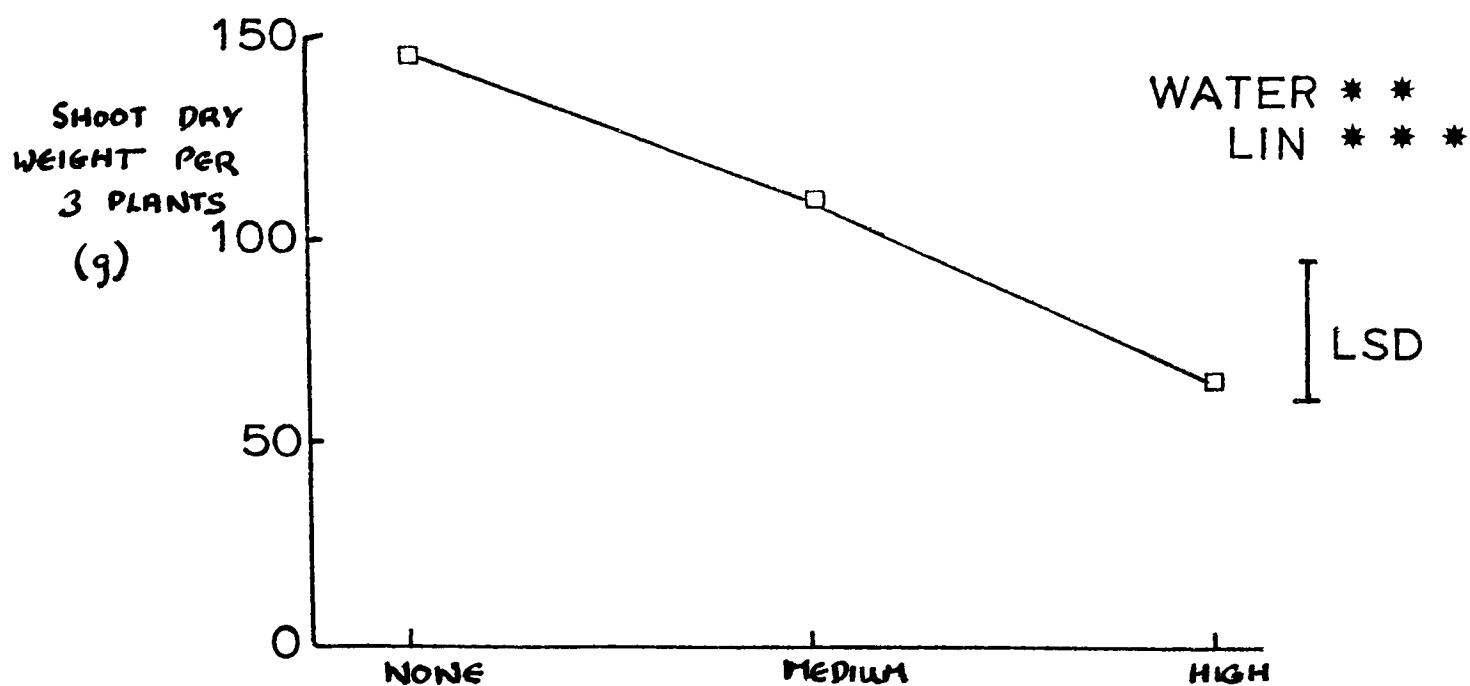


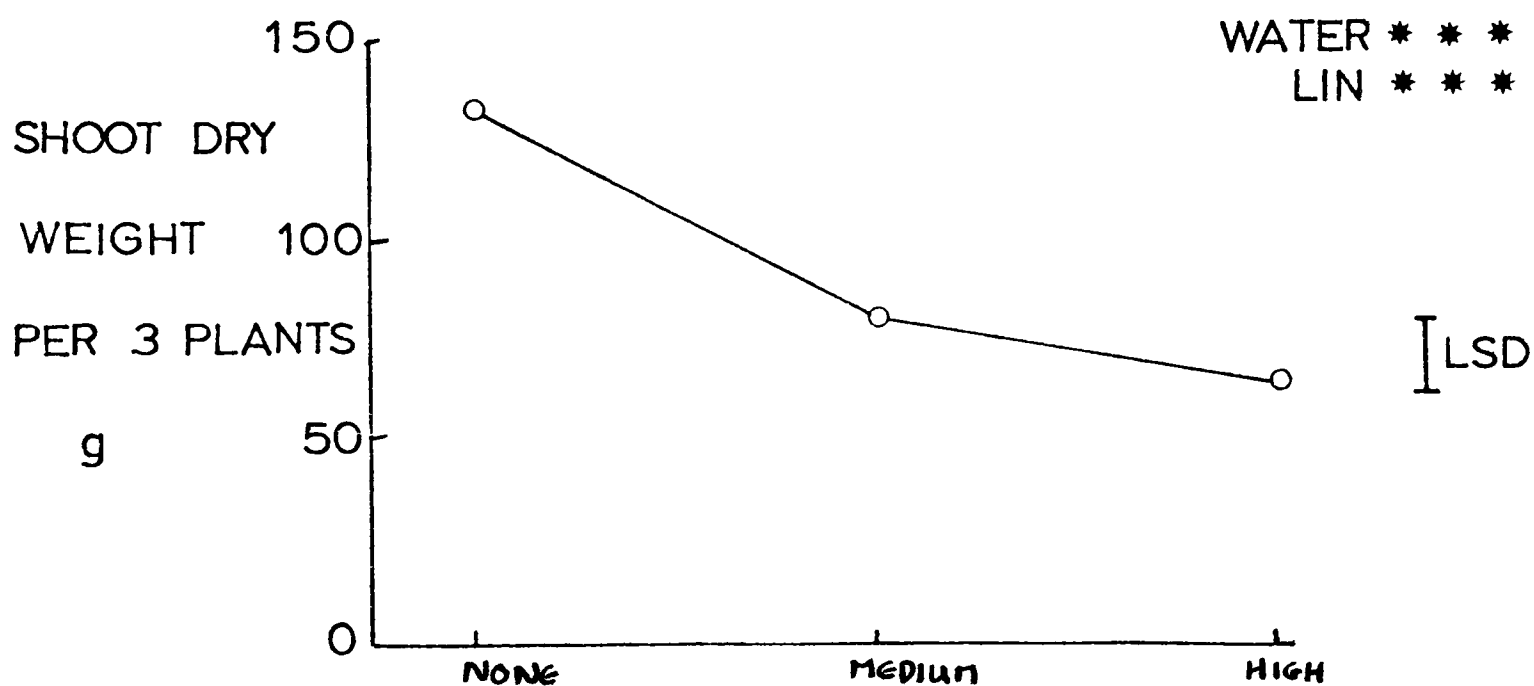
FIGURE 45

Shoot dry weights of H.lanatus & L.perenne in 3 water tables at the first harvest in 1976.

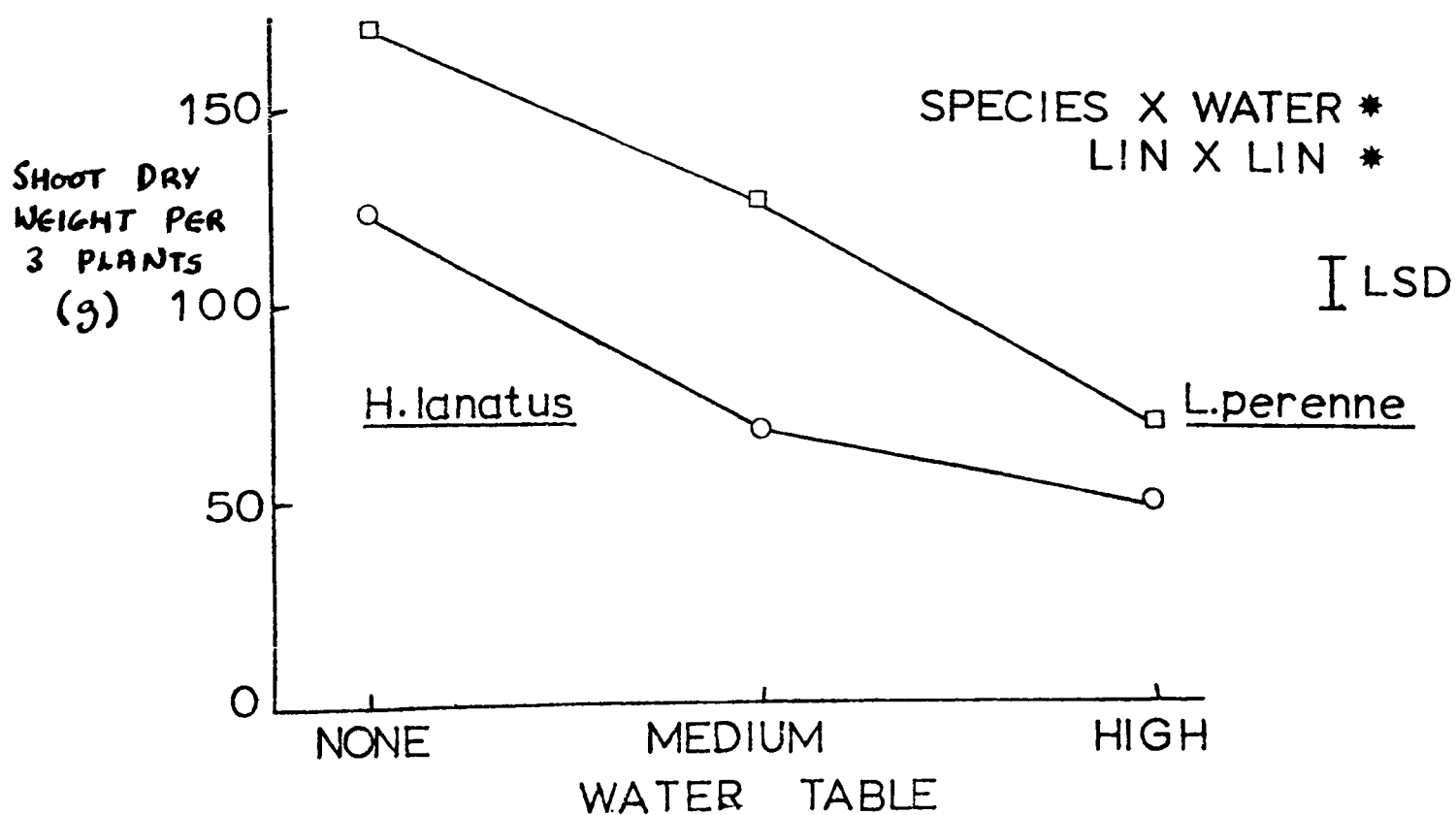
A. L.perenne, mean of pure & mixed cultures



B. H.lanatus, mean of pure & mixed cultures



C. H.lanatus & L.perenne in pure culture



mixture than in monoculture, whereas, L. perenne had a greater yield per plant in monoculture:

TABLE 21

SPECIES	YIELD/3 PLANTS AT HARVEST 1 IN MIXTURE(g)	MONOCULTURE(g)	SIGNIFICANCE
<u>L. perenne</u>	91.7	122.7	*
<u>H. lanatus</u>	105.3	81.2	**

At the second harvest there was a similar decrease in shoot dry weights with increasing height of water table but H. lanatus yielded significantly more than L. perenne in the free-draining treatment (Fig. 46C, p.118). The final harvest showed the same linear decrease in dry weight for H. lanatus, but there was no significant difference between the yields of L. perenne from the three water treatments. Lolium perenne yielded significantly more than H. lanatus at the high and medium water table treatments in monoculture (Fig. 47, p. 119).

SURFACE ROOTS PRODUCED BY

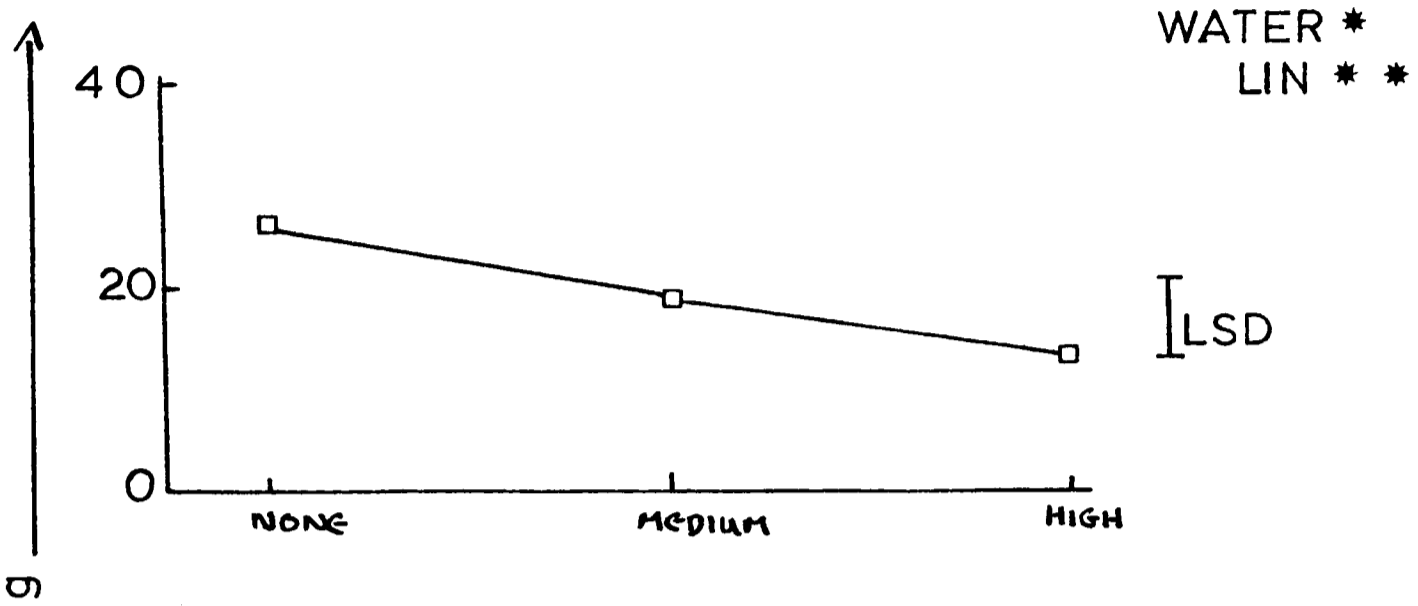
H. LANATUS - 1975

The distinction between the various types of roots produced by H. lanatus is shown in Figure 48 (p.120). Lolium perenne monoculture plants did not produce any surface roots during the experiment. So, the surface roots present in mixed culture were assumed to have been formed by H. lanatus plants as they had done in monoculture. In Figure 49 (p.121) the percentage cover of the soil surface by fine, surface roots is shown as the mean of pure and mixed cultures of H. lanatus for the four water treatments. The figures are arc sine square root transformations. As a guide, the actual percentage cover of the soil surface at harvest two was

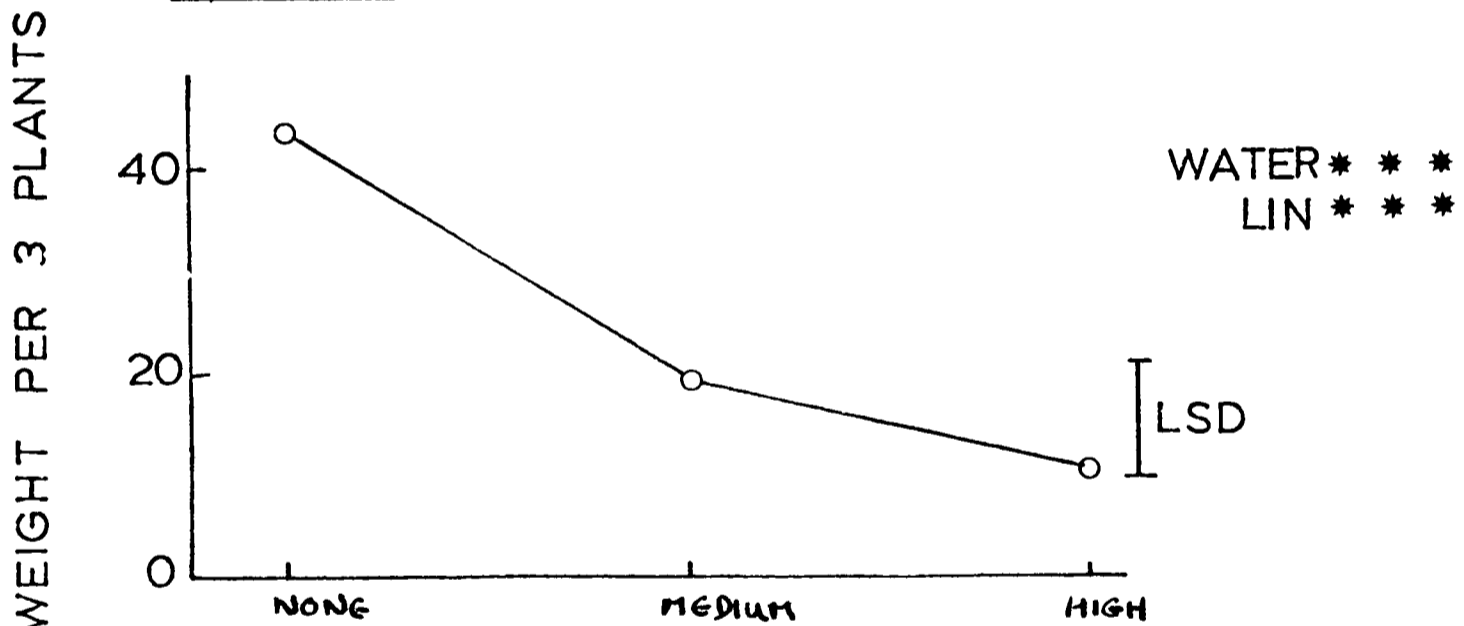
FIGURE 46

Shoot dry weight of H.lanatus & L.perenne in 3 water-table treatments at the second harvest in 1976

A. L.perenne, mean of pure & mixed cultures



B. H.lanatus, mean of pure & mixed cultures



C. H.lanatus & L.perenne in pure culture

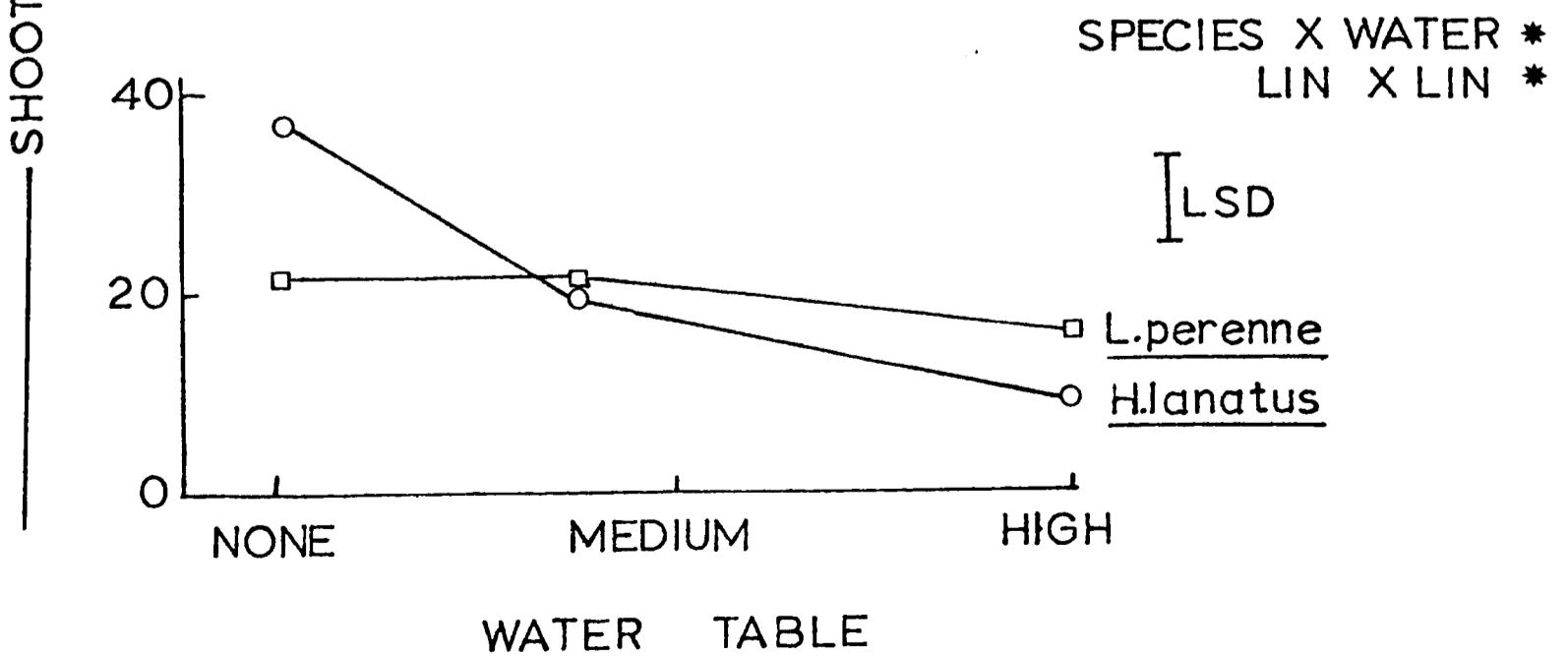
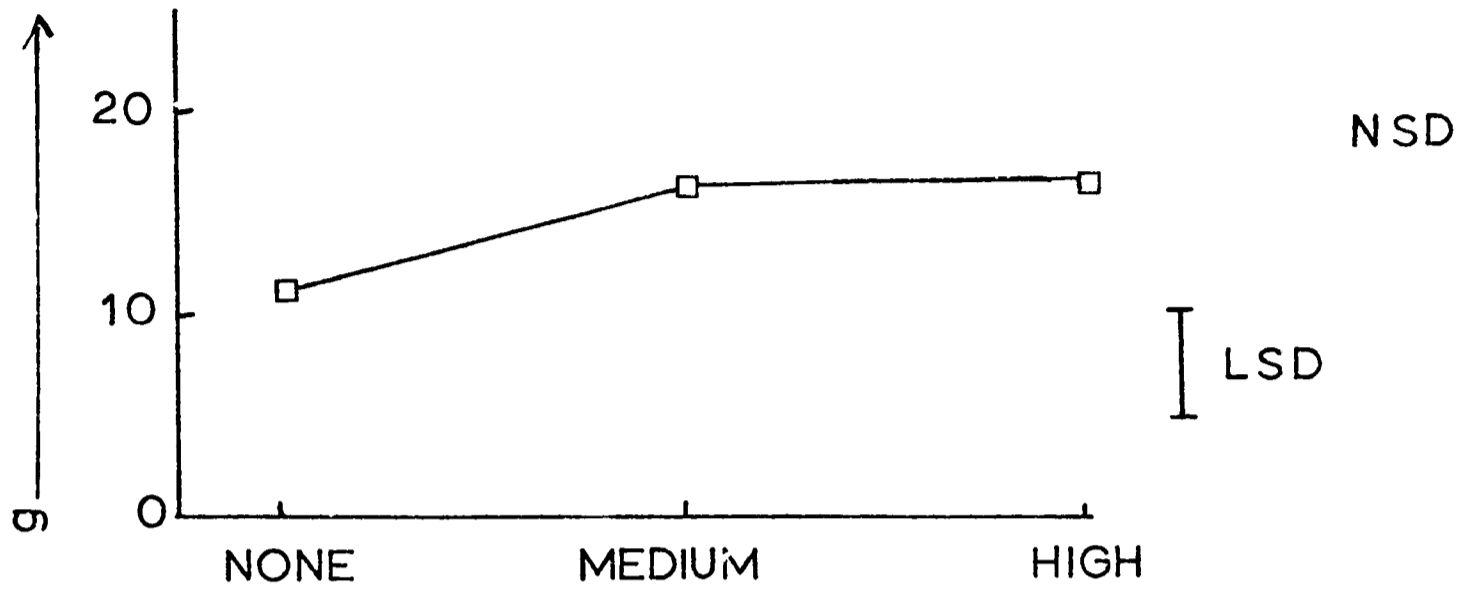


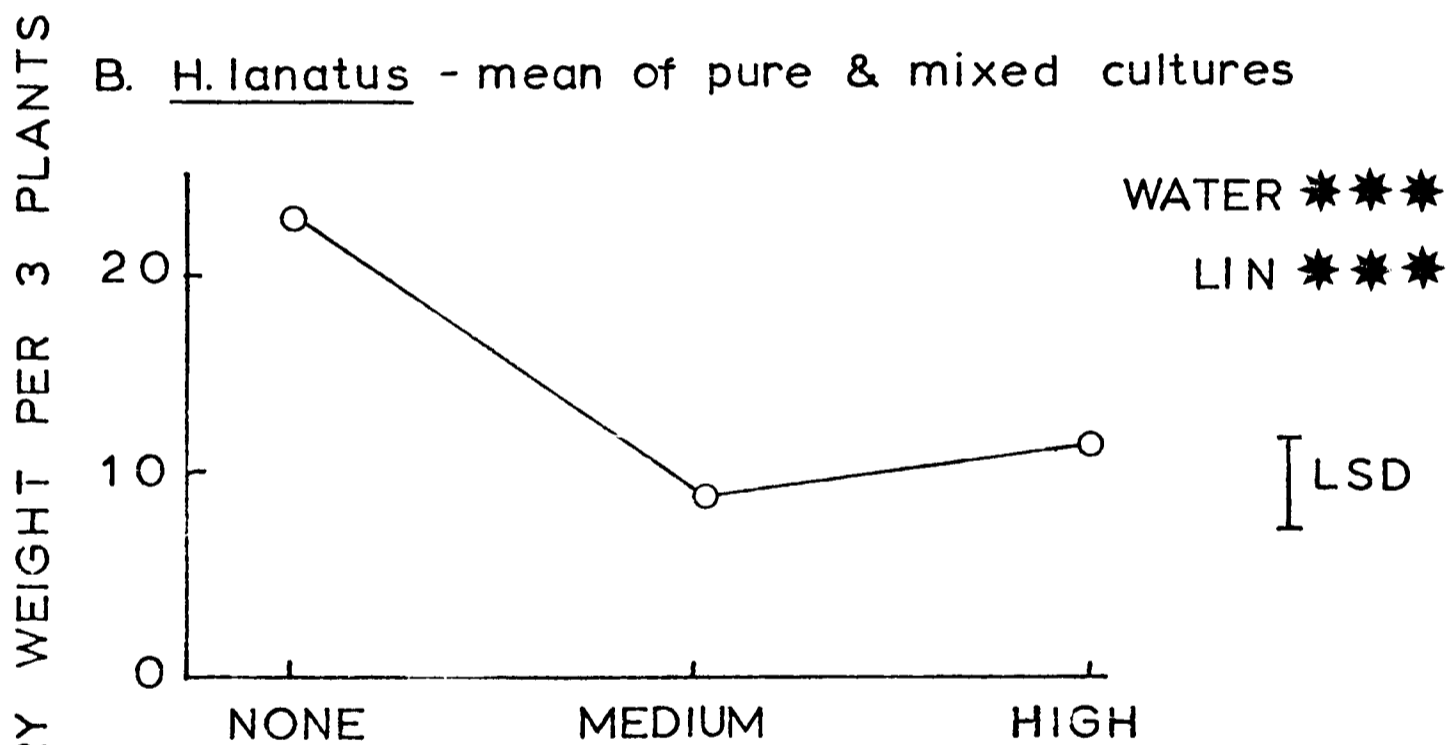
FIGURE 47

Shoot dry weights of H.lanatus & L.perenne in 3 water treatments at the third harvest in 1976

A. L.perenne - mean of pure & mixed cultures



B. H.lanatus - mean of pure & mixed cultures



C. H.lanatus & L.perenne in pure culture

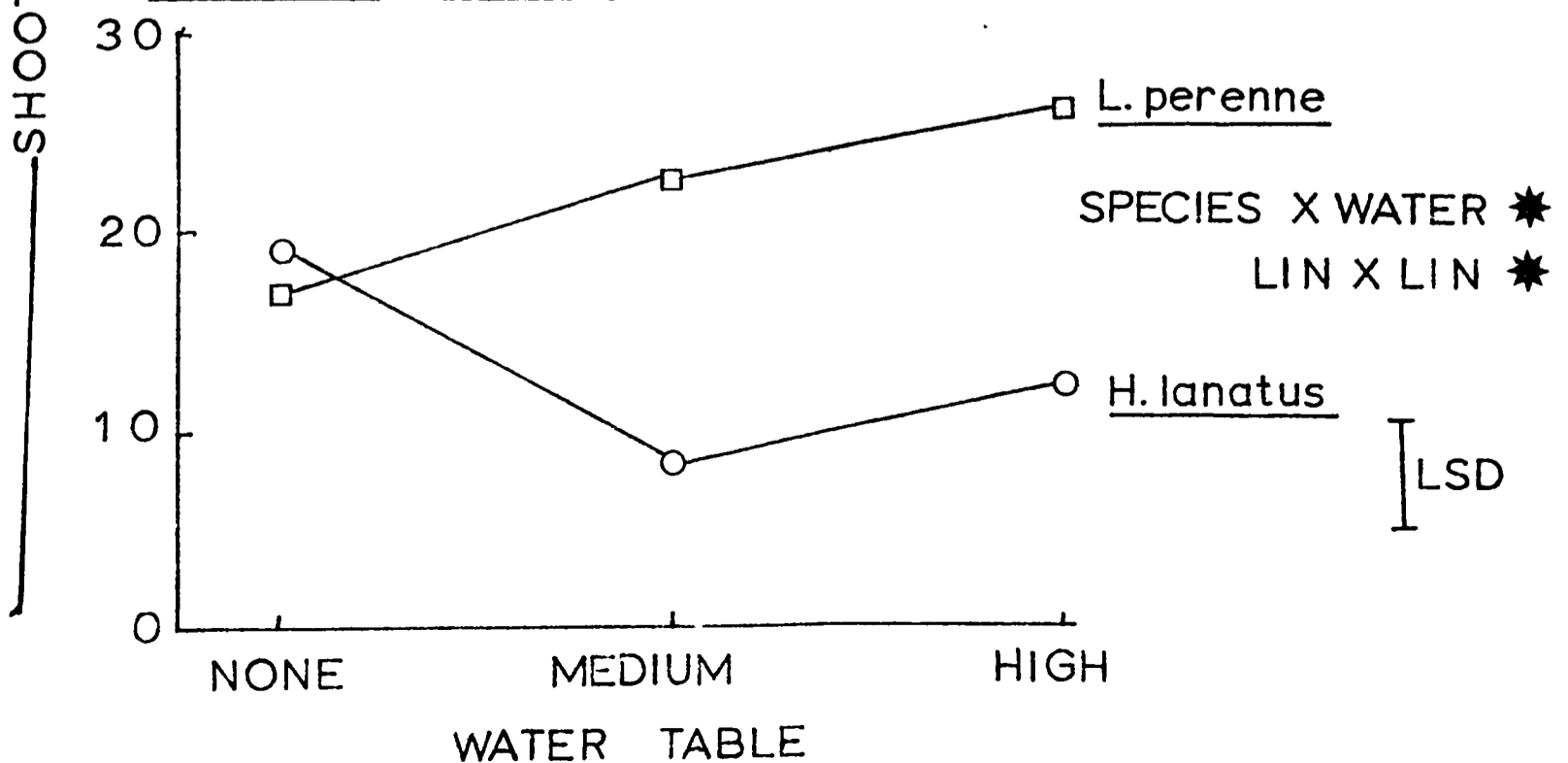


FIGURE 48

The types of roots produced by an H. lanatus plant

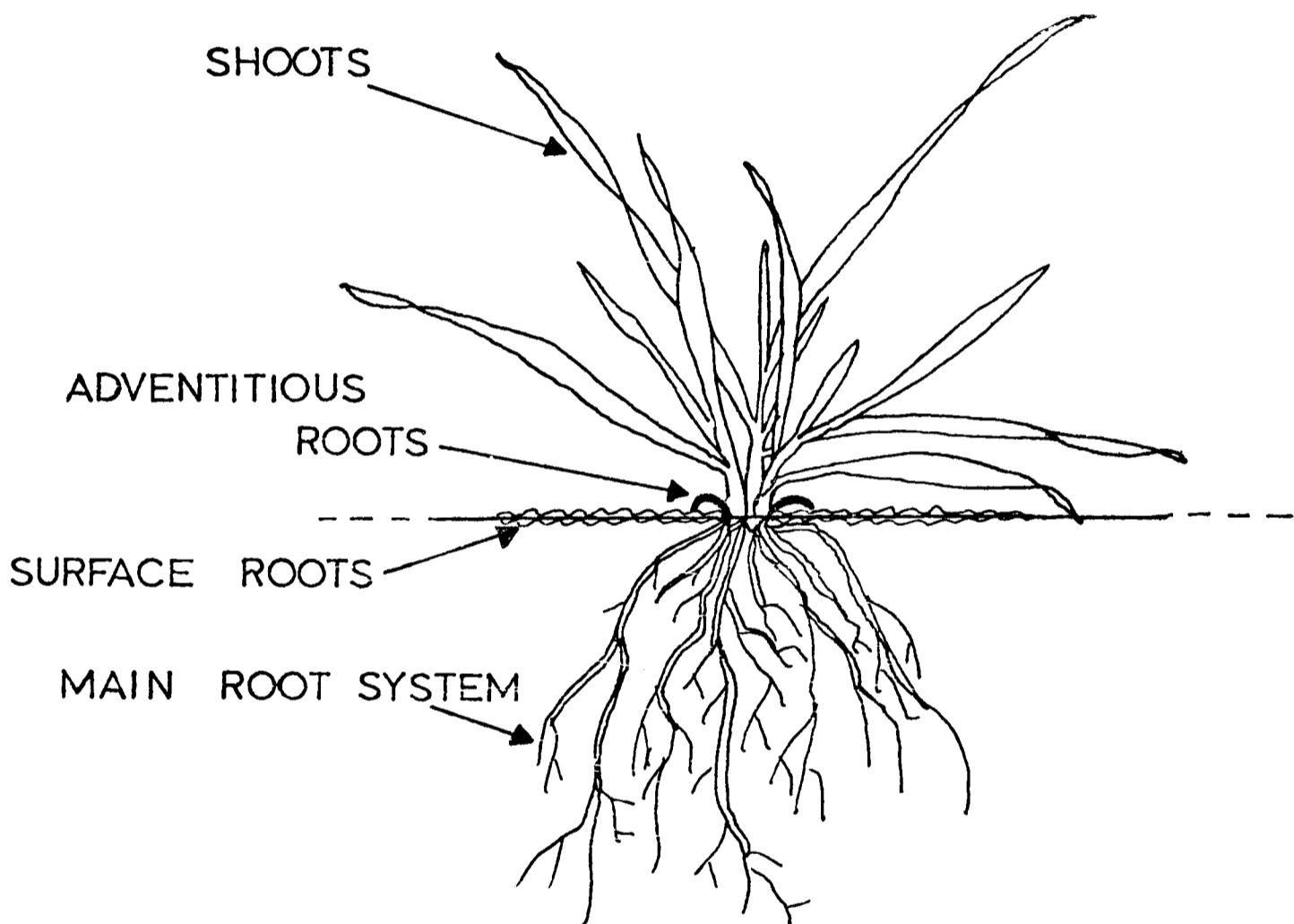
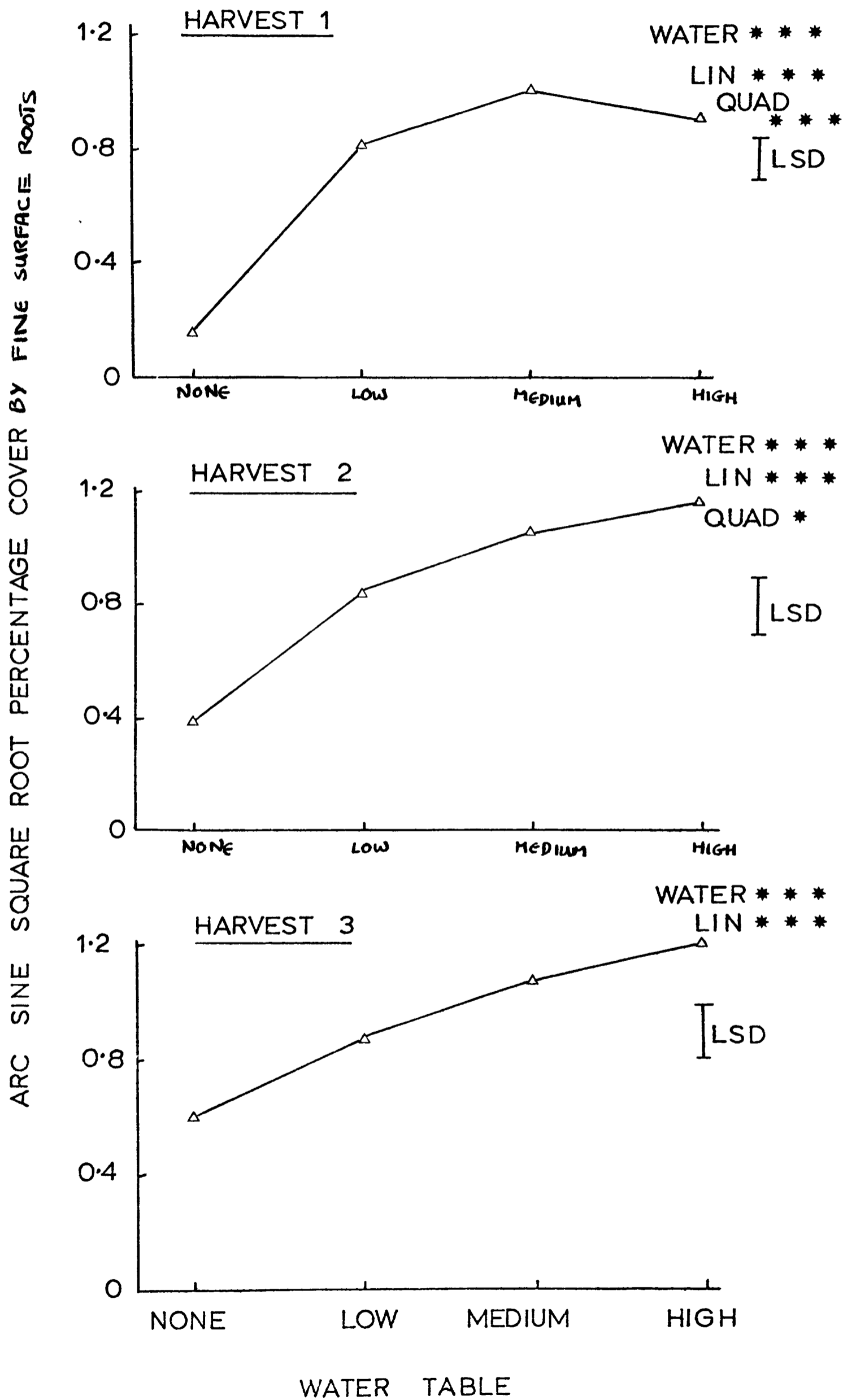


FIGURE 49

Percentage cover of soil surface by fine surface roots of H.lanatus under various heights of water table in 1975

(Figures are means of pure cultures & mixtures with L.perenne)



15% in the free-draining treatment and 83% in the high water table treatment.

At all three harvests there was a highly significant linear trend of more surface roots with increasing height of water table. At the first two harvests there was not such a great difference between the three water table treatments as between the free-draining and low water table treatments but, by the third harvest the response was entirely linear (Fig. 49, p. 121). Photographs of the degrees of surface rooting are shown in Fig. 50, p. 123).

ADVENTITIOUS ROOTS ON

H. LANATUS

1975. At the first harvest there were significantly more nodes with adventitious roots on plants at the low water table than on the others (Fig. 51A, p. 124). By the second and third harvests, however, there was a highly significant linear trend of more nodes having adventitious roots at higher levels of water table (Fig. 51B and C, p. 124).

It was observed, qualitatively, that about half of the adventitious roots on plants in the three water table treatments were around the edge of the clumps and half were inside the clumps. Whereas, in the free-draining treatment what few roots there were tended to be inside the clumps. Also, many of the roots on the free-draining treatment had brown tips, but few of the roots on the low and medium water table plants and none of the roots on the high water table plants were in this condition. There were more and longer adventitious roots per node on the high water table plants than in the other treatments.

1976. In this experiment the number of nodes with adventitious roots on the outside of clumps in monoculture was counted. This was done:

1. To check the previous year's results.

FIGURE 50

View of surface roots in water table experiment,
18 August 1975

A. Free-draining



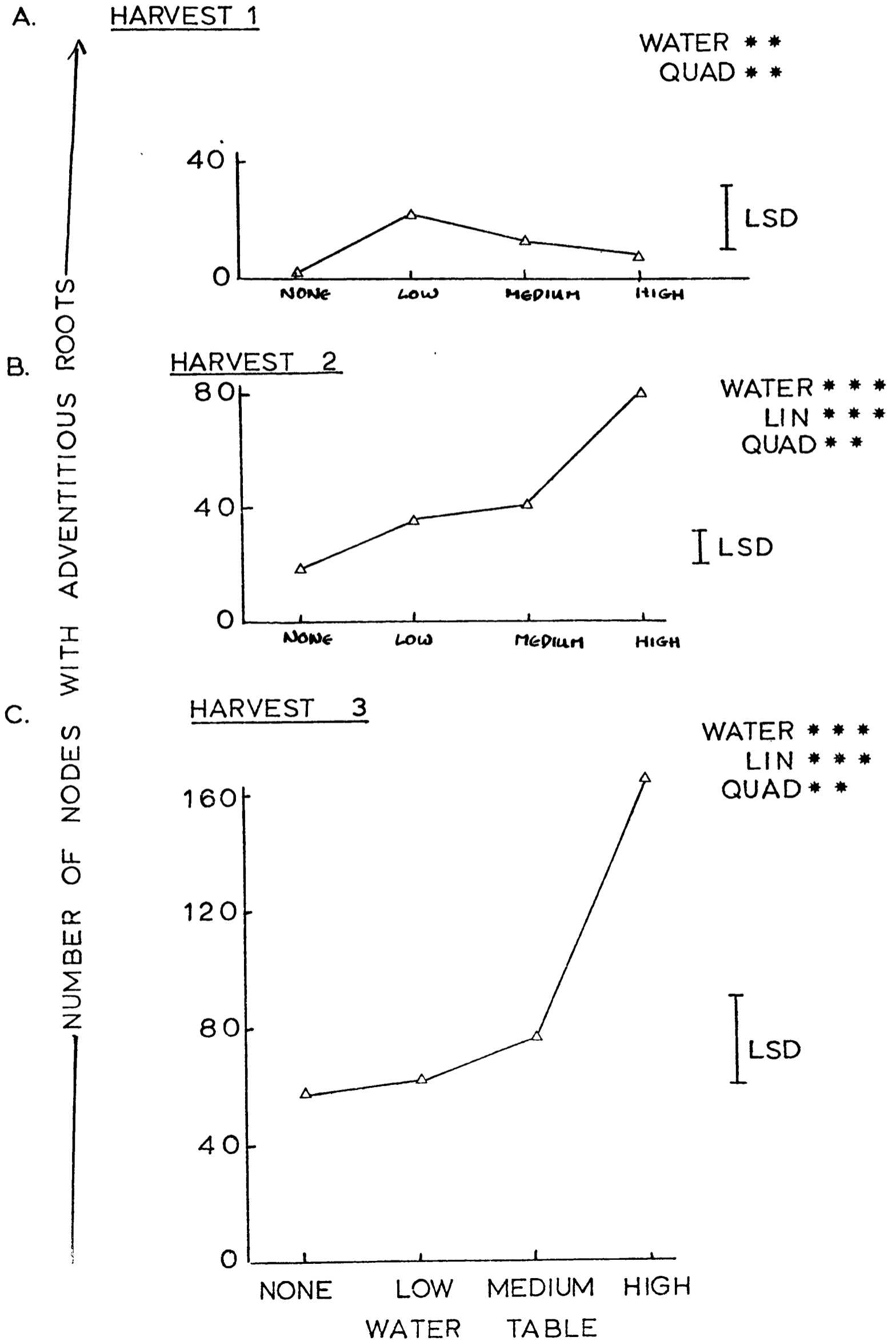
B. High water table



FIGURE 51

Number of nodes with adventitious roots per 3 plants of H.lanatus under 4 water table treatments in 1975

(Figures are means of monocultures & mixtures with L.perenne)



2. Because ^{ADVENTITIOUS} roots outside the clump are likely to be more important for spread.

3. Because the adventitious roots inside clumps were very difficult to see and counts would have been unreliable.

A definite linear increase in the number of nodes with adventitious roots round the edge of a clump with increasing height of water table was found (Table 22, p.126).

DRY WEIGHT OF THE MAIN ROOT SYSTEMS
OF H. LANATUS AND L. PERENNE - 1976

As it was not possible to use more sophisticated techniques an attempt was made to determine root dry weights by sampling, washing and drying. There was no evidence for the two species having different amounts or distributions of main root system. The coefficient of variation was 95% which may help to explain this. Thus, Figure 52 (p.127) shows the distribution of roots for the three water treatments for the mean of the two species. Both grasses produced most roots in the top 50mm of soil under all water treatments.

NITROGEN CONTENT OF H. LANATUS AND
L. PERENNE SHOOTS - 1975

Figure 53 (p.127) gives the mean percentage nitrogen (N) content of the two species combined for the four water treatments. There was no significant difference between the two grasses. Neither was there a significant water x species interaction.

The results showed that the shoots from the free-draining treatment contained 37% N while the other plants all contained less than 23% N. The transformed data show that the higher the water table the lower the N concentration in the shoots but with the greatest drop between the free-draining and low water table treatments (Fig. 53, p.127). This could not

TABLE 22

The number of nodes round the edge of clumps of H. lanatus at which adventitious roots were visible on 30 August 1976

BLOCK	LEVEL OF WATER TABLE		
	HIGH	MEDIUM	NONE
I	111	26	9
II	60	24	6
III	32	21	6

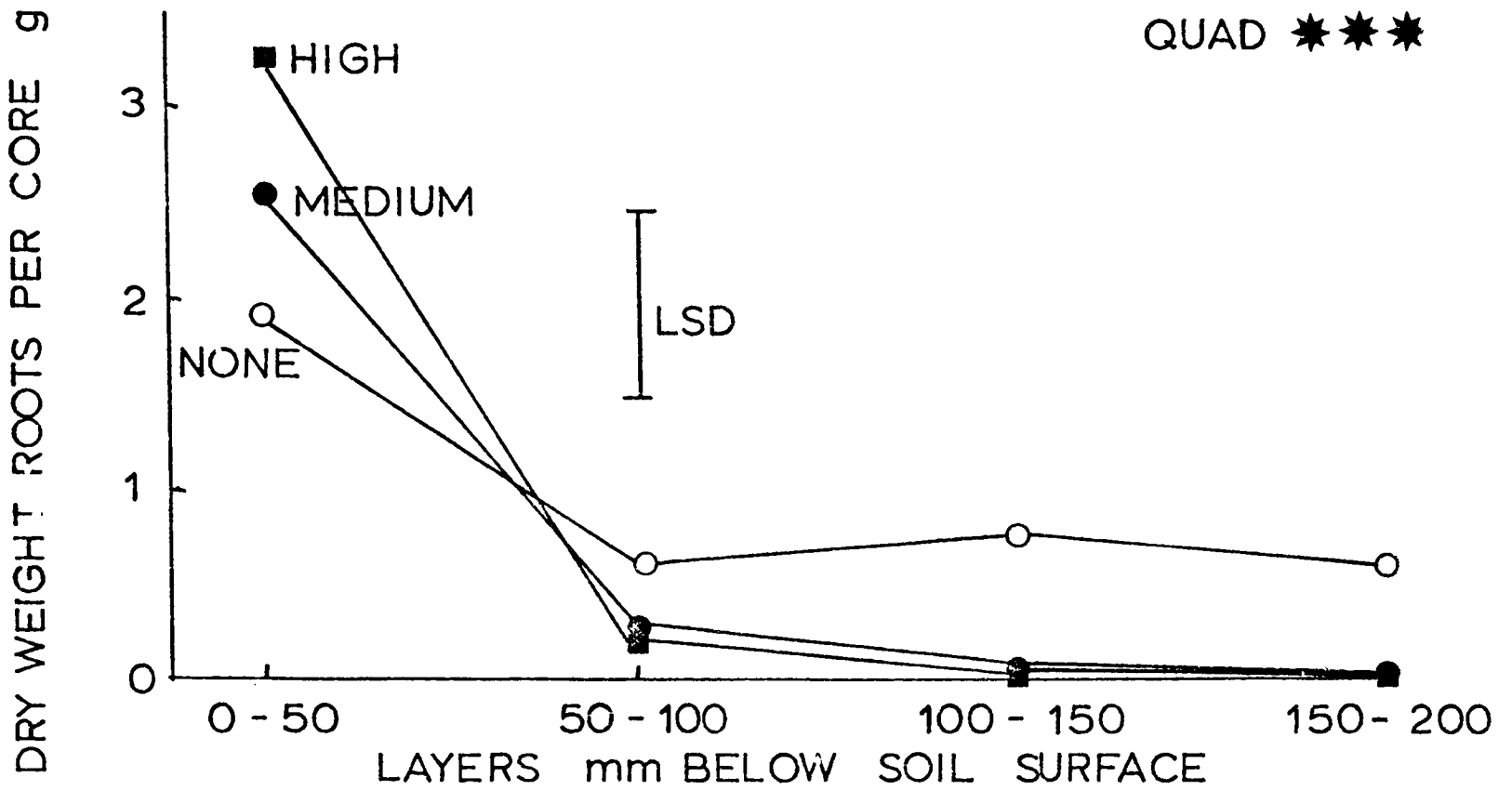
Figures are per 6 plants in monocultures only

As there is no overlap between the numbers recorded for the three treatments, no statistical test is needed.

Mean dry weights of samples of roots of H. lanatus & L. perenne from various depths in pure cultures & 3 water treatments

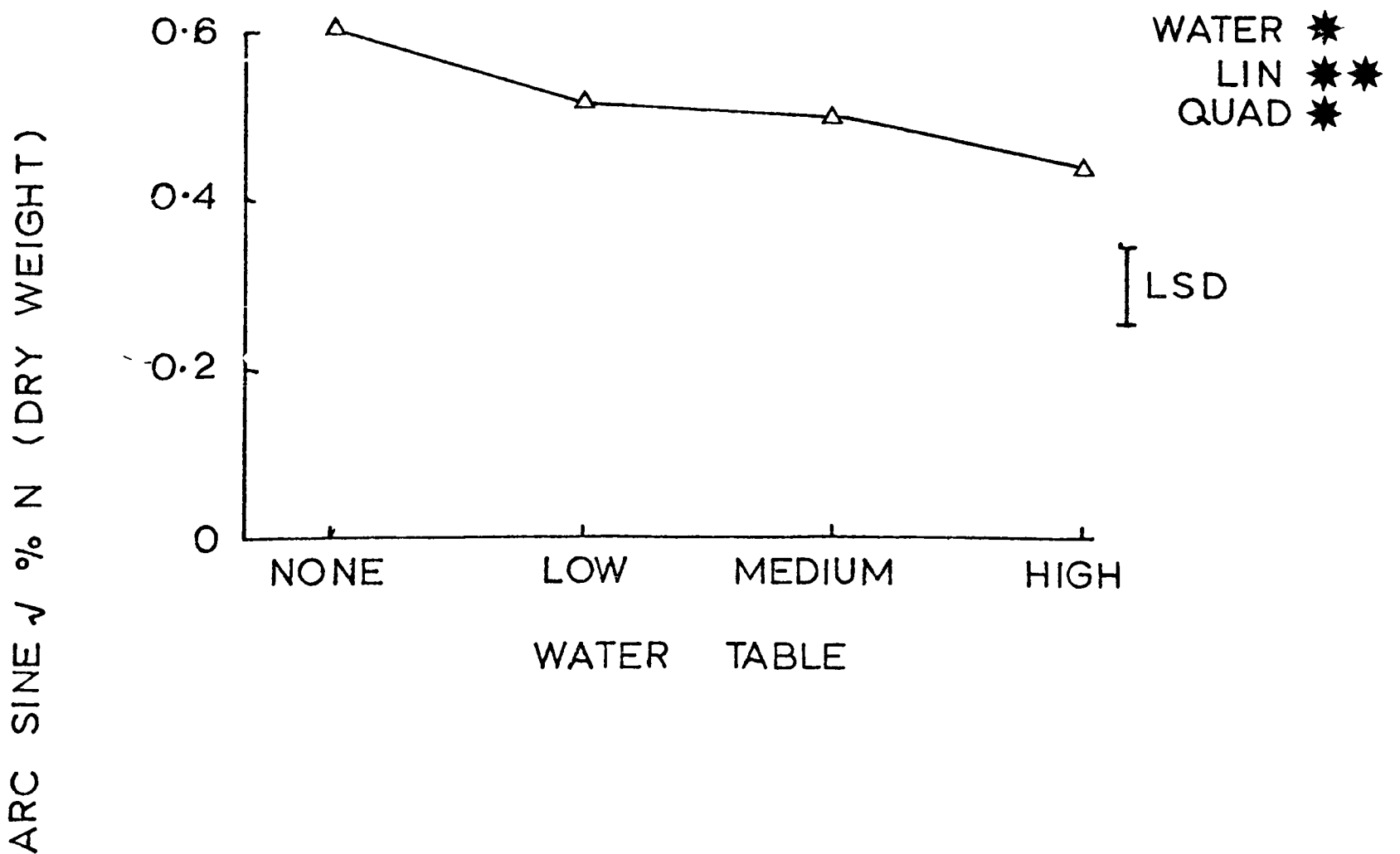
MEAN OF 3 WATER TREATMENTS :

LAYERS ***
 LIN ***
 QUAD ***



percentage FIGURE 53

Mean nitrogen content of shoots of both H. lanatus & L. perenne monocultures in 4 water treatments on 15 September, 1975



have been a dilution effect (i.e. a low concentration due to the same quantity of N being present in a larger plant), since the free-draining treatment plants also had a greater shoot dry weight than plants in the other treatments (Fig. 44B, p. 115).

THE NUMBER OF H. LANATUS TILLERS AND THE PERCENTAGE
OF LIVE TILLERS ON 8 OCT. 1975

There was no significant difference between the number of live tillers per plant in the four water treatments. The actual numbers ranged between ninety seven and 149 tillers per plant. However, the estimated total number of tillers (live + dead) decreased linearly with increasing height of water table (Fig. 54, p. 129). So, the percentage of live tillers increased linearly with increasing height of water table (Fig. 55, p. 129). The figures ranged from 41% live tillers in the 'low' treatment to 67% in the 'high' treatment.

MEAN ANGLES OF FOLIAGE OF
H. LANATUS AND L. PERENNE

1975. The measurements taken in 1975 show that L. perenne became more erect in wet conditions whereas H. lanatus became more prostrate (Fig. 56, p. 130). Under free-draining conditions L. perenne shoots had a mean angle of 28.5° but under a high water table this rose to 46° . The respective figures for H. lanatus were 32° and 23.5° .

1976. In the subsequent experiment similar results were obtained for L. perenne but the change in the angle of H. lanatus leaves, although in the same direction, was non-significant (Fig. 57, p. 131).

NUMBER OF L. PERENNE PANICLES - 1976

The number of panicles at the first harvest was the same for plants in free-draining and medium water table treatments but was greatly reduced under

Total number of tillers on H.lanatus plants at various heights of water table on 8 October 1975

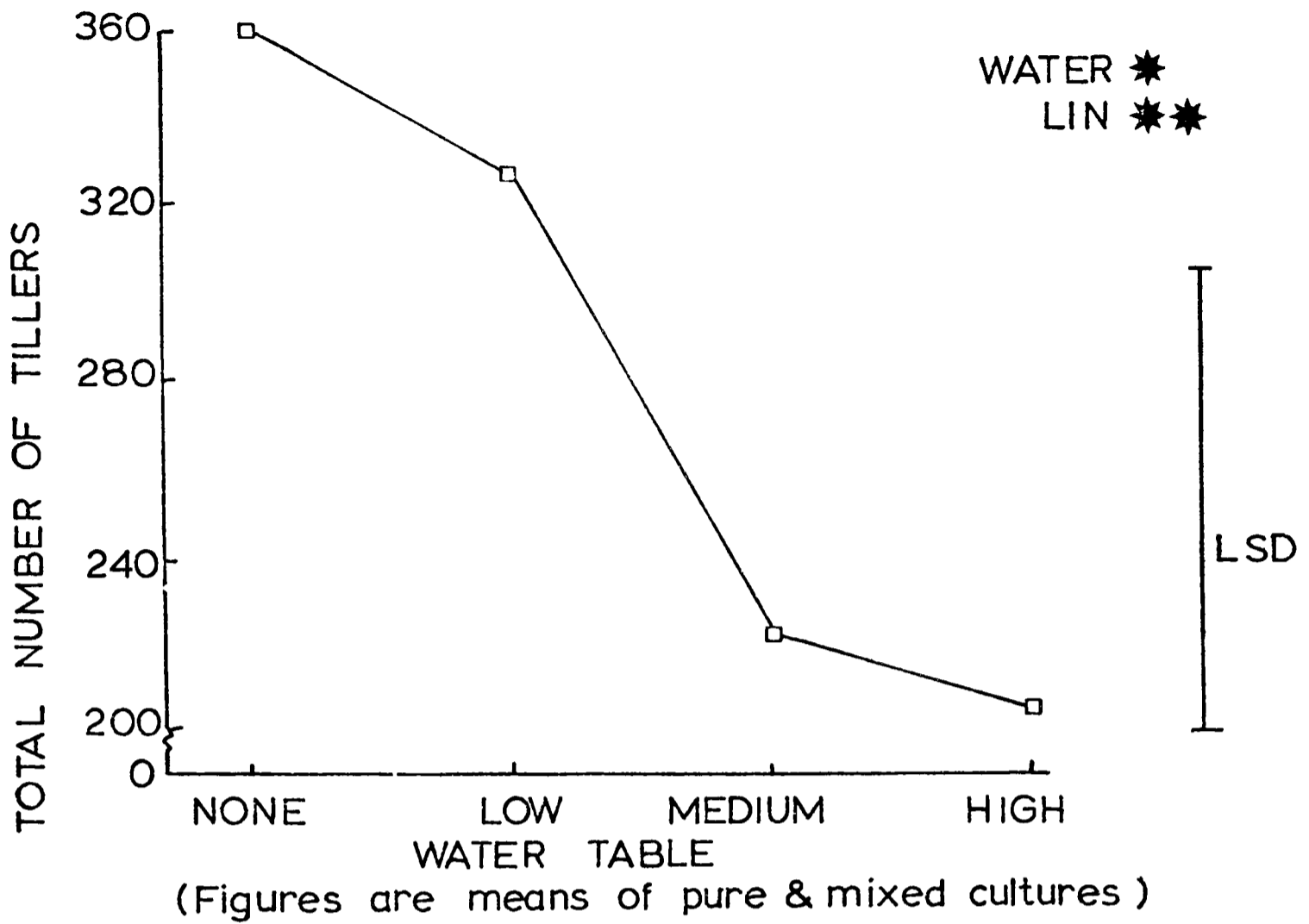
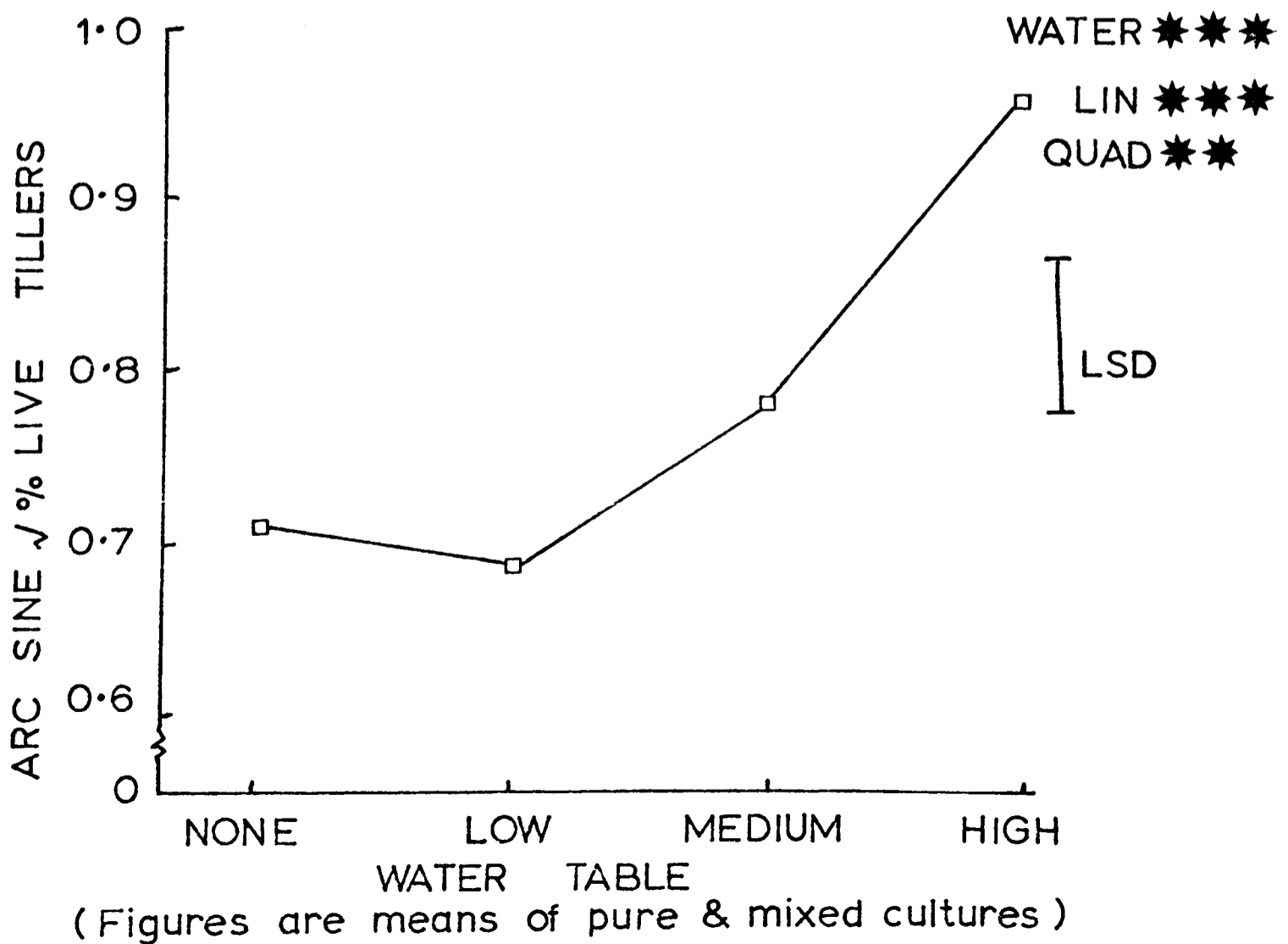


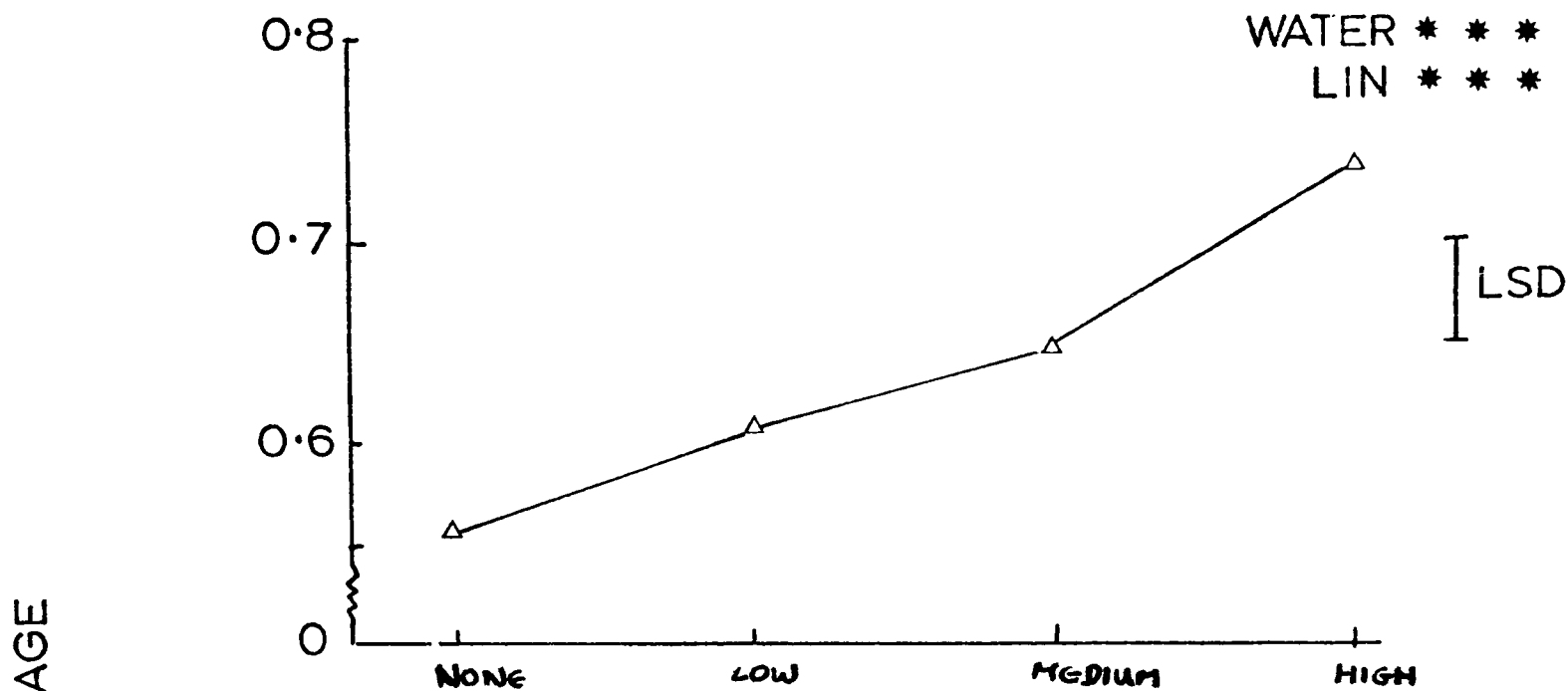
FIGURE 55

Percentage of live tillers on H.lanatus plants at various heights of water table on 8 October 1975



Mean angles of L.perenne & H.lanatus foliage under 4 water table treatments on 4 September 1975

A. L.perenne , mean of pure & mixed cultures



B. H.lanatus , mean of pure & mixed cultures



C. L.perenne & H.lanatus in pure cultures

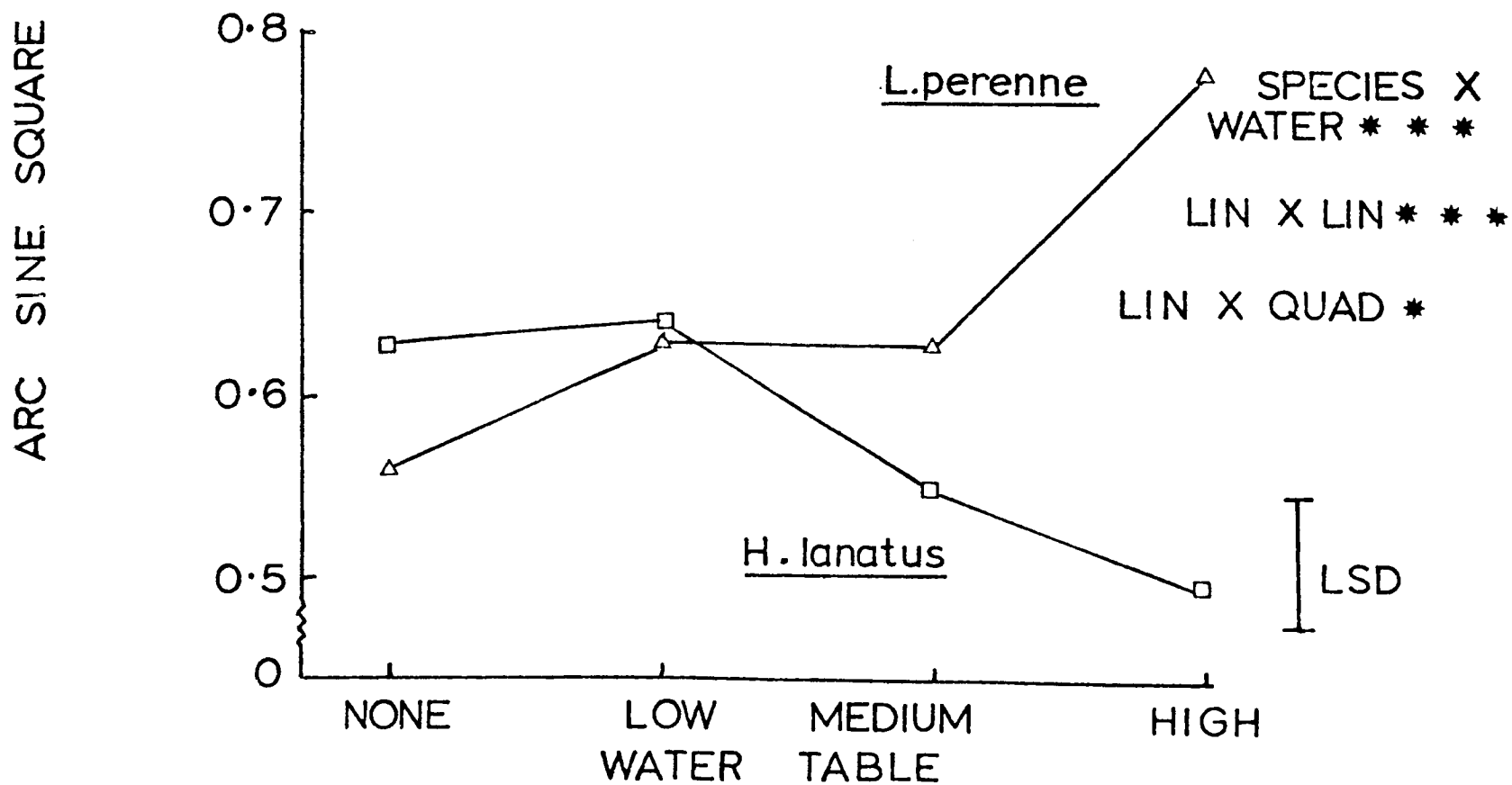
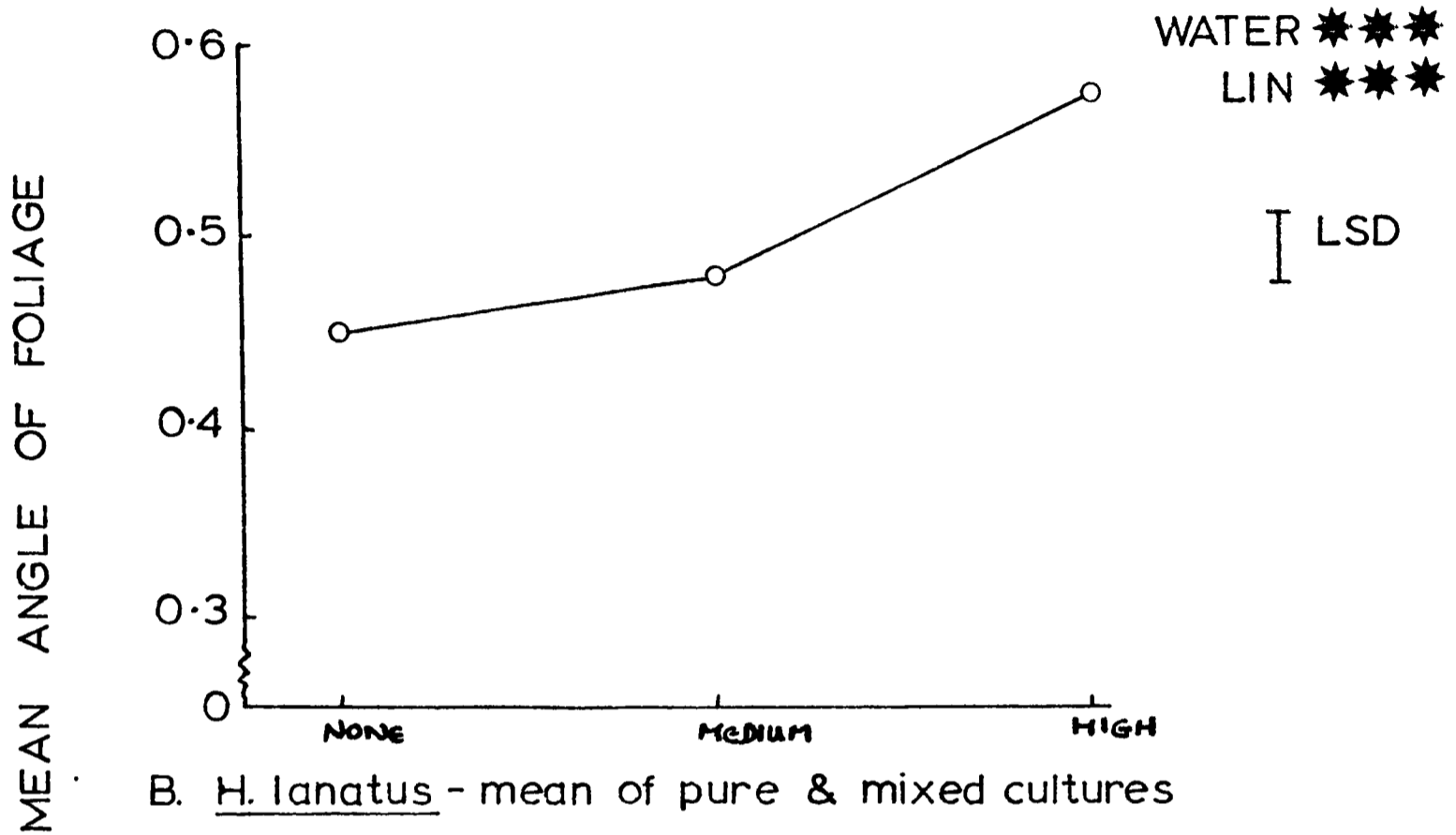


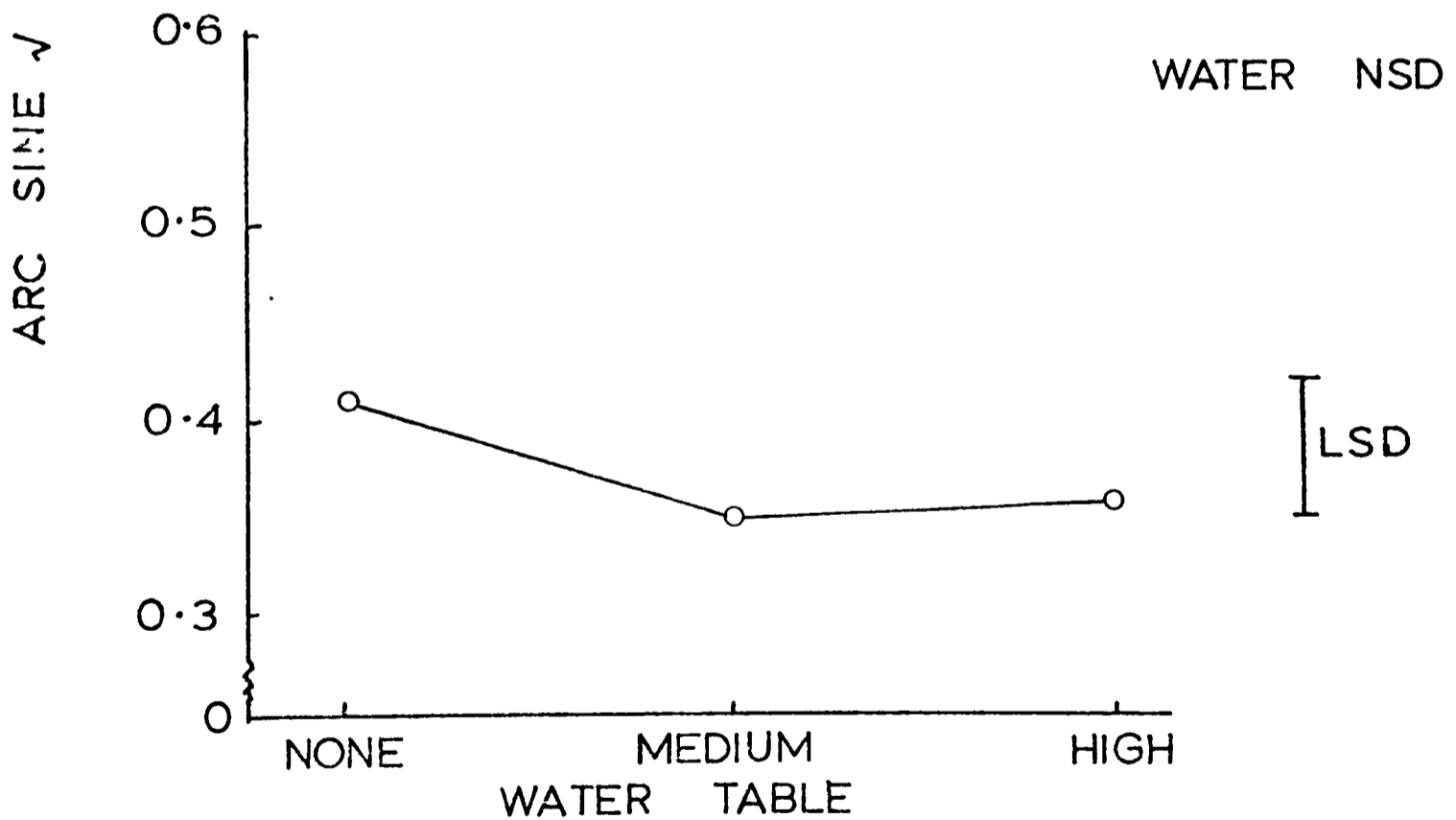
FIGURE 57

Mean angles of foliage of H.lanatus & L.perenne plants at various heights of water table on 24 August 1976

A. L.perenne - mean of pure & mixed cultures



B. H.lanatus - mean of pure & mixed cultures



SPECIES X WATER NSD

high water table conditions (Fig. 58, p.133). There were very few panicles at the second harvest.

DISCUSSION

TENSIOMETER READINGS

1975. The majority of the values in Figure 42 (p.112)oscillate around 25 mbar. This is a lower tension than that of the field capacity of a sandy loam soil (~ 50 mbar). This is because the soil in the containers was not in contact with bulk soil.

The soil water tension rose above that of the estimated pot capacity on several occasions. This is in agreement with plants in free-draining conditions sometimes being wilted and explains why the shoot dry weights at the first harvest were greater for the 'low' plants, where there was always a moist soil, than for those in free-draining conditions which were under moisture stress.

1976. The soil water tension was generally lower than in 1975.

SHOOT DRY WEIGHT OF H. LANATUS

AND L. PERENNE

1975. The peak yield of both species in the low water table treatment at the first harvest may be explained by the consistently hot weather (maximum daily air temperature 14.4°C - 33.4°C , mean 24.3°C) and low rainfall (June - 53.7mm, July - 5.6mm and August - 40.9mm compared to ten year average) during this growing period. The free-draining treatments were under moisture stress (see tensiometer readings, p.132) and so their yields were lower than in the low water table treatment where moisture was always available. Otherwise, the growth of both species decreased with increasing height of water table. This may be due to the restricted nutrients available, to low oxygen levels or to high ethylene levels in the soil (Gill, 1975, Fig. 59, p.134).

FIGURE 58

Number of panicles per 3 plants of L. perenne at 3 water treatments at the first harvest in 1976

(Figures are means of pure & mixed cultures)

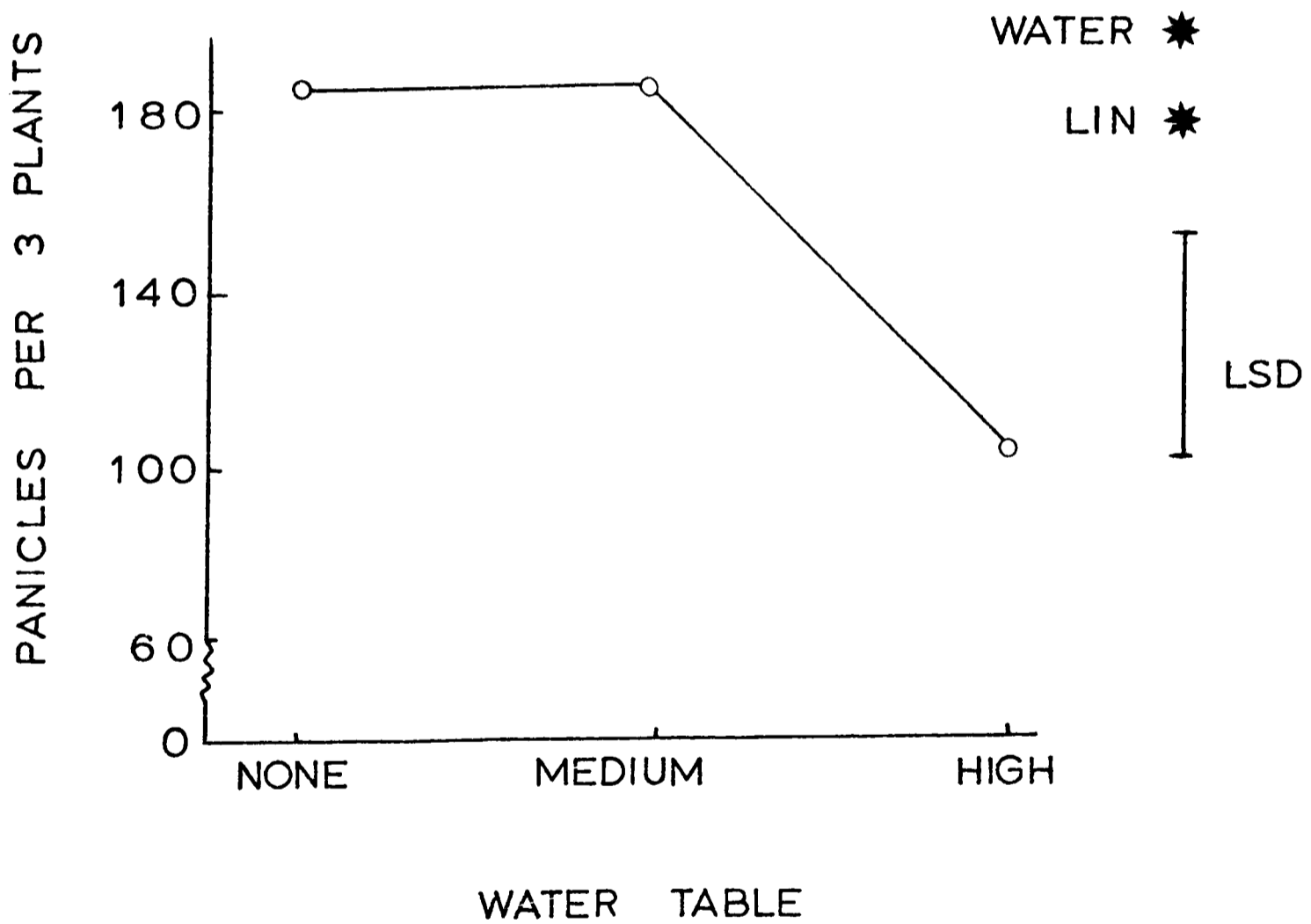
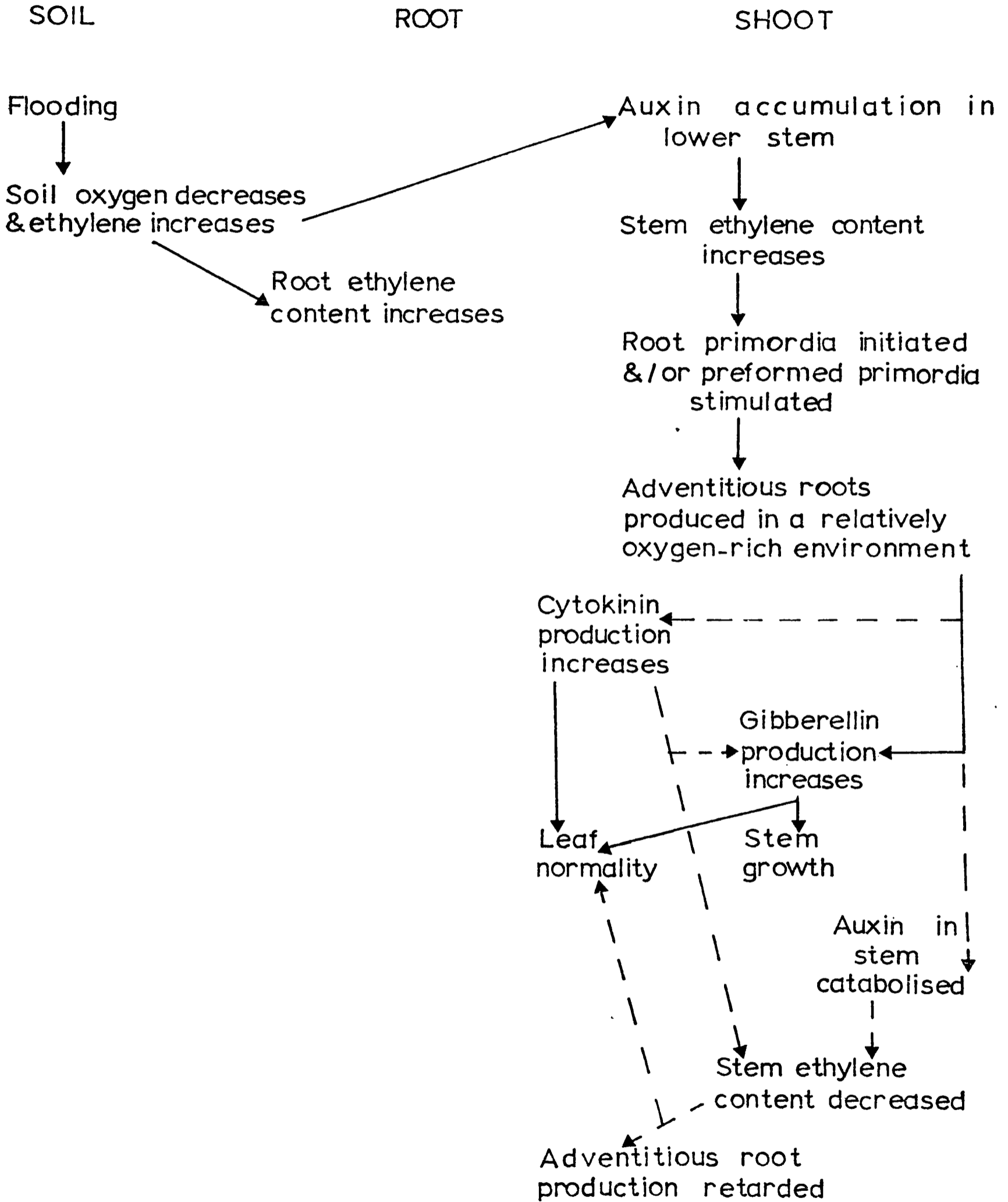


FIGURE 59

Probable causes and possible consequences of adventitious root production under flood. From Gill (1975).



KEY

--- unsubstantiated possibilities

— substantiated possibilities

Holcus lanatus had a mean yield greater than that of L. perenne in monoculture at the first harvest whereas the situation was reversed at the subsequent harvests. This might be due to the seasonal growth pattern of H. lanatus or may mean that the grass was better able to use the high level of nutrients that was available before the first harvest. The greater shoot yield of L. perenne at the last two harvests may well be due to the relatively greater capacity of the species to regrow quickly when cut to 50mm by rapidly mobilising reserves in its shoot bases.

1976. The results of this experiment confirmed those of the previous year in showing that H. lanatus did not yield more than L. perenne in high water table conditions. Indeed it always yielded less than L. perenne in high water table conditions and also yielded more than L. perenne in free-draining conditions at the last two harvests. Holcus lanatus dominated mixtures with L. perenne at the first harvest but not later on, possibly due to its seasonal growth pattern.

In neither experiment did H. lanatus flower. In 1975 this was due to the late start of the experiment and in 1976 it was possibly due to devernalization. So these results are only applicable to vegetative H. lanatus.

SURFACE ROOTS PRODUCED BY

H. LANATUS - 1975

Holcus lanatus responded to high water table conditions by producing large numbers of fine roots on the soil surface. Beddows (1961) has suggested that such roots might make H. lanatus vulnerable to drought. This change in growth form in response to a high water table may well be a mechanism for long term survival. These surface roots may well have been formed at the expense of shoot production. In high water table conditions surface roots may increase oxygen and, hence, nutrient uptake. They may

also tend to prevent the establishment of seedlings near the plant. In a mixture with other species, surface roots may be advantageous in competing for nutrients.

ADVENTITIOUS ROOTS ON

H. LANATUS

After harvests two and three in 1975 and when counted in 1976 there was a clear increase in the number of nodes with adventitious roots with increasing height of water table. The fact that the highest numbers were on the low water table treatment plants after harvest one in 1975 may be explained by assuming that the amount of photosynthate available for forming surface roots was restricted in the medium and high water table treatments (see shoot dry weight yields, Fig. 44A, p. 115). As with the surface roots, the formation may be a mechanism for long term survival, produced at the expense of short term shoot production.

Many plants produce adventitious roots in response to flooding. The recovery of shoots of tomato and sunflower plants following flooding was coincident with the appearance of adventitious roots (Kramer, 1951). Varieties of sugar cane which developed adventitious roots were less severely injured by flooding than those which did not develop them (Sartoris and Belcher, 1941). A possible mechanism for the production of adventitious roots by plants has been outlined by Gill (1975), (Fig. 59, p. 134). According to this hypothesis the low soil oxygen and high soil ethylene levels stimulate adventitious root production.

However, H. lanatus plants in free-draining conditions did produce a few adventitious roots so perhaps the grass responds to a high water table by greatly increasing the number it forms from the normally very low level. The few adventitious roots formed on 'free-draining' plants tended to be on the inside of the clumps. This may be due to the need for a humid atmosphere for their production. In the water table treatments the

atmosphere was always humid all round the plants whereas in the free-draining treatment it was usually dry round the edges of the clumps but moisture was held inside, amongst the leaves, from overhead watering. Also, plants growing in free-draining conditions were more erect than the others (see angle of foliage, p. 128) so the atmosphere might be expected to be less humid round the edges of the clumps.

The observations that there were less adventitious roots per node on 'free-draining' plants and that they were shorter than those on plants in the water table treatments as well as dying at the tips also indicate the better growth of adventitious roots under high water table conditions. It is possible that besides aerating the root system of the plant in high water table conditions, adventitious roots round the edge of a clump may help it to spread subsequently.

DRY WEIGHT OF THE MAIN ROOT SYSTEMS OF

H. LANATUS AND L. PERENNE - 1976

The vertical root penetration of H. lanatus, like that of L. perenne, is restricted by a high water table. This agrees with work by Troughton (1957). For both species the higher the water table the more roots are concentrated in the top 50mm of soil. Thus, if H. lanatus is better adapted than L. perenne to surviving in high water table conditions it is not due to the species producing more vertical roots either in the shallow layer of drained soil or in the waterlogged soil beneath.

NITROGEN CONTENT OF H. LANATUS AND

L. PERENNE SHOOTS - 1975

The nitrogen content of both species declined severely when they were grown in waterlogged soils. This is similar to the results obtained with barley by Drew and Pattiradjawene (1975). It seems that a high water table interferes with the uptake of nitrogen and presumably other nutrients by the

parts of the root system deprived of oxygen. Nitrogen is probably withdrawn from older leaves and transported to younger shoots and roots so that growth can continue, although at a reduced rate. Drew and Pattiradjawene (1975) found that when additional nitrate was supplied to aerated roots of barley near the soil surface normal shoot growth of waterlogged plants was maintained.

It has been reported that H. lanatus roots have a radial cortex with many small, irregular air spaces (Jacques and Munro, 1963) which may increase the efficiency of nutrient uptake when the soil water level is high (Soper, 1959). However, the results of this experiment indicate that H. lanatus is no better than L. perenne at taking up nitrogen from waterlogged soils.

THE NUMBER OF H. LANATUS TILLERS AND THE PERCENTAGE
OF LIVE TILLERS ON 8 OCT. 1975

The lower percentage of live tillers on plants in free-draining conditions may reflect the more rapid growth rate of plants in such conditions and, hence, the more rapid turnover of their tillers. Plants of H. lanatus had similar absolute numbers of live tillers in all treatments. Thus, if the soil water table drops in spring, plants in previously high water table sites will begin growth with a similar number of live shoots to plants in previously well-drained sites. However, plants which have been growing in high water table conditions will contain less nutrients and therefore will not be able to grow as rapidly as their permanently well drained counterparts (see nitrogen content, p. 125).

MEAN ANGLES OF FOLIAGE OF
H. LANATUS AND L. PERENNE

The observations that L. perenne shoots became more erect and the plants did not form adventitious roots whereas H. lanatus shoots became more prostrate and the plants did form adventitious roots as the height of water table increased may or may not be directly related. Presumably both changes

were due to the effect of the high water table mediated possibly through lack of oxygen or excess of ethylene.

NUMBER OF L. PERENNE PANICLES - 1976

The reduction in the number of panicles at the first harvest in high water table conditions is in agreement with the decrease in shoot dry weight. It may have been due to the restricted nutrient supply, low oxygen levels or high ethylene levels.

CONCLUSIONS

Holcus lanatus shows signs of being able to adapt to and, hence, to survive in high water table conditions. Such adaptations take place at the expense of short term shoot production. The formation of surface and adventitious roots may enable the plant to survive better in waterlogged soils by obtaining oxygen and exploiting the nutrient reserves of the surface of the soil to a maximum. In high water table conditions it maintains a similar number of live tillers per plant as in free-draining conditions. It also becomes more prostrate, with adventitious roots situated round the edge of its clumps. Thus, the plant is poised for rapid spread when the water table drops.

Growth in high water table conditions tends not to decrease the shoot production of L. perenne as much as that of H. lanatus. But, L. perenne shows no signs of adaptation for long term survival in a high water table sward.

CHAPTER 8

HERBICIDAL CONTROL OF ESTABLISHED

H. LANATUS IN L. PERENNEINTRODUCTION

A pilot survey of grassland in south-east England found that the amount of H. lanatus in swards increased with age (Morrison and Idle, 1972). A number of management techniques can reduce the amount of H. lanatus present. These include liming acid soil (Hart and McGuire, 1963), applying nitrogenous fertilizer (de Vries and Kruijne, 1960) and frequent defoliation (Riveros, 1963; Mahmoud, 1973). Another possibility is to use herbicides which selectively control established H. lanatus in L. perenne. A survey of the literature revealed a number of promising herbicides, the effects of which are described in the following section.

THE HERBICIDES USED IN THESE

EXPERIMENTS

Dalapon. The reports of Bramley (1961); Allen (1969) and Oswald et al. (1972) indicate that H. lanatus can be greatly decreased by doses of less than 5 kg a.e./ha. In a grazing trial at W.R.O., dalapon was applied annually to a mixed sward in July at 2.8 kg a.e./ha during four years. This reduced the amount of H. lanatus present from 40.2% to 16.0% whilst L. perenne increased from 19.5% to 48.7% (Haggar and Elliott, in press). This treatment is recommended in the Weed Control Handbook (British Crop Protection Council, 1972a). The details of these references are given in Table 23 (p. 141).

TABLE 23

Selected references to the effects of Dalapon on
L. perenne and H. lanatus

AUTHOR	SWARD	PLACE	TIME	DOSE kg a.e./ha	OBSERVATION
Thompson (1958)	Mixed	Hamilton New Zealand	Sept = Spring	5.6	Relative dry matter production over season <u>L. perenne</u> : Control = 100 Dalapon = 99 "Weed grasses": Control = 100 Dalapon = 18 <u>H. lanatus</u> = "most severely affected weed grass"
Meekiah (1959)	Lucerne	New Zealand		5.6	Minimum dose needed to kill <u>H. lanatus</u>
Davies, Hunter & King (1960)	<u>Agrostis</u> / <u>Festuca</u> & <u>Nardus</u> / <u>Molinia</u>	6 sites Scotland	May and July	11.12	<u>H. lanatus</u> highly resistant
Bramley (1961)	Mixed	Wellington New Zealand	March = Autumn	Mean of 4.1 and 8.3	Tolerance (based on point analysis) 3 months later Control = 100 Dalapon L H 56 10
"	"	"	Dec = Summer	"	Dalapon L H 56 20
Allen (1968)	Mixed	Bicester	Early July	3.7	No. of first hits/100 points/plot. 5 wk. later Control L H 51 7 Dalapon L H 68 9
"	"	"	"	5.6	Dalapon L H 54 1
Allen (1969)	Mixed permanent	Lincoln- shire	July	3.36	Dry matter yield 3 months later kg/ha Control Dalapon L H L H 187 41 142 2

cont.

TABLE 23 cont.

Selected references to the effects of Dalapon on
L. perenne and H. lanatus

AUTHOR	SWARD	PLACE	TIME	DOSE kg a.e./ha	OBSERVATION
Oswald (1972)	Mixed permanent	Oxford	July	8	Presence scale/m ² 35 days later Control Dalapon L H L H 4.5 8 3 2
Oswald et al. (1972)	2 yr. <u>L. perenne</u>	13 sites Britain	Late June/ July	2.8	No. of tillers/m ² 6 months later Control Dalapon L H L H 4595 710 4806 244
Fisher & Faulkner (1975)	Monoculture rows field	Belfast	July	5	Tolerance (based on dry wt of autumn cuts) Mean = 100 L H 119 92
Charles et al. (1977)	Mini- swards monocultures	Aberystwyth		2.8	<u>L. perenne</u> cultivars 0-56% depression <u>H. lanatus</u> 38% control
Haggard & Elliott (1977)	Mixed permanent	Oxford	July	2.8	After 4 years mean % cover <u>H. lanatus</u> Control 40.2 Biennial Dalapon 19.0 Annual Dalapon 16.0 <u>L. perenne</u> Control 19.5 Biennial Dalapon 43.5 Annual Dalapon 48.7

Other reports suggest that at least 5.6 kg a.e./ha is needed to substantially reduce the amount of H. lanatus (Thompson, 1958; Meeklah, 1959; Allen, 1968; Fisher and Faulkner, 1975). There are also instances of H. lanatus surviving doses of up to 11 kg a.e./ha (Davies, Hunter and King, 1960; Oswald, 1972). Dalapon gives poor control of H. lanatus in permanent hill swards and in general, the use of dalapon is not a reliable control method. Nearly all the experiments reported in the literature were carried out in summer so it is not possible to consider the effects of spraying at different times of year.

Asulam. Asulam is used for the control of docks (Rumex spp.) in grassland (Savory and Soper, 1973). In experiments designed for this purpose it has also been shown to control selectively H. lanatus in L. perenne (Ministry of Agriculture, Northern Ireland, 1968b). Doses ranging from 2.8 to 6.7 kg a.i./ha on both permanent and newly sown swards, sprayed at various times of the year, have given good selective control of H. lanatus in L. perenne (Ford and Combellack, 1966; Grant, 1968; Oswald et al., 1972; Blair and Holroyd, 1973; Fisher and Faulkner, 1975), as shown in Table 24 (p.144).

Lenacil. Lenacil is used for pre-emergence weed control in sugar beet. Work in Canada has shown that H. lanatus is less tolerant of this chemical, sprayed in May at 6 kg a.i./ha, than are Festuca spp. and Poa spp. (Adamson, 1975). As this chemical had shown signs of some selectivity against H. lanatus it was decided to find out whether L. perenne was resistant to it.

Linuron. Linuron is used for pre-emergence weed control in carrots. At the West of Scotland Agricultural College it was sprayed on a timothy (Phleum pratense) seed crop infested with H. lanatus. This herbicide, applied at 2.24 kg a.i./ha in March, eliminated H. lanatus and increased the dry matter yield of P. pratense from 4.17 to 5.28 t/ha. The mean weight per P. pratense

TABLE 24

Selected references to the effects of Asulam on L. perenne
and H. lanatus

AUTHOR	SWARD	PLACE	TIME	DOSE kg a.i./ha	OBSERVATION
Ford & Combellaack (1966)	Mixed permanent	Dunster	Oct	3.36	% cover Start L H L H 1 86 1 0
"	"	Crediton	"	"	37 4 56 0
Grant (1968)	Hill permanent	New Zealand	Nov (spring)	6.72	% dry wt. after 6 months Control Asulam L H L H 57 18 76 3
Ministry of Agriculture N. Ireland (1968b)	Mixed permanent	N. Ireland	Spring and Autumn	1.68 and 2.24	<u>L. perenne</u> - transitory decrease <u>H. lanatus</u> - severe check
Oswald et al. (1972)	2 yr old <u>L. perenne</u>	13 sites	Late June/ July	2.8	No. of tillers/m ² 6 months after spray Control Asulam L H L H 4595 710 5335 55.5
Blair & Holroyd (1973)	Monoculture	Oxford	Summer and Autumn	3.4	Scores L H Recovers Severely depressed
Fisher & Faulkner (1975)	Monoculture rows field	Belfast	July	6.0	Tolerance based on dry wt. Autumn cuts Mean = 100 L H 108 67

seed head was increased from 88 to 124 mg (Harkess and Hope, 1974). As this herbicide worked so well in P. pratense it was decided to find out whether L. perenne was resistant to it.

Metribuzin. Metribuzin has been used to control many weeds, both pre- and post-emergence, in potatoes. It has given complete control of two to three leaf stage H. lanatus plants, while only checking L. perenne plants, when sprayed at 0.025 kg a.i./ha in a glasshouse experiment (Blair, 1973). It was suggested that a lower dose might still control seedling H. lanatus while doing less damage to seedling L. perenne. When metribuzin was applied to two-year-old plots of the grasses at the much higher dose of 3 kg a.i./ha there was very little selectivity, both species being checked and recovering similarly (Blair, pers. comm.).

Paraquat. Very low doses of paraquat (i.e. less than 1 kg a.i./ha) have given good selective control of H. lanatus in L. perenne, when sprayed in summer and even better results when applied in autumn (Bramley, 1961; Williams, 1967; Sharp, 1968; Oswald, 1972), as shown in Table 25 (p.146). But, Young (1974) found that H. lanatus on hill land was only slightly affected by doses of up to 2.24 kg a.i./ha. This is similar to the failure of dalapon under such conditions. Perhaps H. lanatus growth is reduced less than that of other species in low nutrient conditions and it is better able to tolerate these herbicides. Fisher and Faulkner (1975) found that H. lanatus was more tolerant of 0.5 kg a.i./ha than was L. perenne. However, the various cultivars of L. perenne react differently to paraquat (Faulkner, 1974). This suggests that the tolerance is heritable and could be increased by selection.

Propyzamide. Propyzamide is used for weed control in fruit trees and other crops. When applied in summer at 0.6 to 1.1 kg a.i./ha it has also given good control of H. lanatus in L. perenne (Fisher and Faulkner, 1975;

TABLE 25

Selected references to the effects of Paraquat
on L. perenne and H. lanatus

AUTHOR	SWARD	PLACE	TIME	DOSE kg a.i./ha	OBSERVATION
Bramley (1961)	Mixed	Wellington	March	0.5	Mean tolerance of species over 3 doses based on point analyses 3 months later Control = 100 Paraquat L H 54 3
		New	=	1.0	
		Zealand	Autumn	2.0	
"	"	"	Dec = Summer	"	L H 68 22
Young (1964)	Mixed permanent hill	8 sites	July	0.28	<u>H. lanatus</u> only slightly affected
			and Oct	2.24	
Williams (1967)	Mixed	New Zealand	March	0.14	Cover hits/50 points 9 months later Control Paraquat L H L H 33 4 40 Tr
			= Autumn		
Sharp (1968)	Mixed	New Zealand	Summer	0.14	Hits/100 points 3 months later Control Paraquat L H L H 43 81 34 12
Oswald (1972)	Mixed permanent	Oxford	July	1.0	Presence scale per m ² 14 days later Control Paraquat L H L H 4.5 8 3 2
Faulkner (1975)	Boxes mixture <u>L. perenne</u> & <u>H. lanatus</u> 10 wk. old N.B. <u>L. perenne</u> = paraquat to lerant PRP II	Armagh N. Ireland	July	0.4	Mean dry wt. yields 5 wk. later Control Paraquat PRP II H PRP II H 16.5 4.3 22.0 0
Fisher & Faulkner (1975)	Monoculture rows in field	Belfast	July	0.5	Tolerance (based on dry wt. of autumn cuts) Mean = 100 L H 85 94

Haggar, 1976b), as shown in Table 26 (p.148).

AIM OF THESE EXPERIMENTS

These experiments were designed to compare the effectiveness of the above herbicides in selectively controlling established H. lanatus in L. perenne. The doses were chosen with reference to published work (Table 27, p.149).

In the first two experiments, eight herbicides were applied at various doses to plants in pots during the growing season. Dalapon was included so that the effect of the other herbicides could be compared with this 'standard'. From the results of these experiments, the herbicide treatments could be placed in order of efficacy and suggestions for further field work could be made.

In the third experiment, asulam was applied at a range of doses to plants growing in pots at three times in the autumn. From the literature, asulam seemed to be an especially promising chemical, but there was little information about how application^{to a mixed sward} at different times during the autumn

would affect the result. Also, a field experiment was about to be carried out by the Grass and Fodder Crops Group at W.R.O. in the autumn. In this, asulam at a range of doses was to be applied to a permanent sward containing L. perenne and H. lanatus. It would be interesting to find out, retrospectively, whether the results of this long term field work could have been predicted from the results of my short term autumn experiment using plants growing in pots.

METHOD AND MATERIALS (1 AND 2)

EXPERIMENT 1. THE EFFECT OF EIGHT HERBICIDES ON ESTABLISHED H. LANATUS AND L. PERENNE WHEN APPLIED IN EARLY SUMMER

Clumps of both L. perenne and H. lanatus were dug up from the W.R.O. grassland on 17 December 1975. Individual tillers with shoots 50-100mm long

TABLE 26

Selected references to the effects of Propyzamide
on L. perenne and H. lanatus

AUTHOR	SWARD	PLACE	TIME	DOSE kg a.i./ha	OBSERVATION
Fisher & Faulkner (1975)	Monoculture rows in field	Belfast N. Ireland	June	0.6	Tolerance (based on dry wt. of autumn cuts) Mean = 100 L H 137 70
Ministry of Agriculture N. Ireland (1975)	Boxes mixtures	Belfast		0.4	4 months later <u>H. lanatus</u> eliminated PRP II <u>L. perenne</u> as control
Haggan (1976b)	Mixed	Ilmer Bucks	July	1.1 gramules	% cover unspecified time <u>H. lanatus</u> : Control = 26 Propyzamide = 2 <u>L. perenne</u> ? unaffected

TABLE 27

Sources of the doses of the herbicides
used in these experiments

HERBICIDE	SOURCES OF DOSES USED
Asulam	Harkess & Hope (1974)
Dalapon	Haggar & Oswald (1976)
Lenacil	Adamson (1975)
Linuron	Harkess & Hope (1974)
Paraquat	Harkess & Hope (1974)
Metribuzin	Blair (1973)
Propyzamide	Haggar (1976a)

TABLE 28

The doses of the herbicides used in the experiments

HERBICIDE	DOSE kg a.i./a.e./ha			
	NONE	LOW	MEDIUM	HIGH
Asulam	0	0.56	1.12	2.24
Dalapon	0	1.4	2.8	5.6
Lenacil	0	2.8	5.6	11.2
Linuron	0	0.56	1.12	2.24
Metribuzin	0	0.37	0.75	1.5
Paraquat	0	0.09	0.18	0.36
Propyzamide granules	0	0.56	1.12	2.24
Propyzamide liquid	0	0.56	1.12	2.24

a.i. = active ingredient

a.e. = acid equivalent

and roots were planted separately in 60mm cubic containers filled with general purpose potting compost. They were grown in a glasshouse in which the mean weekly maximum temperature was 18.3°C and the mean weekly minimum temperature was 9.9°C . The plants were in a 16h day, were watered regularly and given a 1% solution of Vitafeed weekly. They were trimmed three times to about 50mm.

On 16 and 17 March the established plants were transplanted into 250mm diameter pots outside on a paved area. A piece of nylon mesh with 1mm diameter holes was placed over the drainage hole and covered with a 25mm layer of gravel. The pots were filled with an unsterilized sandy loam soil, into which had been mixed fertilizer and other compounds (Appendix 7, p.251).

Two plants of each species were put into each pot. Throughout the experiment the plants were watered regularly and given a 1% solution of Vitafeed weekly. There were ninety six pots to accommodate the following treatments: eight herbicides applied at four doses (including zero) on each of three dates. The three factor interaction was used as the residual. The herbicides and doses used are shown in Table 28 (p. 149). Details of the products used and the full chemical names of the herbicides are given in Appendices 9 (p.253) and 10 (p.254).

The plants were cut to 50mm above soil level a week before applying the herbicides. The day before spraying, the relevant plants were brought inside so that they would be dry. Spraying was carried out using a laboratory pot sprayer, details of which are given in Appendix 11A and B (p.255). The plants were not put back outside until the day after spraying, so that the herbicides would not be washed off the leaves too soon. The dates of the various operations are given in Table 29 (p.151).

Each week from treatment until harvest, the plants were visually scored on a 0 to 7 scale, from 0 = completely dead to 7 = as control. The scale points are defined in Appendix 11C (p.255). The plants were photographed

TABLE 29

Dates of the various operations involved in the herbicide experiments

EXPERIMENT	DATE CUT TO 50mm	SPRAY DATE	PHOTOGRAPH DATE	HARVEST DATE
8 herbicides summer	27 Apr	4 May	7 Jun	6 Jul
"	18 May	25 May	28 Jun	27 Jul
"	8 Jun	15 Jun	20 Jul	17 Aug
8 herbicides autumn	12 Oct	19 Oct	24 Nov	21 Dec
Asulam	31 Aug	7 Sep	12 Oct	9 Nov
"	27 Sep	4 Oct	-	6 Dec
"	2 Nov	9 Nov	-	11 Jan ('77)

TABLE 30

Herbicidal treatments showing good selective control of H. lanatus in L. perenne

HERBICIDE	DOSE kg a.i./ha (mean 3 dates) or TIME (mean 3 doses)
Metribuzin	0.37
Linuron	1.12
Propyzamide (granules)	2.24
Paraquat	Early May
Paraquat	0.09
Asulam	Early May
Propyzamide (granules)	Early May

These treatments have been placed in order of decreasing ratio of:

d.wt. green L. perenne

d.wt. green H. lanatus

five weeks after treatment (Fig. 60, p. 153) and harvested, by cutting off the shoots at soil level, four weeks later. The number of L. perenne panicles present was recorded at harvest.

There was a very large amount of shoot material produced from each pot in this experiment. It would have taken too long to remove all the brown material from each sample in order to measure the dry weight of the green material. So, a method of estimating this was required. Each sample was spread out and scored on a 0 to 10 scale for the amount of green material present. One sample of each score from each species was separated into green and brown material and the dry weights of both components were recorded (Appendix 12, p. 256). These figures were used to estimate the dry weight of green material present from the total dry weight of all the samples.

EXPERIMENT 2. THE EFFECT OF EIGHT HERBICIDES ON ESTABLISHED H. LANATUS AND L. PERENNE WHEN APPLIED IN OCTOBER

The procedures for this experiment were mainly the same as for Experiment 1. The differences are outlined below:

The tillers were dug up on 2 and 3 August 1976. They were established with a mean weekly maximum temperature of 29.7°C and a mean weekly minimum temperature of 10.5°C. On 8 September the plants were transplanted into sixty four pots, being made up of two blocks each of eight herbicides applied at four concentrations. The herbicides were applied at one date in October, as opposed to three dates in summer. After harvest each species was separated into green and brown material and the dry weight of the green material was recorded.

RESULTS (1 AND 2)

VISUAL SCORES

The weekly visual scores on the plants during the nine weeks after treatment are shown in Figures 61 to 68 (pp. 154 to 161). These graphs have

Mixtures of H.lanatus & L.perenne sprayed with linuron
on 25 May & photographed on 28 June 1976



Control bottom right , increasing doses clockwise

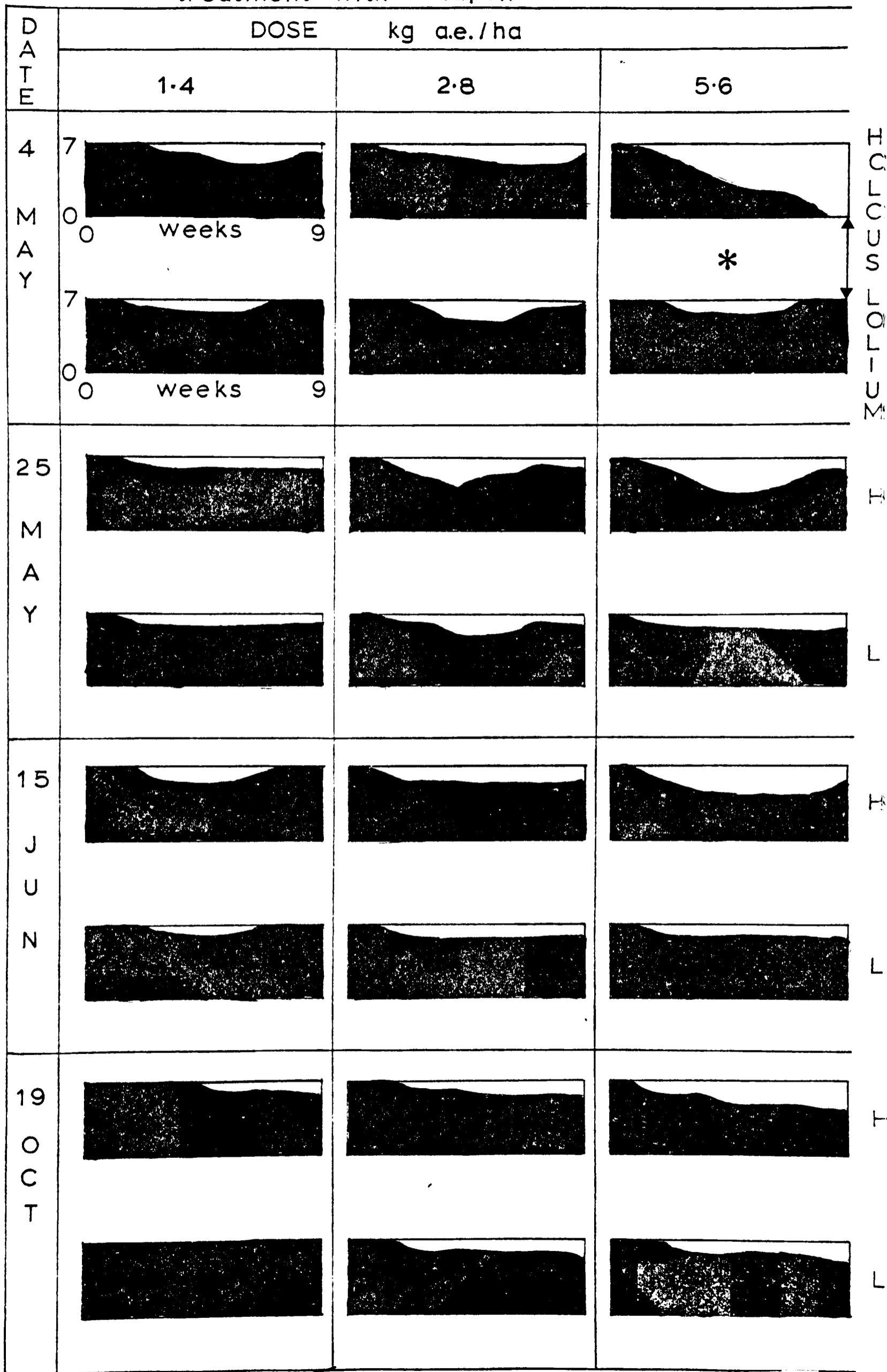
FIGURE 61
 Scores of *H.lanatus* & *L.perenne* green material after
 treatment with Asulam

DATE	DOSE kg a.i. / ha			
	0.56	1.12	2.24	
4 MAY				H L
			*	
25 MAY				H L
			*	
15 JUN				H L
			*	
19 OCT				H L
			*	

KEY 0 = all dead

7 = as control

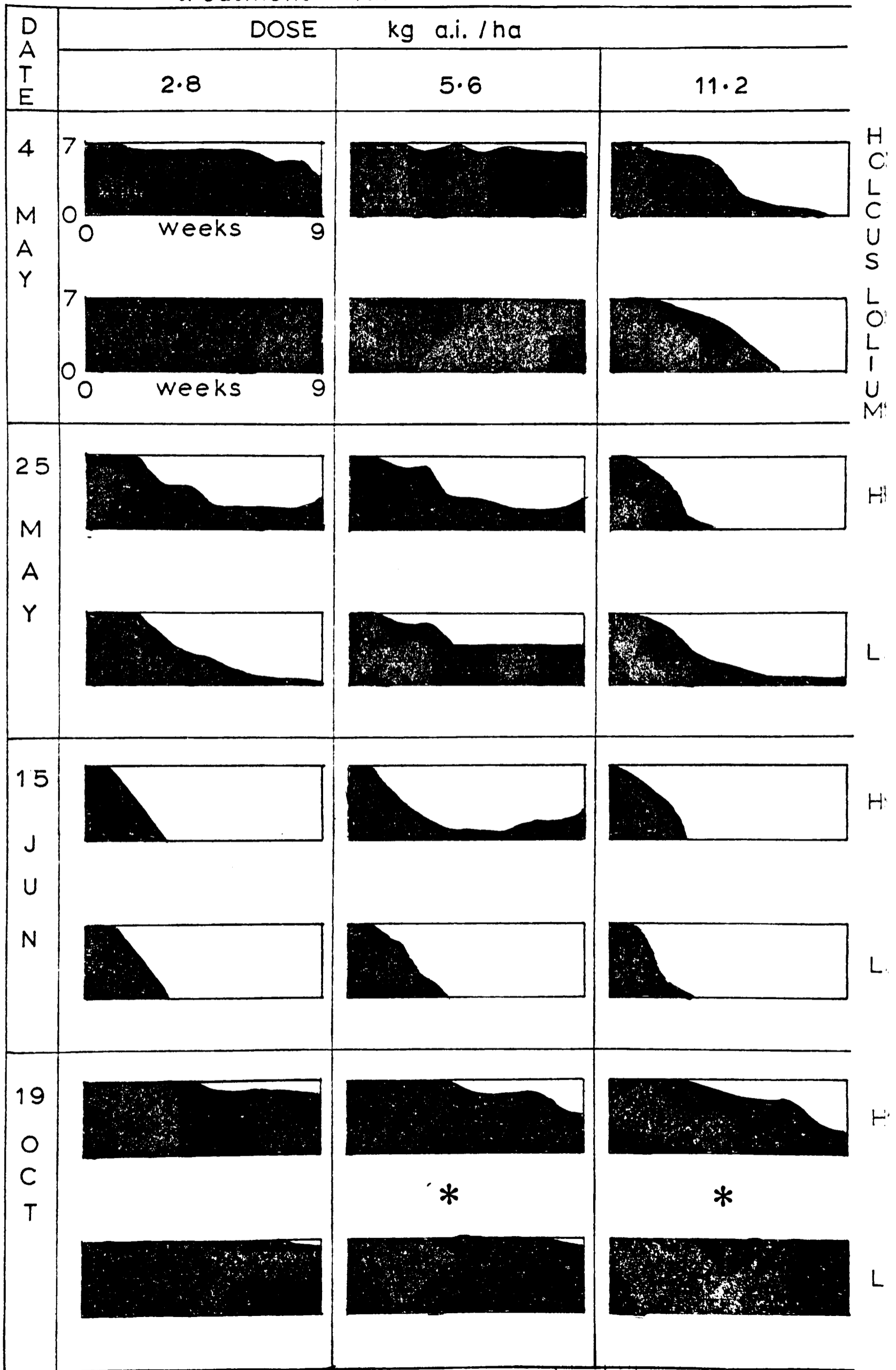
Scores of H.lanatus & L.perenne green material after treatment with Dalapon



KEY 0 = all dead

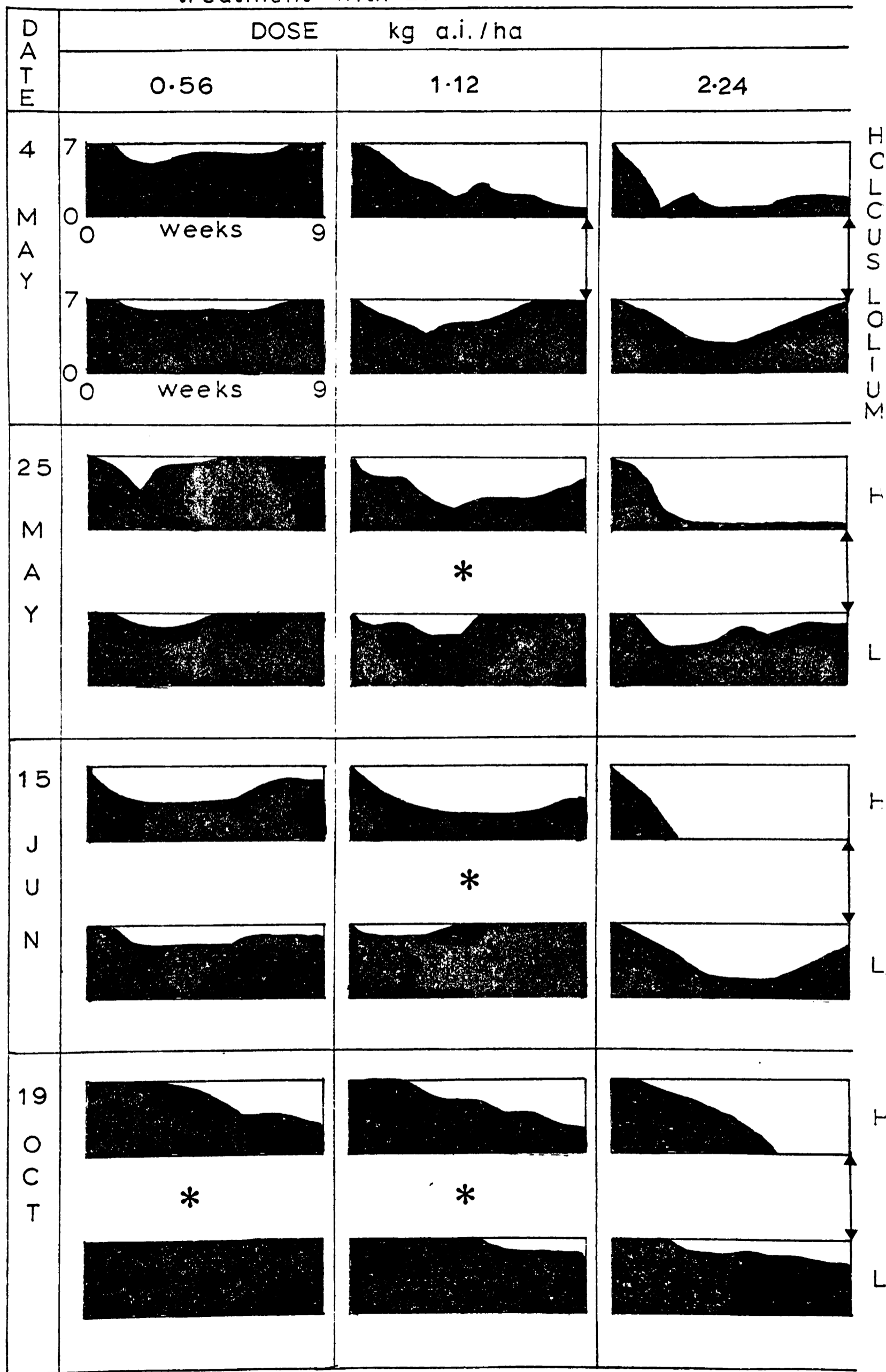
7 = as control

FIGURE 63
 Scores of H.lanatus & L.perenne green material after
 treatment with Lenacil



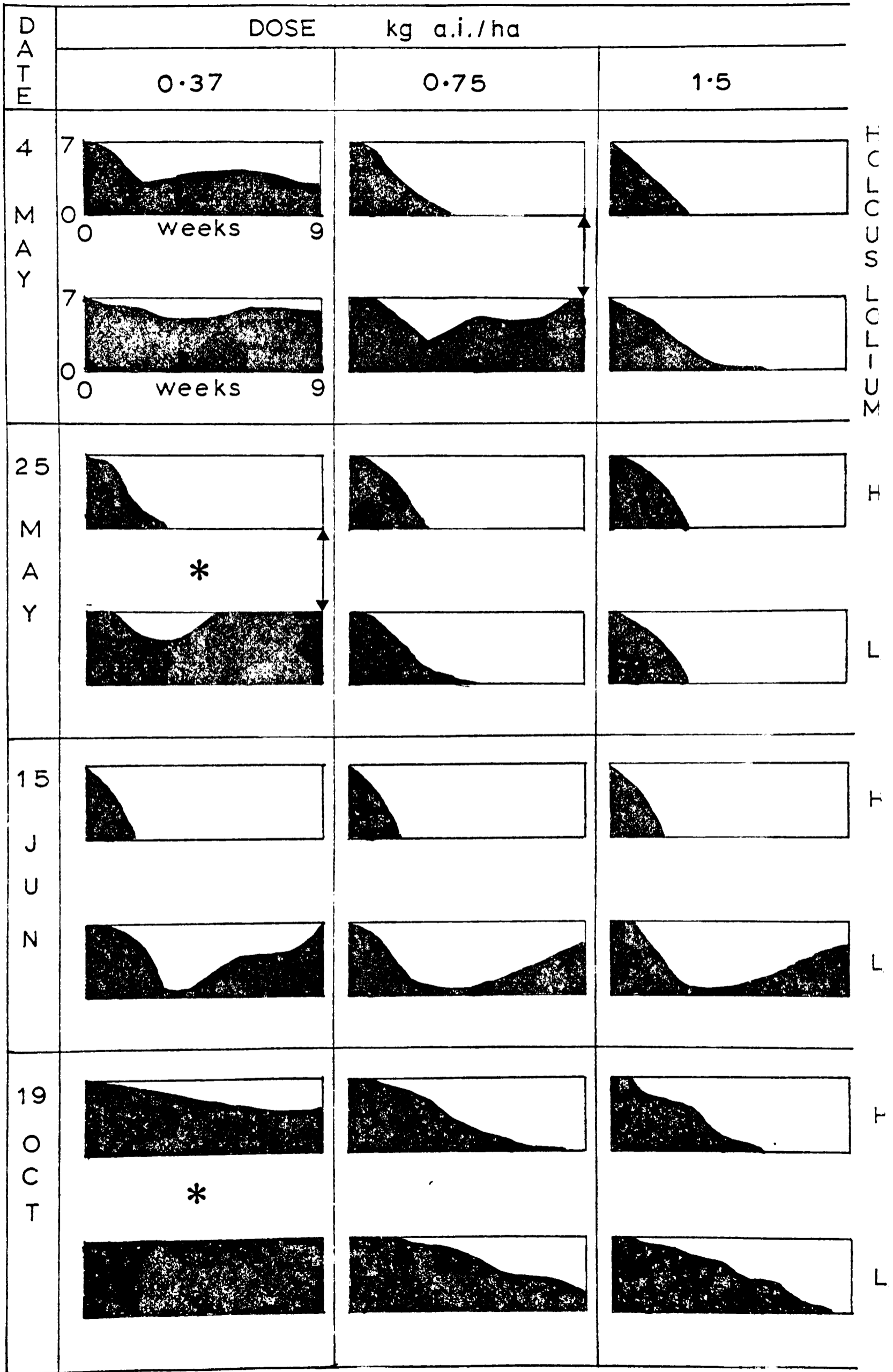
KEY 0 = all dead 7 = as control

FIGURE 64
 Scores of *H.lanatus* & *L.perenne* green material after
 treatment with Linuron



KEY 0 = all dead 7 = as control

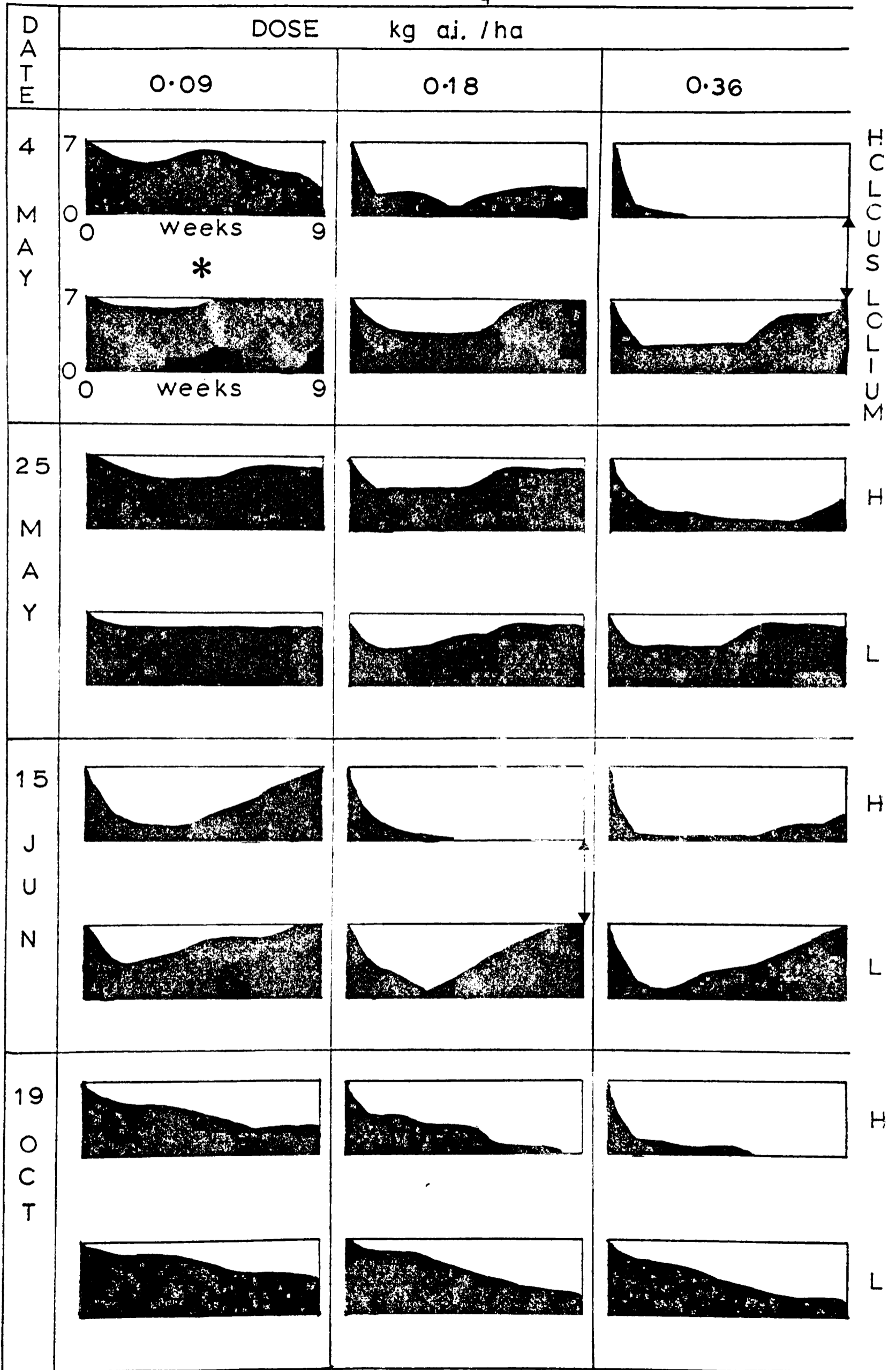
Scores of H.lanatus & L.perenne green material after treatment with Metribuzin



KEY 0 = all dead

7 = as control

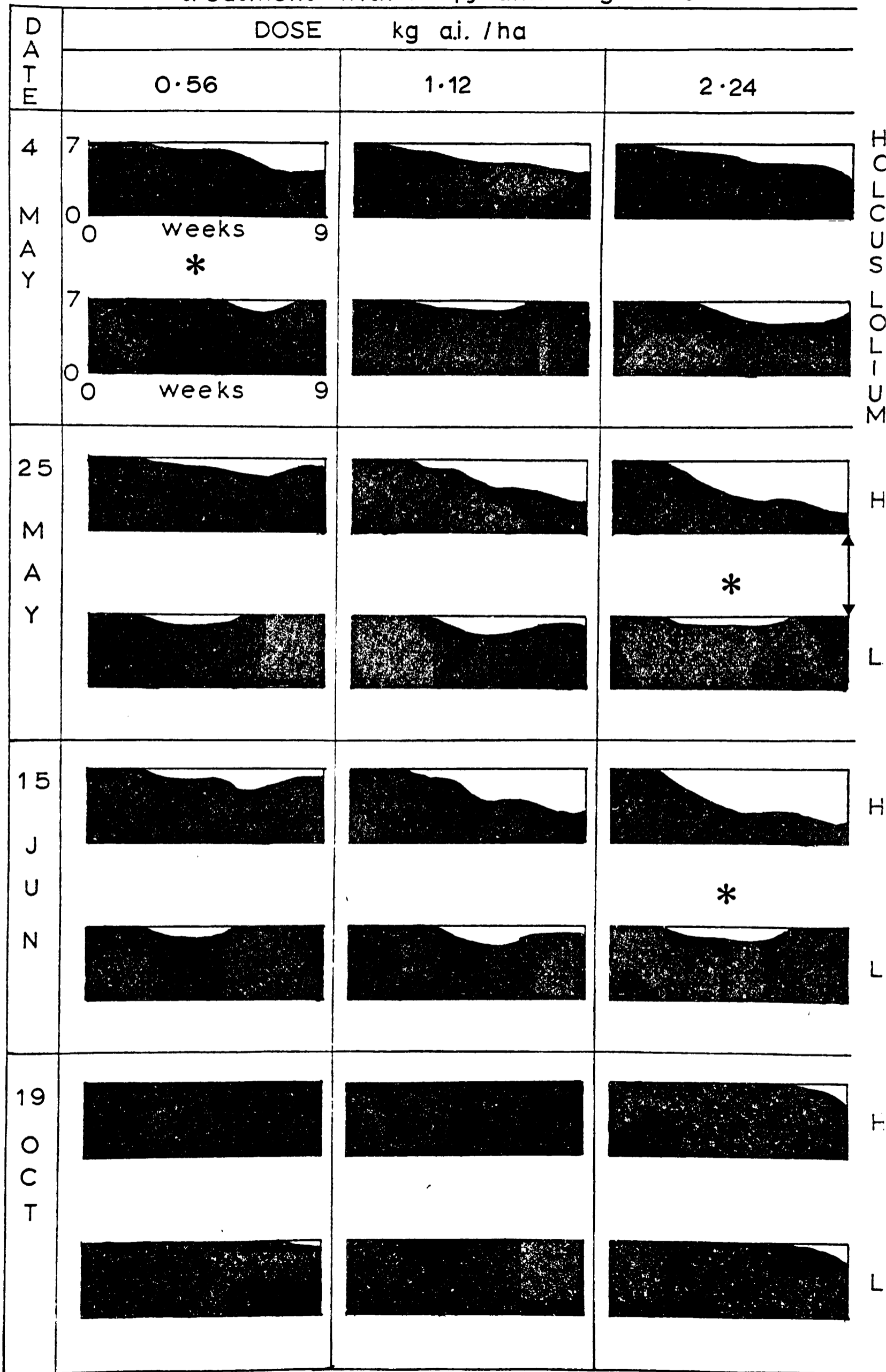
FIGURE 66
 Scores of H.lanatus & L.perenne green material after
 treatment with Paraquat



KEY 0 = all dead

7 = as control

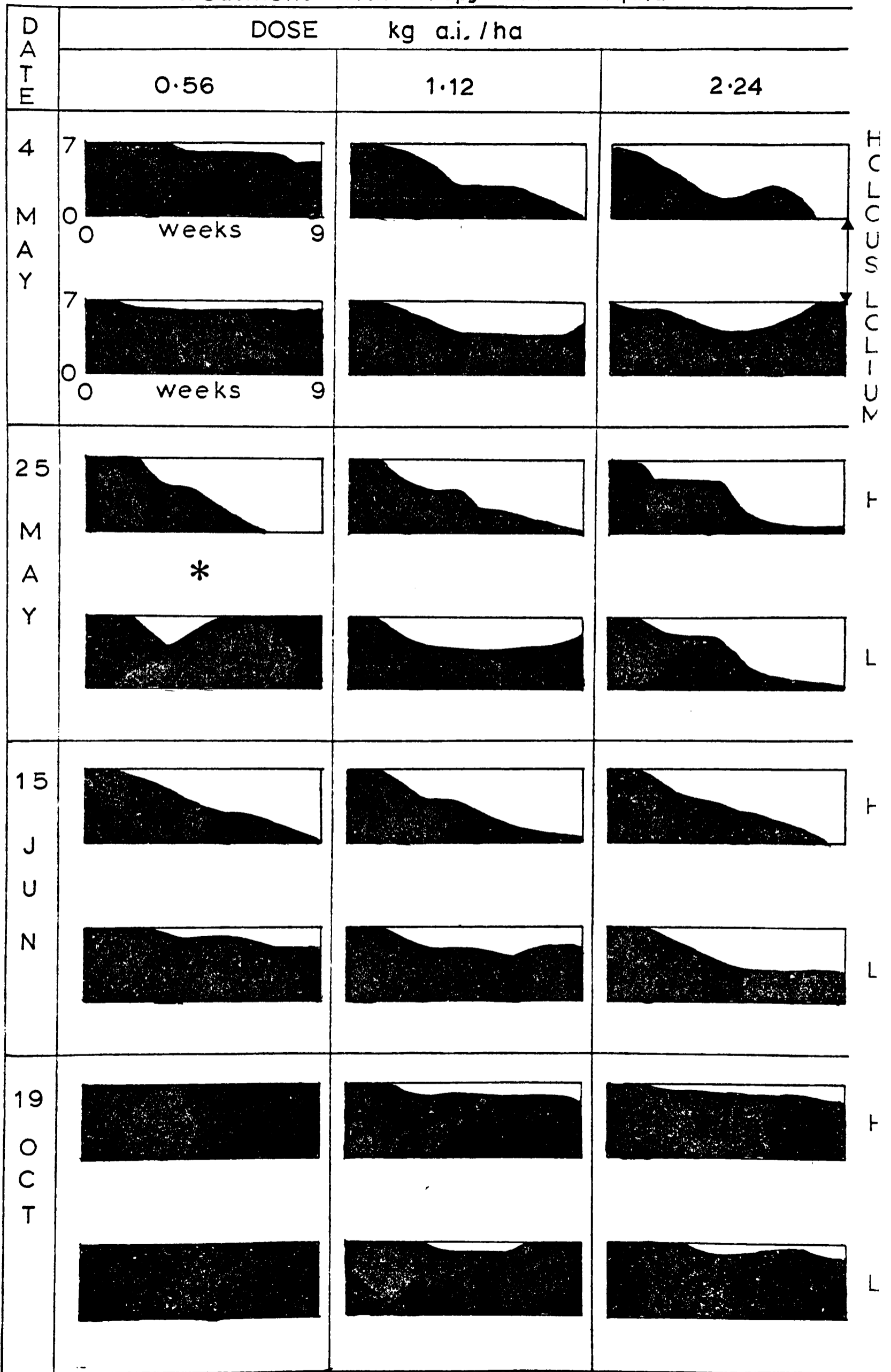
Scores of *H.lanatus* & *L.perenne* green material after treatment with Propyzamide granules



KEY 0 = all dead

7 = as control

Scores of H. lanatus & L. perenne green material after treatment with Propyzamide liquid



KEY 0 = all dead

7 = as control

been used to calculate a "selective factor" for each herbicidal treatment:

$$\begin{aligned} \text{Selective factor} &= \frac{\text{Holcus suppression}}{\text{Lolium suppression}} \\ &= \frac{\text{Holcus white area}}{\text{Lolium white area}} \end{aligned}$$

When this exceeded four units, the treatment was marked with an asterisk. In instances where the L. perenne was not damaged (i.e. L. perenne white area = 0), the selective factor is infinity. Such treatments have been marked with an asterisk only if the H. lanatus white area formed at least 25% of the total (an arbitrary figure). Also, where there was a difference of at least five units in the visual scores of the two species on the day of harvest this has been indicated by an arrow. The impression of the effects of the herbicides obtained from the visual scores of both experiments is as follows:

Asulam. The only useful concentration was 2.24 kg a.i./ha and this gave the best selectivity when applied in early May (Fig. 61, p. 154). But, even at this date there were signs of H. lanatus recovering.

Dalapon. A dose of 5.6 kg a.e./ha applied in early May gave very good results. All other treatments were poor (Fig. 62, p. 155).

Lenacil. All summer treatments were very damaging to both species. But the two higher doses gave promising results in October (Fig. 63, p. 156).

Linuron. Doses of both 1.12 kg a.i./ha on 4 May and 2.24 kg a.i./ha on all four dates gave good results (Fig. 64, p. 157).

Metribuzin. Only the lowest dose of 0.37 kg a.i./ha used in May or October was at all promising. Otherwise the herbicide was too damaging (Fig. 65, p. 158).

Paraquat. The response to this chemical was variable. Doses of 0.36 kg a.i./ha in May and 0.18 kg a.i./ha in June gave good results but all other treatments were much less selective (Fig. 66, p.159).

Propyzamide (granules). The use of 2.24 kg a.i./ha gave good results. Otherwise the herbicide damaged both species similarly (Fig. 67, p.160).

Propyzamide (liquid). In general the liquid form of the herbicide was more damaging than the granules. A dose of 1.12 kg a.i./ha was useful if applied at either date in May as was 2.24 kg a.i./ha applied in early May and 0.56 kg a.i./ha in late May (Fig. 68, p.161).

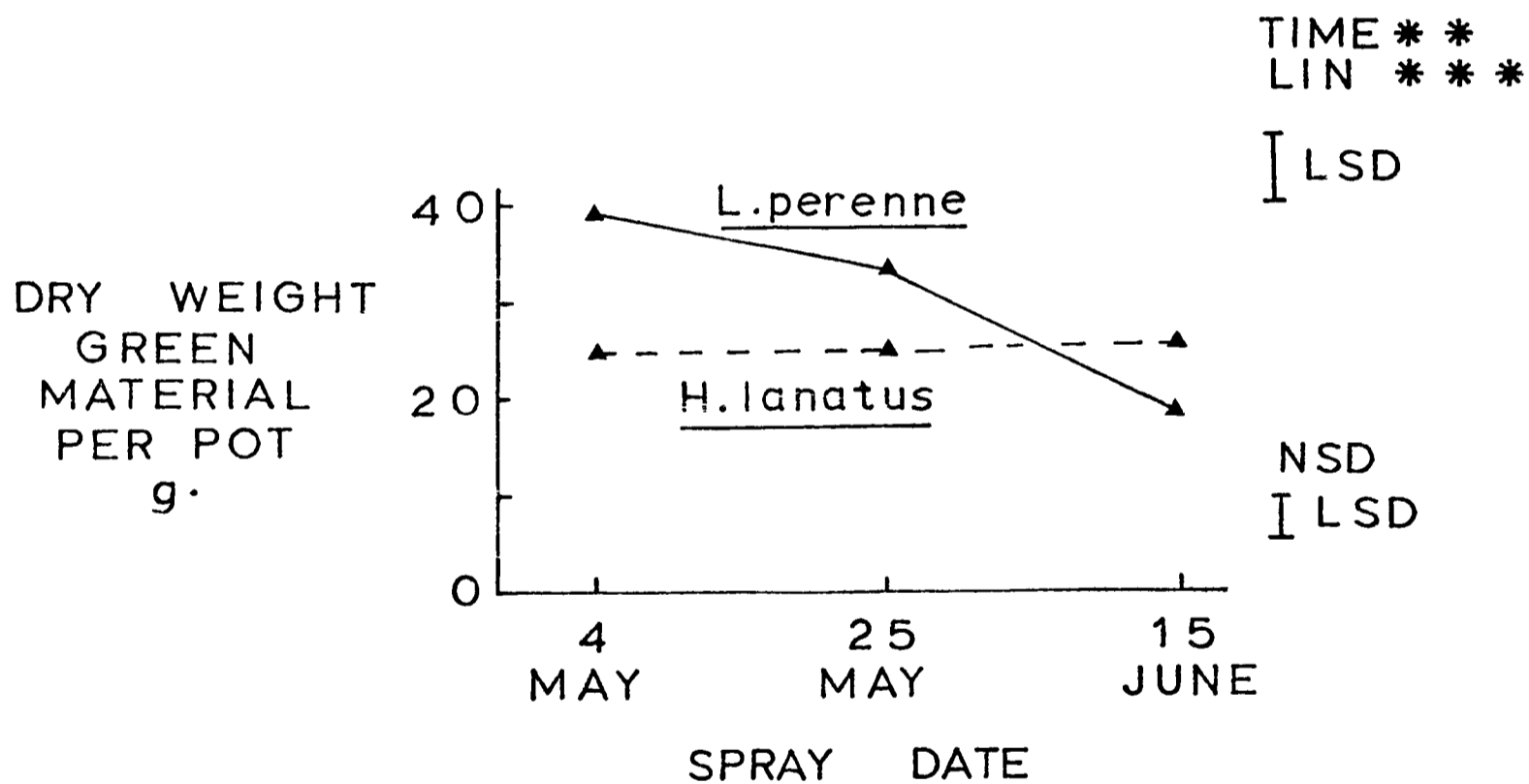
DRY WEIGHT YIELDS AT HARVEST

Experiment 1. The mean dry weight of green L. perenne present declined over the three dates of herbicide application whereas the amount of green H. lanatus remained the same (Fig. 69, p.164). The mean dry weight of green H. lanatus present declined as the mean level of herbicide used increased (44.8g → 9.8g) (* * *) but L. perenne was unaffected (27.8g → 26.3g) (NSD). The dry weights of harvested green material of the two species are presented separately for each herbicide in Figures 70 to 77, (pp.165 to 172). The results from the three dates of treatment have been summarised as the mean of three dates and the mean of three doses so that statistically significant differences can be seen.

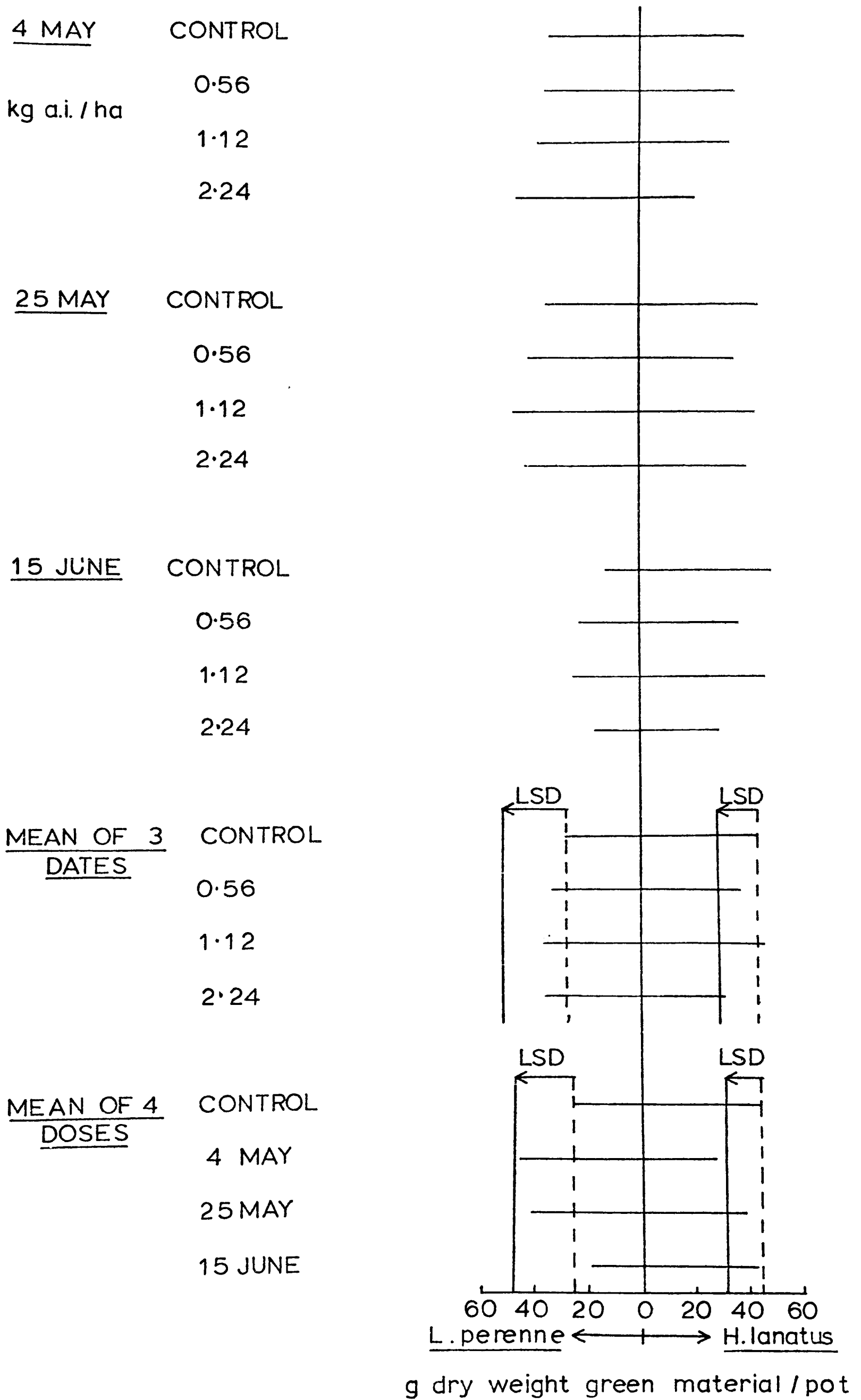
Many doses of the herbicides decreased the amount of H. lanatus present but only two (lenacil at 11.2 kg a.i./ha, Figure 72, p.167 and metribuzin at 1.5 kg a.i./ha, Figure 74, p.169) significantly decreased the amount of L. perenne. The only instance when a significant increase in L. perenne was recorded was when paraquat was applied at 0.09 kg a.i./ha (Fig. 75, p.170). However, several other treatments approached significance. The treatments shown in Table 30 (p.151) gave both a significant decrease in the amount

FIGURE 69

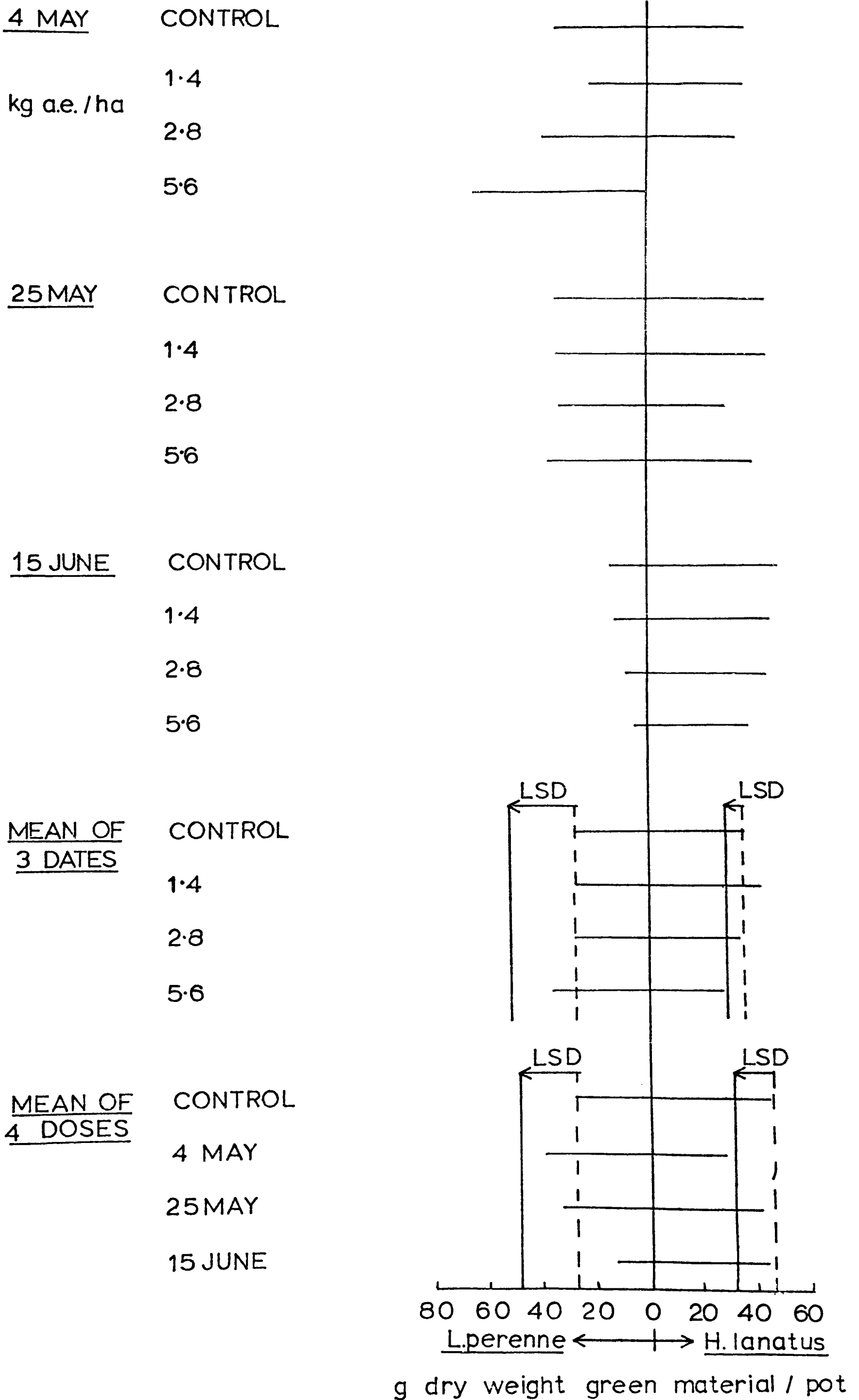
The amounts of H.lanatus & L.perenne harvested 9 weeks after 3 treatment dates (mean of all treatments), in summer



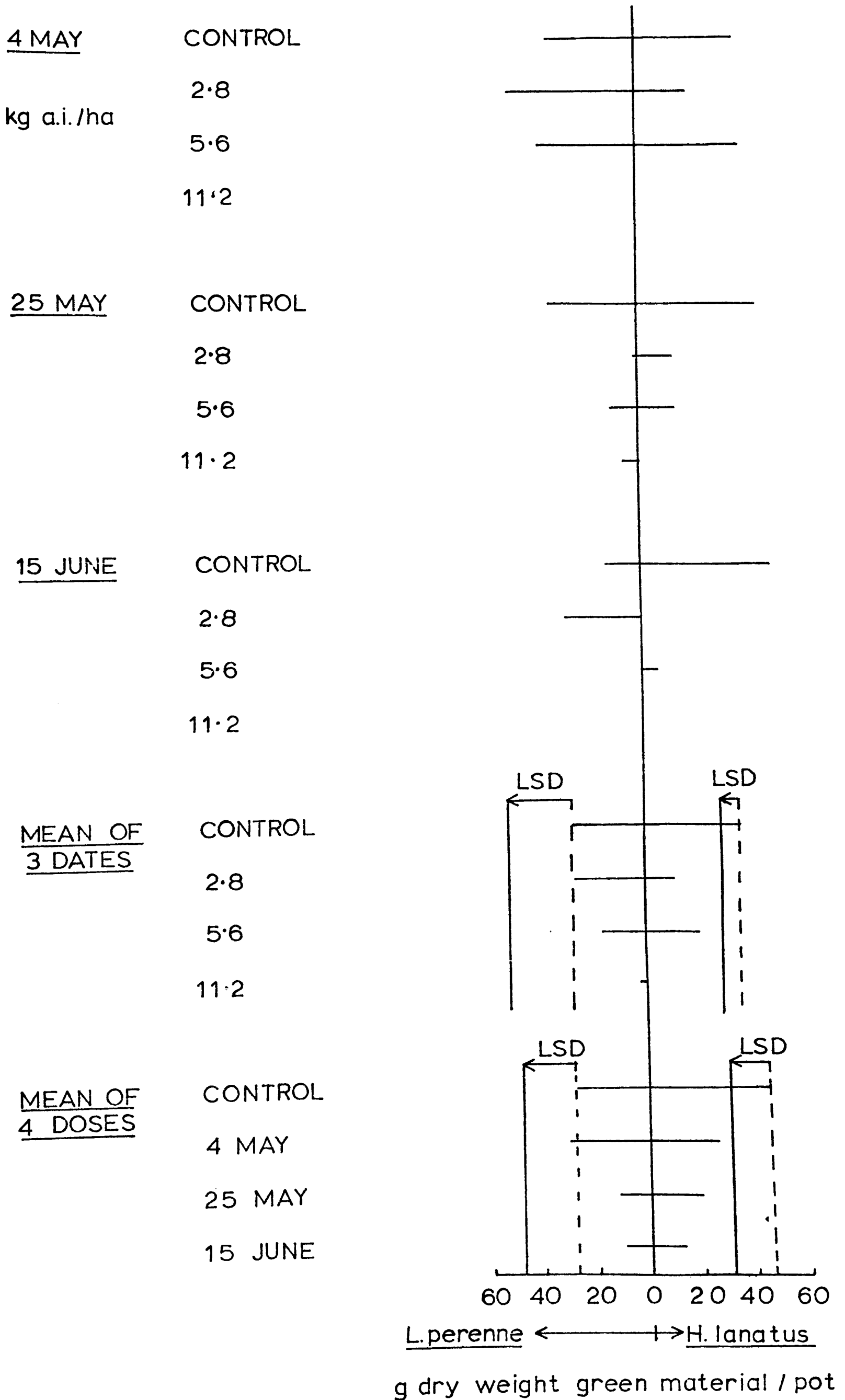
The amount of H. lanatus & of L. perenne 9 weeks after applying asulam at 4 doses & 3 times during summer



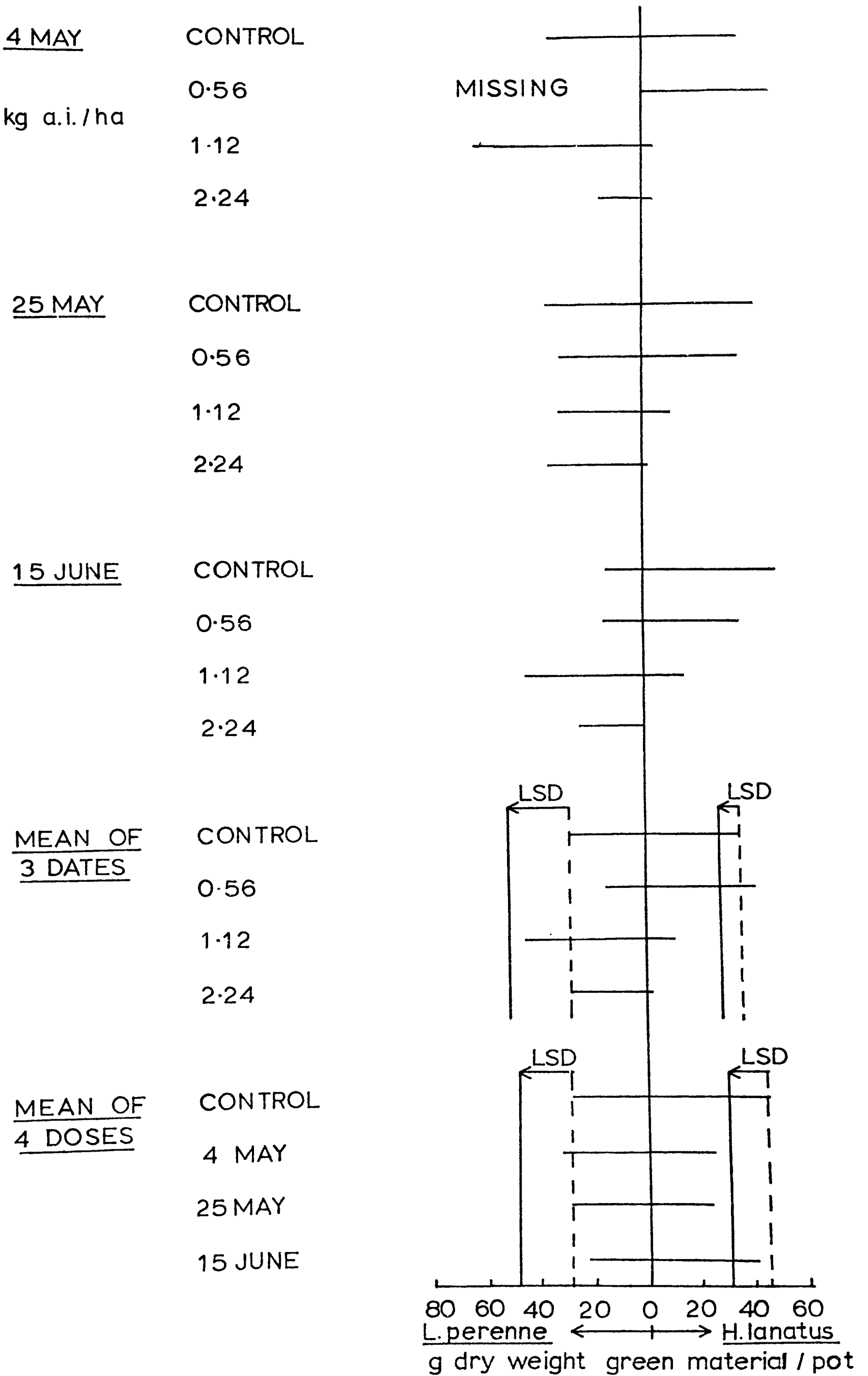
The amount of H.lanatus & of L.perenne 9 weeks after applying dalapon at 4 doses & 3 times in summer



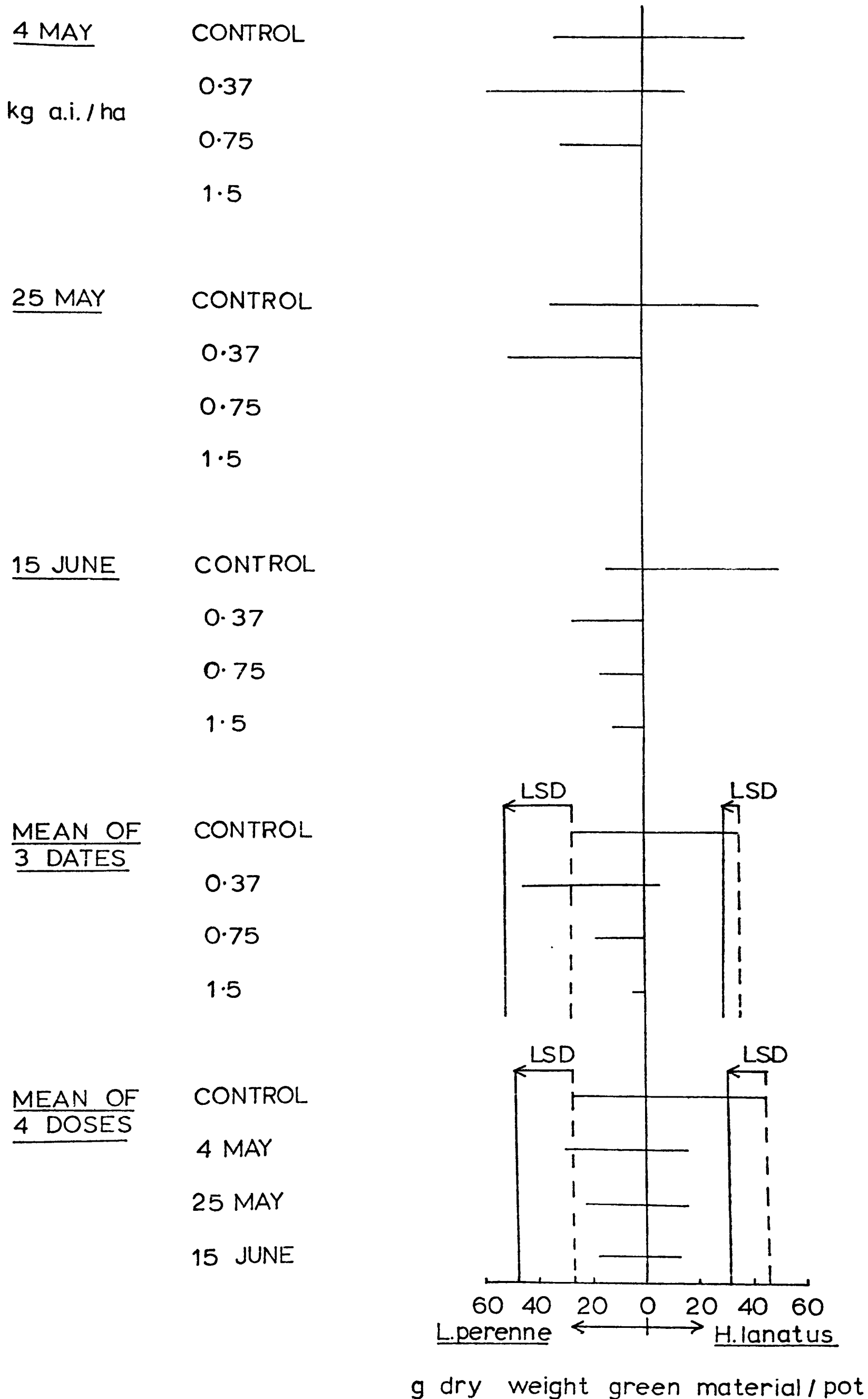
The amount of H.lanatus & of L.perenne 9 weeks after applying lenacil at 4 doses & 3 times in summer



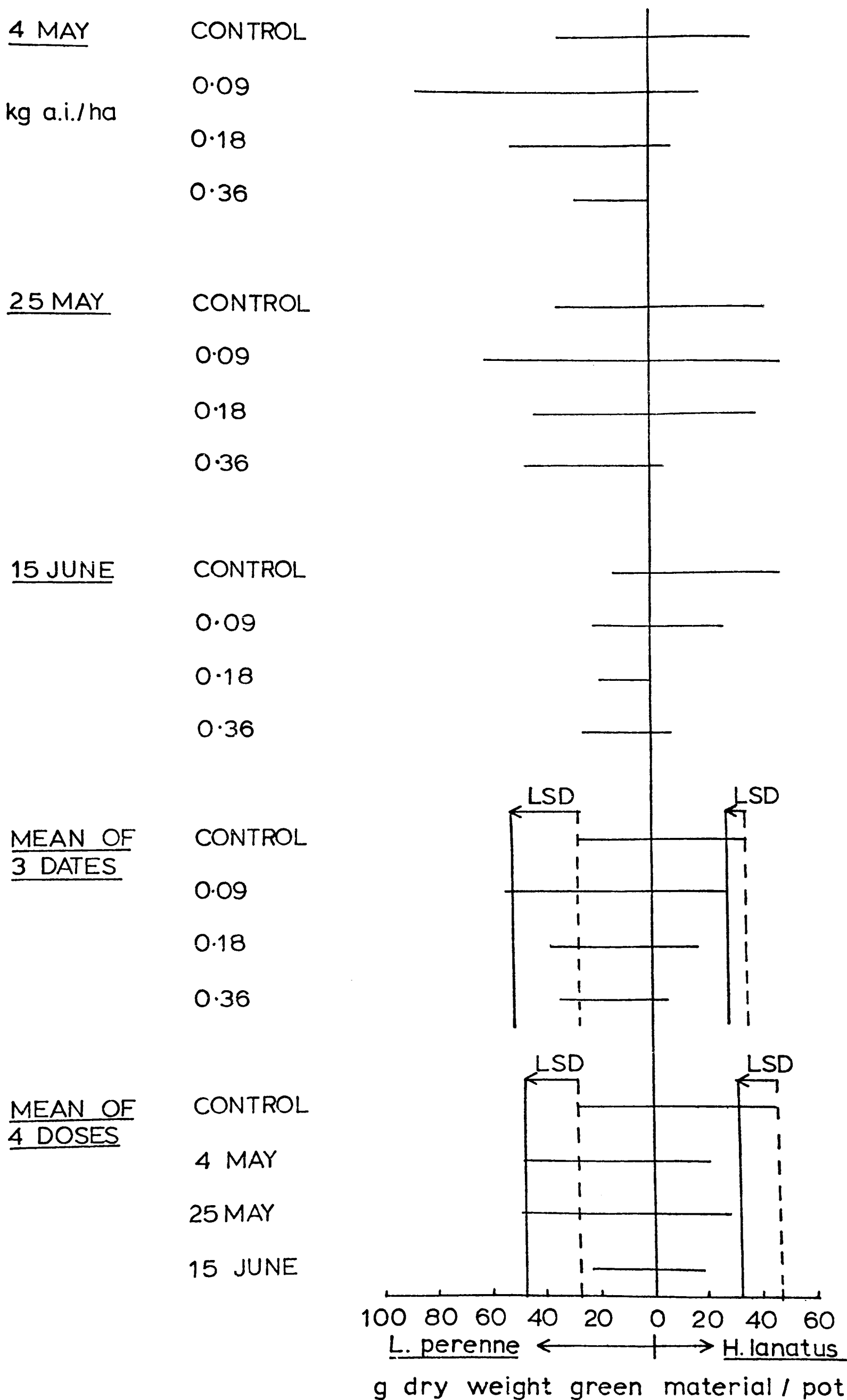
The amount of *H. lanatus* & of *L. perenne* 9 weeks after applying linuron at 4 doses & 3 times in summer



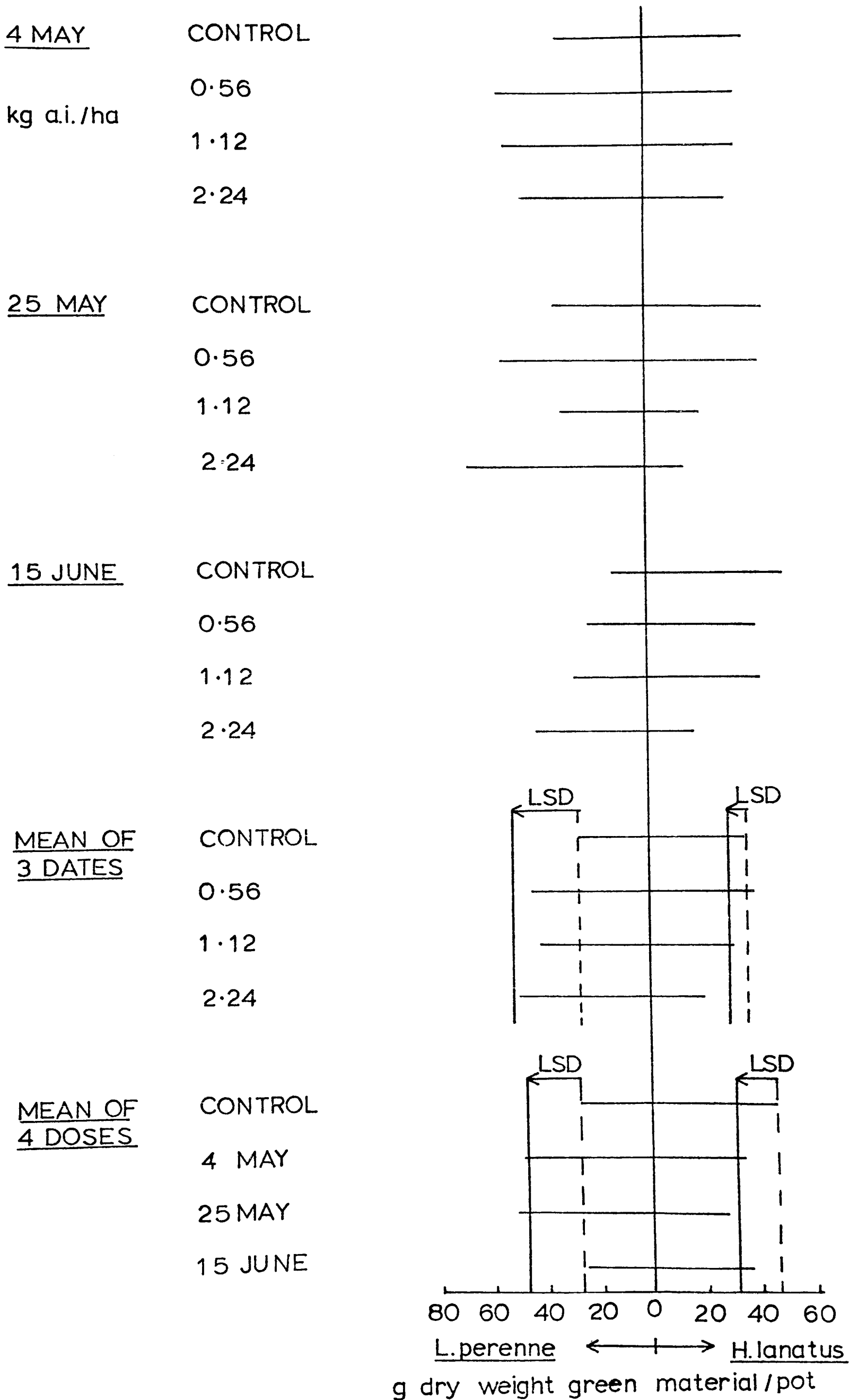
the amount of H.lanatus & of L.perenne 9 weeks after applying metribuzin at 4 doses & 3 times in summer



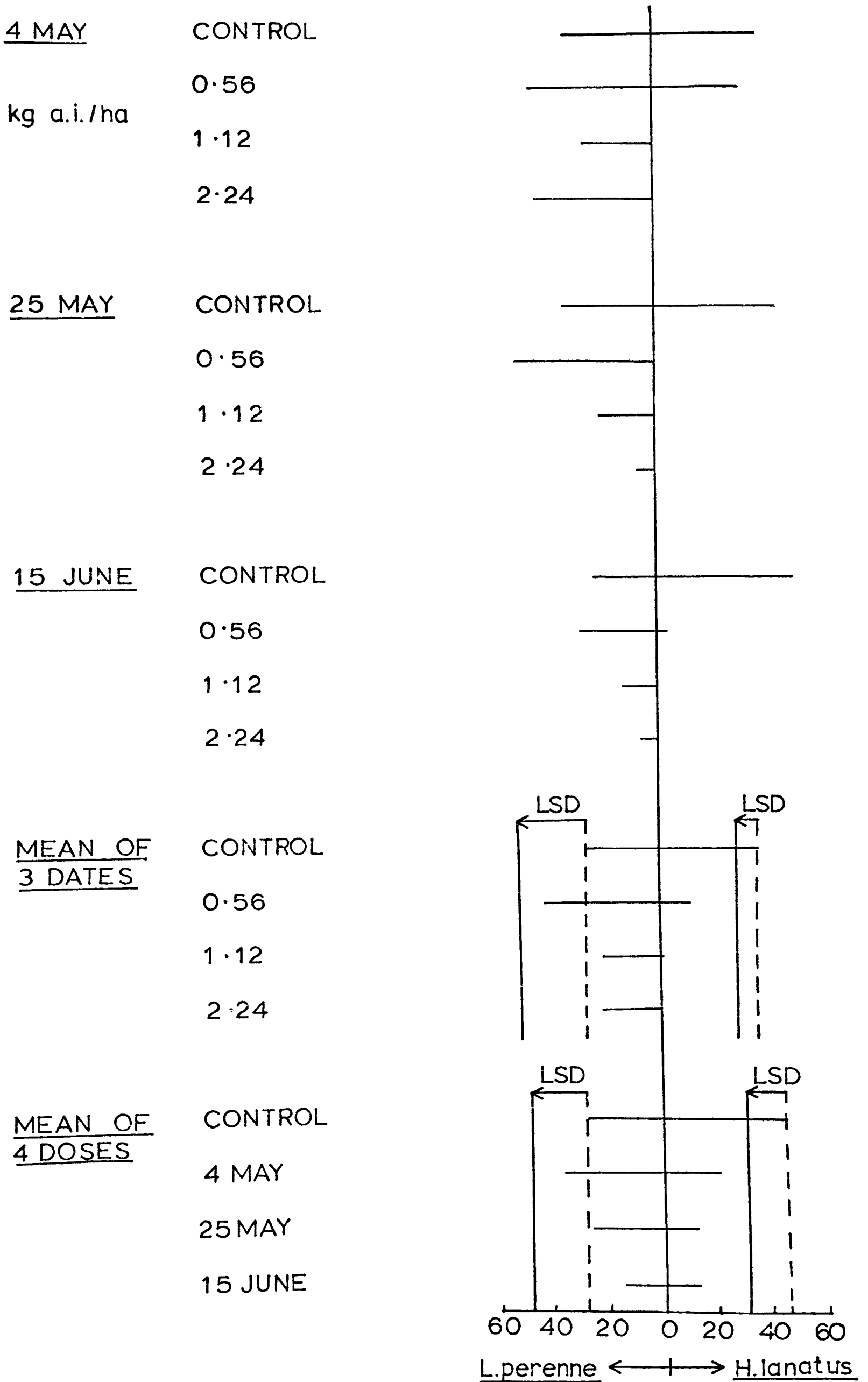
The amount of H.lanatus & L.perenne 9 weeks after applying paraquat at 4 doses & 3 times in summer



The amount of H.lanatus & of L.perenne 9 weeks after applying propyzamide granules at 4 doses & 3 times in summer



The amounts of *H.lanatus* & *L.perenne* 9 weeks after applying propyzamide liquid at 4 doses & 3 times in summer



g dry weight green material/pot

of H. lanatus and a significant (or almost significant) increase in the amount of L. perenne.

Experiment 2. There was a very highly significant difference between the mean dry weight of green H. lanatus harvested from the two blocks of this experiment. Block 1 = 4.19g, Block 2 = 2.09g (* * *). There was no significant difference between the treatments in the proportion of green L. perenne which they produced.

Figure 78 (p. 174) gives a summary of the yields from this experiment. The plants were much smaller at harvest than those in the summer (Experiment 1). Although a number of treatments did significantly reduce or kill H. lanatus they also tended to damage L. perenne severely. Exceptions were asulam at 0.56 kg a.i./ha, metribuzin at 0.37 kg a.i./ha and propyzamide granules at 0.56 kg a.i./ha which approached significant levels of increased live L. perenne and decreased levels of live H. lanatus at harvest (Fig. 78, p. 174).

NUMBER OF L. PERENNE INFLORESCENCES

The numbers of L. perenne inflorescences produced after treatment by each herbicide in the first experiment are given in Figure 79 (p. 175). Treatment with lenacil or propyzamide (liquid) caused significantly fewer inflorescences to be produced. Many of the inflorescences on plants treated with higher doses of propyzamide (liquid) on 4 or 25 May were distorted. The rachis was long and curly with large, widely spaced florets.

DISCUSSION (1 AND 2)

EXPERIMENT 1

Most of the treatments which were found to be selective on the basis of the dry weight of green material were also picked out as selective by the visual scores. But, the group of treatments which appeared promising in

FIGURE 78

Amount of green material of H.lanatus & L.perenne, 9 weeks after applying 8 herbicides on 19 October

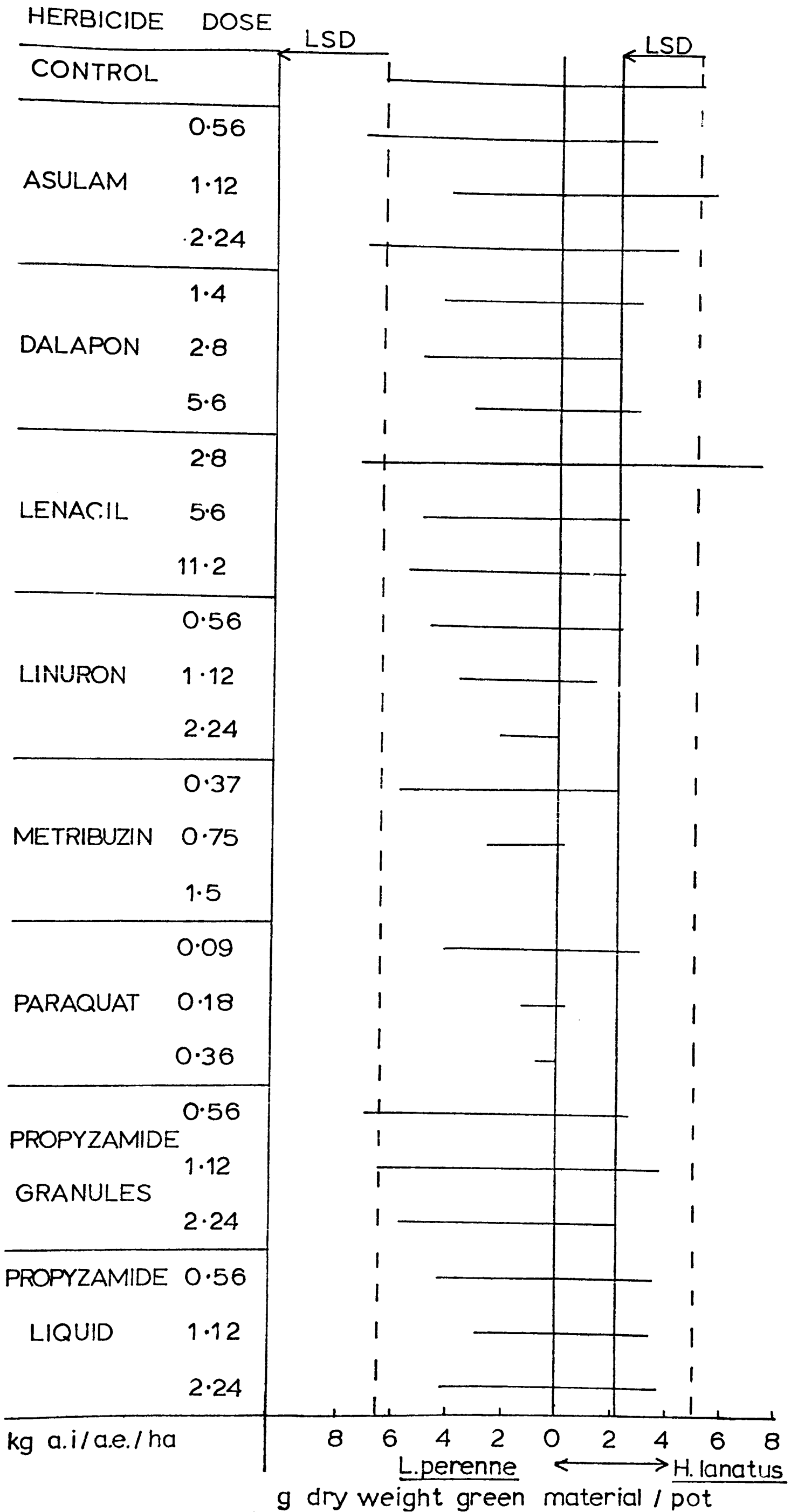
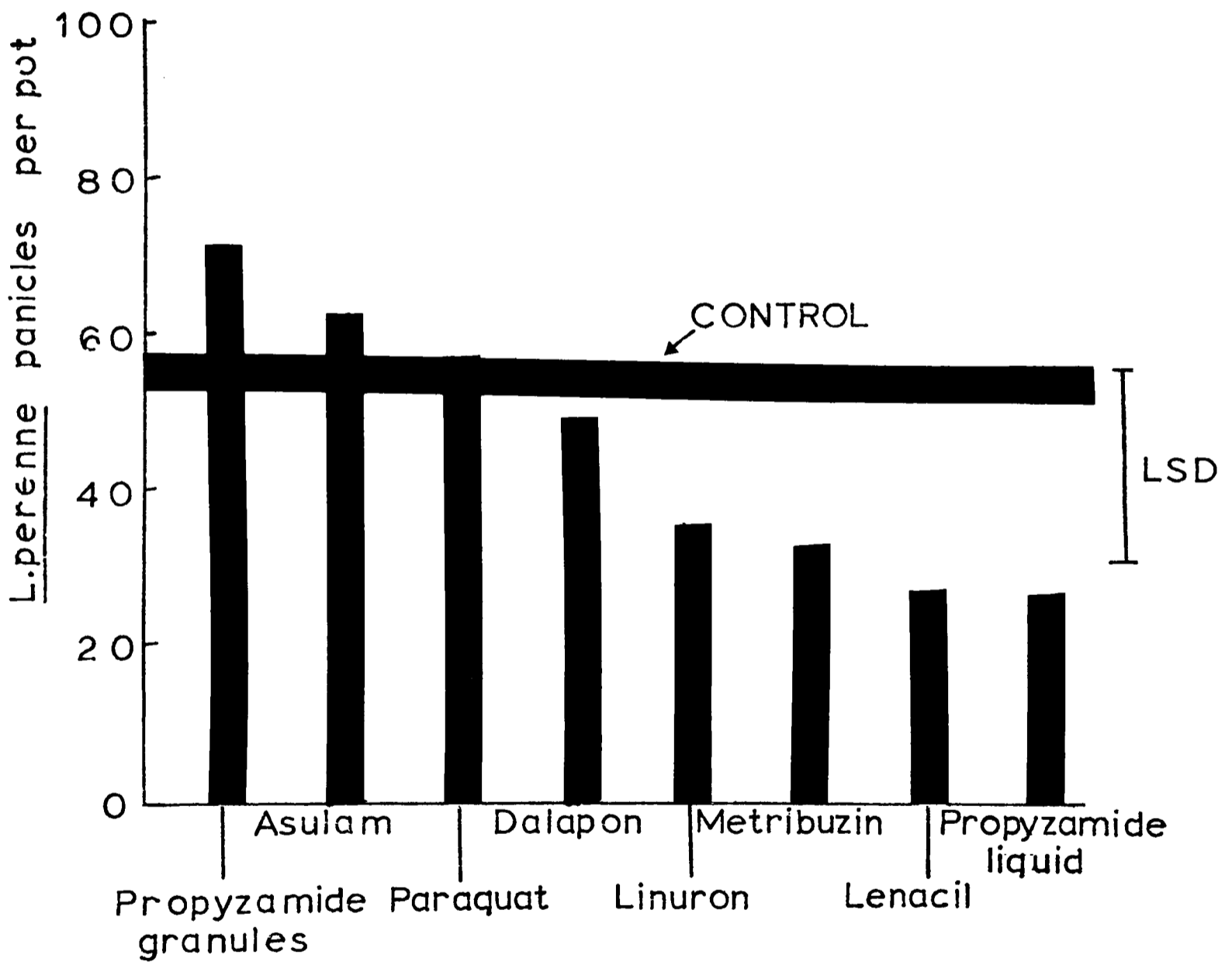


FIGURE 79

The number of L.perenne panicles per pot
(mean of 3 summer dates & 3 doses)



terms of visual scores also included some treatments which were found not to be selective at harvest. Thus, although visual scores are a quick and easy method of picking out promising treatments, dry weights are needed in order to narrow these down to the ones which are suitable enough to be followed up by field experiments.

The mean dry weight of green L. perenne decreased over the summer harvests, whereas that of H. lanatus remained the same. This may be accounted for partly by the fact that L. perenne flowered whereas H. lanatus had not been vernalized by mid-December and so did not flower. Thus, the L. perenne plants produced panicles which ripened, turned brown and so were not included in the dry weight, whereas H. lanatus plants remained vegetative and greener throughout the summer.

The yield of green H. lanatus declined as the mean level of herbicide used increased, but the yield of L. perenne was unaffected. This indicates that, in general, the selectivities of the herbicides were in the right direction. However, the good selectivity of a particular concentration of a certain herbicide at a certain time is more important than the overall trends of eight herbicides.

This experiment suggests that three of the herbicides used are unsatisfactory. Lenacil, although it damaged H. lanatus (in agreement with Adamson, 1975) proved too damaging to L. perenne, on which it had not previously been tested. Propyzamide (liquid) behaved similarly. Dalapon, on the other hand was not damaging enough to H. lanatus. This supports the findings of a number of workers (Table 23, p. 141). However it was not applied at the recommended time of July (British Crop Protection Council, 1972a) and it did damage H. lanatus in October (Experiment 2, p.174).

In contrast, linuron, applied at 1.12 kg a.i./ha in summer, showed good selectivity. This demonstrates that L. perenne can tolerate this herbicide as can Phleum pratense (Harkess and Hope, 1974). Metribuzin at 0.37 kg

a.i./ha, applied in summer, also gave good results. This is in contrast to field work at W.R.O. in which a dose of 0.75 kg a.i./ha applied in July had little effect on two-year-old swards (Blair, pers. comm.).

The very low dose (0.09 kg a.i./ha) of paraquat, applied in summer worked well. This agrees with the work of Sharp (1968) in New Zealand. Propyzamide applied as granules at 2.24 kg a.i./ha in summer was also a useful treatment. This agrees with previous work carried out at W.R.O. (Haggar, 1976b). All these herbicides tended to give better results when applied in May rather than in June.

The effect of propyzamide (liquid) in deforming L. perenne ears, when sprayed in May, indicates that this is far too late to spray a herbage seed crop. Work in Scotland has shown that timothy (Phleum pratense) can be sprayed with many of these herbicides in March without the occurrence of any ear deformities (Harkess and Hope, 1974). The fact that propyzamide granules, asulam and dalapon did not decrease the numbers of L. perenne panicles reinforces the selectivity of the chemicals shown by the dry weights.

EXPERIMENT 2

In general, herbicides applied on 19 October showed little selectivity between H. lanatus and L. perenne. Paraquat at all doses and metribuzin at the higher doses damaged both species severely. Most other chemicals did little damage to either species. Asulam and propyzamide (granules) at 0.56 kg a.i./ha gave the best results but they were not significant. However, applying herbicides to a sward in October is likely to be more attractive to a farmer than doing so in May/June. Less grass production will be lost and it is a much less busy time of the year. Also, because of the colder weather in autumn, regrowth was slower than after the summer treatments so that the full selective potential of the herbicides may not have been realised within nine weeks.

The H. lanatus plants in Block 2 of this experiment were much smaller than those in Block 1. This was probably because the plants in Block 1 were more sheltered from the cold wind and there was noticeably more damage from birds nipping off young H. lanatus shoots from plants in Block 2 than Block 1.

METHOD AND MATERIALS (3)

EXPERIMENT 3. THE EFFECT OF ASULAM ON ESTABLISHED H. LANATUS AND L. PERENNE PLANTS WHEN SPRAYED IN AUTUMN

The plants were raised and transplanted as described in Experiment 1 (p.147) but in this experiment only one plant of each species was transplanted into each pot. By August the plants were large, having been growing eight months since they were established from single tillers.

The experiment consisted of three randomised blocks. The same four concentrations of asulam were used as in the previous two experiments (Table 28, p.149). There were three dates of spraying (Table 29, p.151). On 11 August the plants were scored on a 0 to 10 scale for the amount of the soil surface area they covered. This percentage data was transformed (arc sine square root) and used, together with the subsequent yield data, in a covariance analysis. This was non-significant, showing that the variation in the size of the plants at the start of the experiment was not important. So, the uncorrected harvest yields were used.

The plants were cut, sprayed, visually scored and photographed as described in Experiment 1. Nine weeks after spraying, the shoots were harvested at soil level and the dry weight of the green shoot material from each species was recorded. The dates of these operations are given in Table 29 (p.151).

RESULTS (3)

VISUAL SCORES

The weekly visual scores of the plants during the nine weeks after each herbicide application are shown in Figure 80 (p.180). Useful selectivity was only shown by the higher doses sprayed on 7 September and 4 October. There was little damage to either species from the latest treatment.

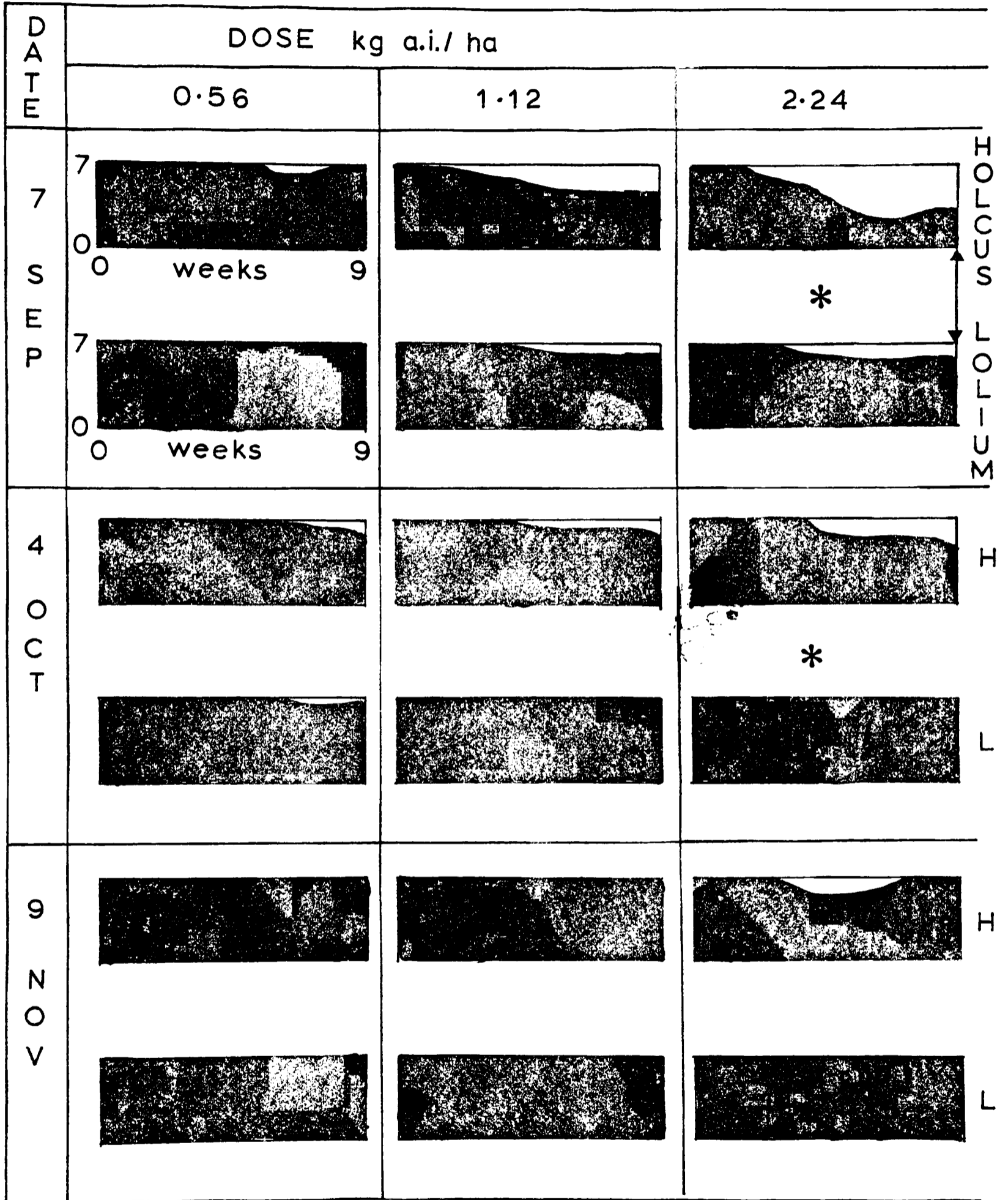
DRY WEIGHT YIELDS AT HARVEST

The results are presented as the means of the three dates of application in Figure 81 (p.181). As the concentration of asulam increased, less green H. lanatus was present at harvest. The amount of L. perenne present also declined slightly, but not significantly. In Figure 82 (p.182) the results are presented as the means of the concentrations used. There was much more L. perenne present as a result of spraying on 7 September than on the later dates. But, there was no significant difference between the amounts of H. lanatus present at the harvests (Fig. 82, p.182). It follows from this that the percentage of live L. perenne in the mixture resulting from the 7 September treatment was greater than that from the later dates. The relevant transformed data are shown in Figure 83 (p.183).

DISCUSSION (3)

In this experiment, asulam showed good selectivity when applied in early September but not when applied later in the year. This good result is in agreement with the preliminary results of a field experiment sprayed at about the same time at W.R.O. (Haggar, pers. comm.). The use of asulam at 1.12 kg a.i./ha between April and September has been recommended for the control of mature and seedling docks (Rumex spp.) in established swards (British Crop Protection Council, 1972b). So, if asulam is applied to control H. lanatus, there may be an added bonus of dock control.

FIGURE 80
 Scores of *H.lanatus* & *L.perenne* green material
 after treatment with Asulam in autumn



KEY 0 = all dead

7 = as control

FIGURE 81

The amounts of H.lanatus and L.perenne harvested nine weeks after treatment with asulam in the autumn (mean of 3 dates)

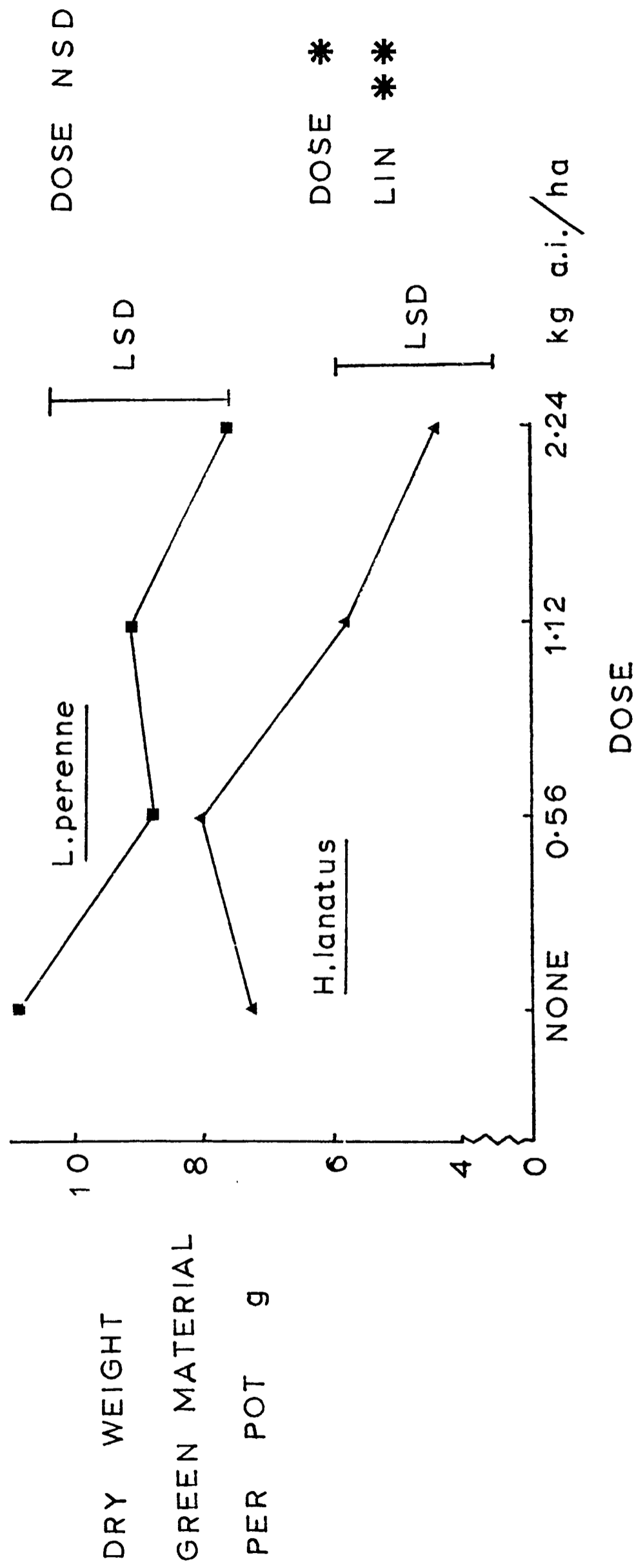


FIGURE 82

The amounts of H.lanatus and L.perenne harvested 9 weeks after treatment with asulam in autumn (mean of 3 doses & control)

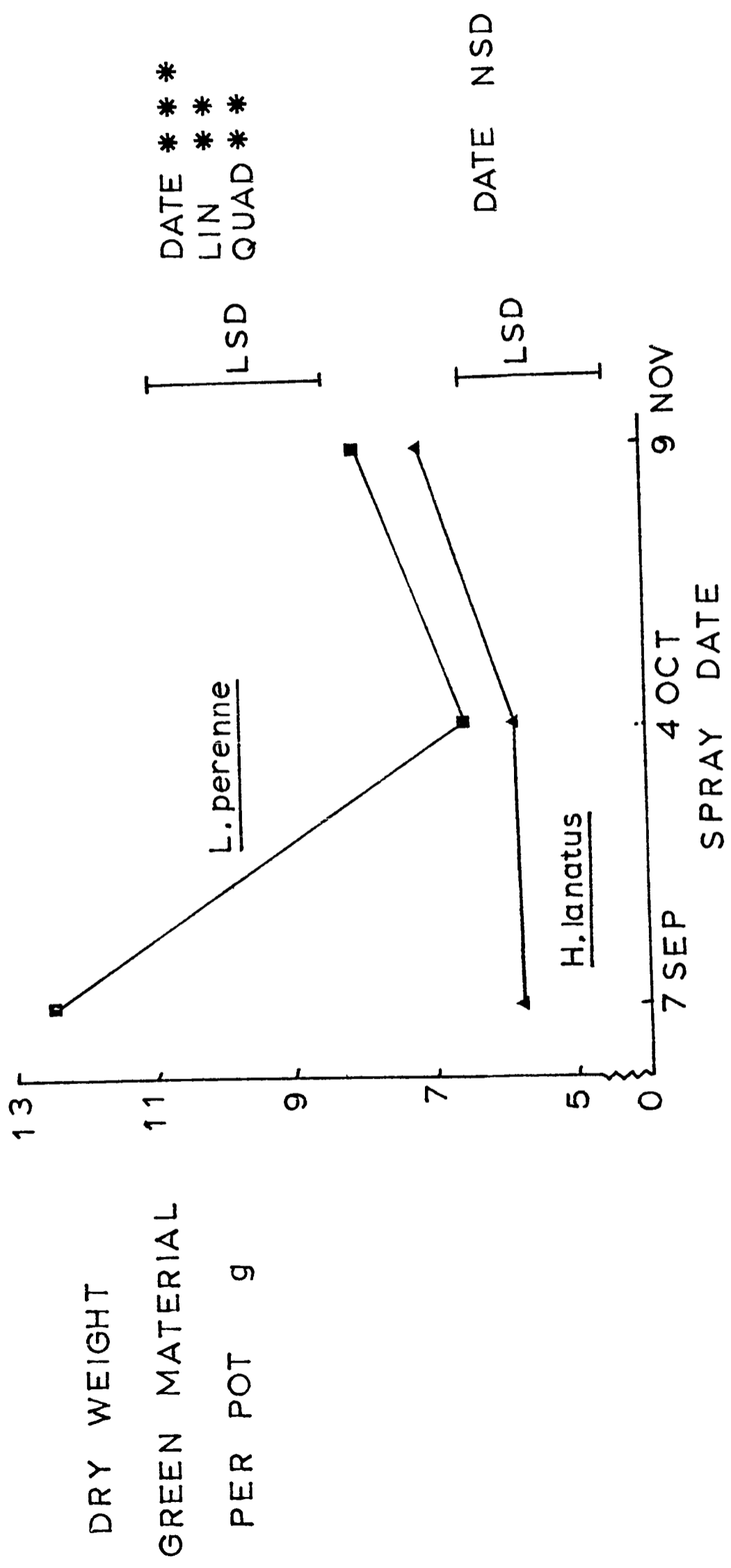
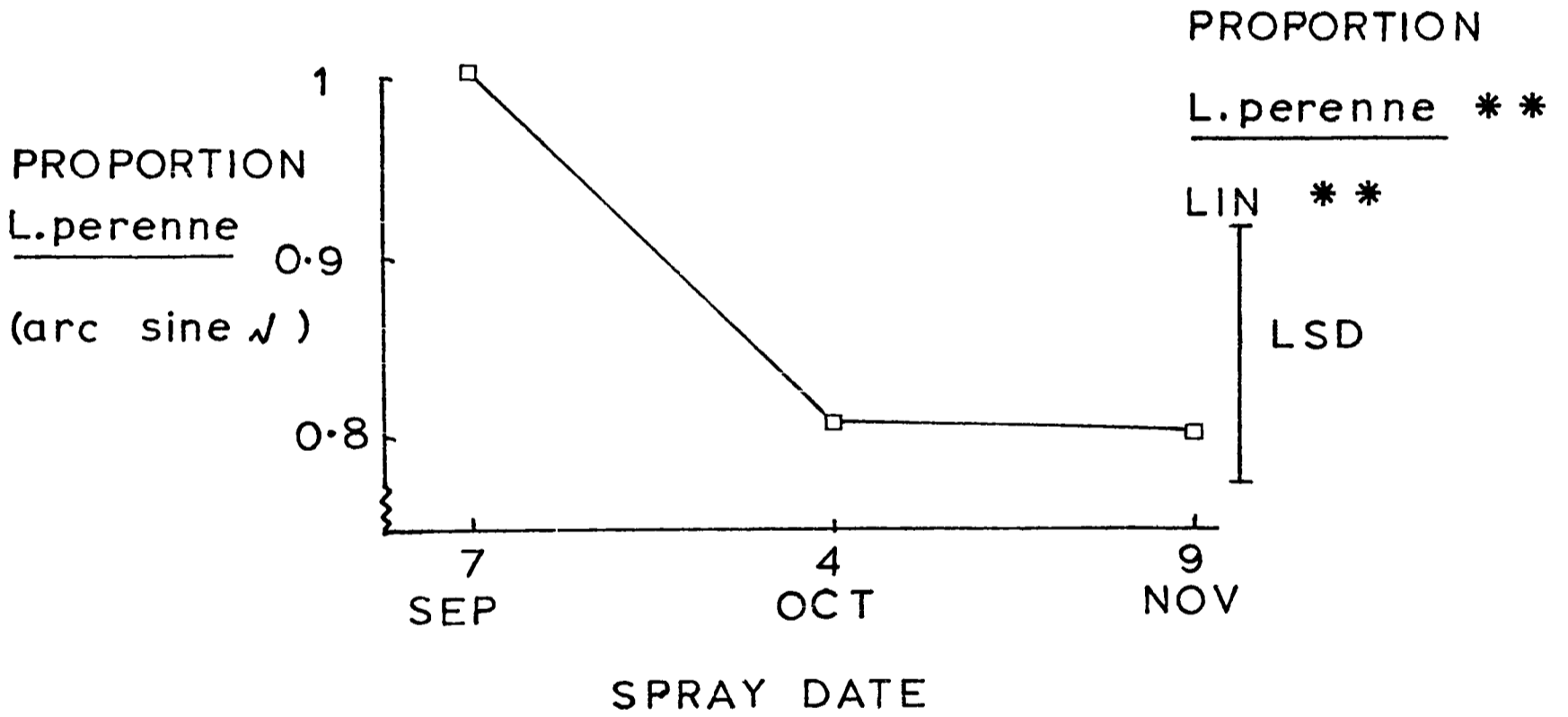


FIGURE 83

Proportion of L.perenne in green material
 9 weeks after spraying asulam on 3 dates
 in autumn (mean of 3 doses & control)



GENERAL DISCUSSION

SELECTIVE CONTROL IN SPRING

AND EARLY SUMMER

This work has shown that there are several herbicides which can control established H. lanatus in L. perenne during May and June. In order of efficacy the three giving the best control of H. lanatus with the least damage to L. perenne were:

paraquat	0.09 kg a.i./ha
propyzamide (granules)	2.24 " " "
linuron	1.12 " " "

Paraquat is a comparatively cheap herbicide. However, its selectivity depends greatly upon the weather conditions at the time when it is applied. For example, high humidity and high temperature enhance its toxicity (Muzik, 1977). Therefore, propyzamide granules and linuron may be more reliable.

SELECTIVE CONTROL IN AUTUMN

It will often be uneconomic to apply herbicides in May and June. The grass is growing rapidly then and so a considerable decrease in grass production for silage or hay will result. This work has shown that asulam at 1.12 to 2.24 kg a.i./ha can be used successfully in early September. It is possible that late July/August would also give good results. No herbicides were applied during this time in these experiments; but, other workers have obtained good results with asulam in July (Oswald et al., 1972; Fisher and Faulkner, 1975). Such treatment would also check the growth of docks (Rumex spp.) (British Crop Protection Council, 1972b). The promising, but non-significant effect of propyzamide (granules) at 0.56 kg a.i./ha in October may be worthy of further investigation both because the treatment is in a convenient formulation and at a convenient time of year.

OTHER POSSIBLE CHEMICALS

There are several other chemicals mentioned in the literature which merit investigation. These include carbetamide (Soper and Hutchinson, 1974), defenzoquat and bromacil (Fisher and Faulkner, 1975) and bromoxysone and chloroxysone (Wain, 1972). Details of these references are given in Table 31 (p.186). Such preliminary work, together with the results of these three experiments should be followed up in field experiments.

BREEDING HERBICIDE TOLERANCE

Instead of searching for new chemicals to solve this problem, another approach is to breed a strain of ryegrass which is especially tolerant of a herbicide that kills H. lanatus. A strain of paraquat-tolerant L. perenne (PRP II) has been developed in Northern Ireland. Faulkner (1975) sprayed an established mixture of this strain and H. lanatus with paraquat at 0.4 kg a.i./ha in July. The H. lanatus was killed and the yield of the tolerant L. perenne was significantly increased, as shown in Table 25 (p.146).

If such a tolerant strain of L. perenne was sown on a field scale the selective control of H. lanatus in the sward would be much easier. It would be killed by the paraquat unless and until any herbicide-resistant mutants appeared. However, in general, herbicide-resistant weeds appear less frequently than fungicide-resistant fungi or insecticide-resistant insects.

If the initial dose of paraquat was high enough to ensure that virtually all H. lanatus plants in the sward were killed and if a natural population of H. lanatus was allowed to grow in the hedgerow, the chance of any resistant H. lanatus spreading in the sward would be reduced. Firstly, there would be few or no such plants in the sward because of the high initial dose used. Secondly, any plants which did survive and flower would tend to outcross with the hedgerow population. If, as in L. perenne, there is more than one pair of resistant genes and they show incomplete dominance (Faulkner, pers. comm.), the progeny would be only partially resistant.

TABLE 31

Selected references to the effects of Carbetamide, Difenzoquat, Bromacil, Bromoxysone and Chloroxysone on L. perenne and H. lanatus

AUTHOR & HERBICIDE	SWARD	PLACE	TIME	DOSE kg a.i./ha	OBSERVATION
Wain (1972) Bromoxysone & Chloroxysone	Permanent	Wye Kent		4.5 6.7	<u>H. lanatus</u> eliminated Little effect on <u>L. perenne</u>
Soper & Hutchinson (1974) Carbetamide	<u>Festuca</u> <u>L. perenne</u> <u>H. lanatus</u> permanent	Shalford Essex	Jan	0.35	<u>H. lanatus</u> severely affected <u>L. perenne</u> unaffected
Fisher & Faulkner (1975) Bromacil	Monoculture rows in field	Belfast N. Ireland	June	1.0	Tolerance (based on dry wt. autumn cuts) Mean = 100 L H 116 82
Fisher & Faulkner (1975) Difenzoquat	Monoculture rows in field	Belfast N. Ireland	July	7.5	Tolerance (based on dry wt. autumn cuts) Mean = 100 L H 121 71

In the long run, whether the genes for resistance would spread through the H. lanatus population or not would depend mainly on the extent of paraquat usage and the fitness of the resistant genotype. In addition to paraquat-tolerant ryegrass, work is underway to develop a dalapon-tolerant strain of L. perenne (Faulkner, 1974). A possible disadvantage of using paraquat on PRPII L. perenne swards is that while H. lanatus would be killed, L. perenne plants would probably be somewhat scorched before recovering and farmers might dislike this initial appearance of the sward.

ALTERNATIVES TO SELECTIVE CONTROL

IN ESTABLISHED SWARDS

An effective way of preventing H. lanatus establishing in a ryegrass sward is to prevent H. lanatus seedlings growing in the L. perenne seedbed. Ethofumesate, sprayed pre-emergence, can do this (Table 32, p. 188). The use of 1.5 kg a.i./ha in August gave good control of emerging H. lanatus seedlings over a wide range of sites (van Hoogstraten et al., 1975). Ethofumesate does not control established H. lanatus (Hammond et al., 1976). The control of H. lanatus seedlings in a ryegrass sward by ethofumesate will obviate or delay the need for the use of herbicides to control established H. lanatus.

CONCLUSIONS

Propyzamide (granules) at 2.24 kg a.i./ha and linuron at 1.12 kg a.i./ha gave good control of established H. lanatus in L. perenne when applied in May/June. At the more convenient time of early September, asulam at 1.12 and 2.24 kg a.i./ha also gave good results. The use of propyzamide granules in October is a potentially useful treatment which is worthy of further investigation.

TABLE 32

Selected references to the effects of Ethofumesate
on H. lanatus and L. perenne

AUTHOR	SWARD	PLACE	TIME	DOSE kg a.i./ha	OBSERVATION
Van Hoog- Straten et al. (1975)	Pre-emergence of <u>L. perenne</u> sward	143 sites several countries	Aug	1.5	95-100% control of <u>H. lanatus</u> Up to 2 kg a.i./ha did not reduce <u>L. perenne</u> yield
Hammond et al. (1976)	Pre-emergence of <u>L. perenne</u> sward	Essex	Aug	2.0	Score 26 Nov 10 = unharmed plant 0 = dead Control Ethofumesate L H L H 8 9 8 0
"	48 days after sowing <u>L. perenne</u> sward	"	Sept	3.0	Score 26 Nov Control Ethofumesate L H L H 8 8 1 8
"	96 days after sowing <u>L. perenne</u> sward	"	Nov	3.0	Score 26 Nov Control Ethofumesate L H L H 9 9 9 6

Thus, for swards in which H. lanatus is undesirable, e.g. for silage production, this work has shown that there are a number of herbicidal treatments which can control it selectively in L. perenne, better than the recommended dalapon. This work needs to be followed up by field experiments.

CHAPTER 9

CONCLUSION

MAIN RESULTS

FACTS FROM LITERATURE REVIEW

- Holcus lanatus is a very adaptable and competitive species.
- Shoot and root growth can be very vigorous and the species has ecotypes which enable it to grow in a wide range of environments.
- It is a valuable and persistent species on hill land and it has been sown both to provide fodder on acid, low nutrient soils and to prevent soil erosion.
- In lowland ryegrass swards it has been regarded as a weed because livestock reject it when it flowers.
- Beef cattle have, however, made better liveweight gains on pure H. lanatus than on pure L. perenne swards.

GROWTH STUDY OF H. LANATUS

- Spaced plants produced up to 240,000 seeds.
- Most seeds germinated soon after they were shed onto moist soil but they could germinate at any time of year.
- Seed shed and germinated in early summer produced larger plants which shed more seed the next year than plants arising from seed shed in late summer whose germination was delayed by drought.

- Seedlings did not establish well in a tall sward.
- Plants growing in the field needed to be vernalized in order to flower.
- Measurements of plant length and breadth provided a better estimate of tiller numbers than did infra-red photographs.
- Differences in the colour of lemmas and paleas were associated with differences in germination.
- Spikelets glued to cotton germinated better than spikelets loose on the soil surface.
- Plants of the New Zealand cultivar, Massey Basyn were taller with wider leaves, heavier panicles and spikelets and a greater shoot fresh weight than local, Oxfordshire, H. lanatus.

SPREAD OF H. LANATUS BY RUNNERS

- Runners formed during the autumn on spaced plants.
- Cutting the plants in spring/summer allowed plantlets on the runner to grow better.

FLOWERING OF H. LANATUS

Day length and temperature.

- In general, local, Oxfordshire H. lanatus plants, grown in pots, needed to be vernalized in order to flower.
- The minimum exposure needed for flowering was between twenty five and twenty nine days with a minimum temperature $< 5^{\circ}\text{C}$.
- Longer cold treatment produced more panicles.
- Short days enhanced the effect of vernalization.

- To a small extent, long exposure (five months) to short days replaced vernalization.

Time of cut.

- Plants cut when in bud produced vegetative summer regrowth.

CUTTING HEIGHT AND FREQUENCY

- Higher cutting increased the total shoot dry weight yield of H. lanatus but not of L. perenne.
- Less frequent cutting increased the total shoot dry weight yield of both species.
- In a glasshouse experiment, H. lanatus dominated a mixture with L. perenne. This did not occur in the field.
- Stubble yields generally followed shoot dry weight yields.
- Both frequent and low cutting restricted H. lanatus and L. perenne flowering.

TREADING

- Animal treading decreased the growth of H. lanatus more than that of L. perenne.
- Resultant bare patches were invaded by Poa annua and H. lanatus seedlings.

WATER TABLE

- Holcus lanatus responded to a high water table by producing adventitious roots and fine, surface roots rather than shoots.
- When L. perenne was grown with a high water table its flowering was reduced.

HERBICIDES

- Propyzamide granules at 2.24 kg a.i./ha and linuron at 1.12 kg a.i./ha gave good control of established H. lanatus in L. perenne when applied during May and June.

- In early September, asulam at 1.12 and 2.24 kg a.i./ha gave good results.

SIGNIFICANCE OF RESULTS AND

SUGGESTIONS FOR FURTHER WORK

This study has compared local, Oxfordshire, H. lanatus with an outstanding cultivar of L. perenne (S23) selected for production and suitability for agriculture. Holcus lanatus performed as well as L. perenne in many experiments. This suggests it may be valuable in agricultural production. Similarly, the situations in which it performed less well indicate its limitations as a fodder species.

Important attributes of H. lanatus are:

- Tolerance of acidic, low nutrient and high water table conditions.
- Prolific seed production, some of which are dormant.
- Vegetative spread by runners which may be increased if a plant is out in spring. This needs to be studied in a sward.
- Aggressive growth under high or infrequent defoliation. This needs to be confirmed for flowering H. lanatus in a sward.
- Reduction in growth if cut closely or trodden.
- Rapid decline in digestibility with flowering. The causes of devernalization remain to be investigated.

Holcus lanatus is at its best in long-term swards under moderate grazing and occasional cutting for hay or silage. Lolium perenne is better suited to high nitrogen, short-term swards or for conservation. Also, the dormancy of some of the seed of H. lanatus would be a disadvantage in short-term sown swards. However, its tolerance of changes in pH, water table and nutrient levels suggest it is especially suited to parts of northern and western

Britain. In order to assess fully the agricultural value of H. lanatus its nutritional value to livestock must be discussed.

At moderate levels of nitrogen fertilizer, H. lanatus gave a greater dry matter yield, digestibility and nitrogen yield over the year than L. perenne (Haggar, 1976a). Also, wide variations in the amounts of H. lanatus and L. perenne in a sward did not make any significant difference to the liveweight gains of beef cattle (Haggar and Elliott, in press). It was only during spring that a high L. perenne content was related to high liveweight gains. During the rest of the season, cattle gained more weight on swards with a high H. lanatus content (Haggar et al., in press).

Thus, H. lanatus has considerable merit as a fodder grass in long-term swards provided it is managed so as to avoid the production of unpalatable flower heads. If it is to be sown for animal production, then Massey Basyn should be considered in preference to the local, Oxfordshire, H. lanatus used in these experiments. Several herbicides could be used to remove local H. lanatus in preparation for sowing Massey Basyn. However, these herbicides need further testing in field trials.

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APPENDIX 1

Text of review article submitted to Herbage abstracts

THE BIOLOGY OF HOLCUS LANATUS L. (YORKSHIRE FOG)

AND ITS SIGNIFICANCE IN GRASSLAND

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INTRODUCTION

Holcus lanatus L. is a grass of European origin now widely distributed throughout the world. In Britain it is called Yorkshire Fog and in the United States, Velvet Grass. It is common near the sea as well as inland, being abundant in meadows, pastures, rough grassland and waste ground. The grass is a tufted, softly hairy perennial (Hubbard, 1968) which is competitive in grassland and can tolerate a wide range of edaphic factors.

A recent census of the grassland of England and Wales showed that 4.2 million ha (71%) were more than six years old or permanent (Ministry of Agriculture, Fisheries and Food, 1973). Holcus lanatus is an important constituent of old swards and therefore provides a considerable proportion of the fodder for livestock in England and Wales.

It has been regarded as a weed in lowland ryegrass swards because it is unpalatable to grazing animals when it begins to flower in summer (Garner, 1963) but recent experimental work (Moloney, 1962, 1963, 1964; Murphy, 1965; Haggard et al. in press) has contradicted this view. On hill land it has usually been classified as a useful species.

The biology of H. lanatus has been covered in a detailed review by Beddows (1961). This review therefore updates that information and attempts to assess its status in agricultural production.

ECOLOGY AND DISTRIBUTION

Since the review by Beddows (1961), Carroll and Jones (1962) have made a study of the cytotaxonomy of the genus Holcus. They list the characteristics by which H. lanatus may be distinguished from H. mollis (creeping soft grass). Hybrids between the two species can occur and tend to resemble H. mollis.

Holcus lanatus has been introduced to all the other continents from Europe. It has recently been found on several sub-antarctic islands (Walton, 1975). In a preliminary study of the grassland round Sheffield, Grime and Lloyd (1973) found H. lanatus was positively associated with north facing slopes. However, this relationship was not confirmed by a further, more extensive survey (Grime and Hodgson, personal communication).

This same survey found that H. lanatus was especially abundant in meadows, pastures, waste soil tips and limestone quarry heaps. The grass occurred in both species-rich and species-poor vegetation. In altitude it was fairly evenly distributed up to 400 m and on all slopes up to 50°. There was no correlation between the amount of H. lanatus and the amount of bare ground in a habitat (Grime and Hodgson, personal communication).

LIFE CYCLE

In Britain, H. lanatus has an obligate requirement for vernalisation in order for it to flower, but there is no record of a daylength requirement (Evans, 1964). Plants from Southern Europe tend to flower in the year of sowing, whereas those from Northern Europe flower only in the following year as they require vernalisation (Bocher and Larsen, 1958).

Holcus lanatus flowers from late May onwards with a peak in early June (McNeill, 1973; Mortimer, 1974; Watt, unpublished data).

SEED PRODUCTION

Seed Shed. The dispersal unit of H. lanatus is the complete spikelet, resulting almost entirely from cross-pollination (Beddows, 1931). These are shed in large numbers from June to early autumn during dry, windy weather. The germination of seed collected at different times after anthesis was studied by Bittera and Gruber (1937) who found that 100% viability was not reached until 20 days after anthesis.

Work at Oxford (Watt, 1976) showed that spaced plants of H. lanatus grown from seed sown monthly from January to June produced an average of 177,000 seeds per plant the next summer, with a mean of 370 seeds/panicle. However, in a closed sward at Bangor, H. lanatus, which was the dominant grass, shed only 19,000 seeds per square metre, the number of seeds per panicle ranging between 100 and 380, with a mean of 270 (Mortimer, 1974).

The mean weight per seed of H. lanatus has been calculated as 0.50 mg (Hayes, 1976), 0.32 (Grime and Hodgson, personal communication) and 0.37 mg (Watt, unpublished data).

Seed reservoir in soil. A seed population flux diagram for H. lanatus in a sward has been worked out by Mortimer (1974). He estimated that half of the seeds died, whilst 37% germinated and 13% were buried. Holcus lanatus seeds were 14% viable after 10 years burial, 125 mm deep in mineral soil (Welsh Plant Breeding Station, 1962).

In an old hill sward in Wales, Milton (1935) found the equivalent of 30 million buried viable H. lanatus seeds per hectare in the top 180 mm of soil. This is an unusually high figure. In most old hill swards there are between two and ten million viable seeds per hectare (Chippindale and Milton, 1934; Milton, 1943; Milton, 1948). Douglas (1965) found only 1.4 million seeds beneath a lowland permanent pasture and 0.7 million beneath an 8 year old lowland sward.

Effects of animals on seeds. Invertebrates can both bury H. lanatus seeds and damage the resultant seedlings. When invertebrates were present, 25% more of the H. lanatus seeds placed on the soil surface were buried than when they were absent. When invertebrates were excluded, H. lanatus seedlings were more likely to give rise to established plants. These experiments also showed that if the surface of the soil was disturbed, more H. lanatus seeds were buried (Mortimer, 1976).

Moles bring viable H. lanatus seeds up to the soil surface in their hillocks (Jalloq, 1975). Earthworms can also transport H. lanatus seeds, (McRill, 1974).

In Hawaii, when wild pigs dug up the native Deschampsia/Panicum grassland, H. lanatus became established from seed (Spatz & Mueller-Dombois, 1975). Krach (1959) studied the viability of H. lanatus seeds eaten by birds. He found that seeds which had passed through sparrows were killed, whereas those eaten by rooks had only slightly reduced viability.

Dormancy. Holcus lanatus seeds can germinate immediately at maturity over a wide range of soil temperatures (Watt, 1976). Although the majority of freshly shed seeds germinate rapidly in moist conditions (Watt, unpublished data) there is evidence for both innate or induced and enforced dormancy (Hart, 1961; Mortimer, 1974). Mortimer's work showed that considerable numbers of viable H. lanatus seeds can survive the winter, dormant in the soil. Thus, if a sward containing the species is ploughed and re-seeded, there will always be some viable H. lanatus seeds present, ready to germinate near the soil surface and provide a nucleus of H. lanatus plants in the new sward.

GERMINATION AND ESTABLISHMENT

Time. Monthly sowings of H. lanatus in the field during 1975, showed that March and September sowings emerged most quickly (Watt, 1976). Mortimer

(1974) sowed H. lanatus seed weekly during the period of shedding, from July 19 onwards. He found that the earlier a seed was shed, the greater was the chance of it establishing.

When H. lanatus seeds were sown in the field in Oregon at intervals between September 26 and November 8 it was found that the later the seed was sown the fewer and smaller were the seedlings which were present the next spring (Hart and McGuire, 1964).

Temperature. The importance of diurnal fluctuating temperatures for the germination of buried H. lanatus seeds in the field has been shown in work at Sheffield (Thompson, Grime and Mason, 1977). In laboratory experiments they found that H. lanatus seeds germinated readily in the light at 22°C. In the dark at 22°C their germination was much less. However, when H. lanatus seeds were tested in the dark at diurnal fluctuating temperatures of 22°C and 10°C they germinated nearly as well as in the light. They have found that beneath a gap in the turf there may often be a diurnal fluctuation of more than 10°C, whereas it is never greater than 4°C under turf. Thus, buried H. lanatus seeds might be expected to germinate if they are under a gap in the turf but not if they are covered by a layer of turf.

When H. lanatus seeds were sown in Oregon at 10 day intervals from 8 September to 8 November the seedlings emerged more and more slowly during this period which was significantly correlated with a decrease in the mean soil temperature (Hart, 1961).

Moisture. A moist soil is essential for H. lanatus germination. This was shown by work at Oxford in which H. lanatus seeds were sown monthly throughout 1975 (Watt, 1976). Seedlings emerged from all sowings but the May, July and August ones took a long time to reach 50% seedling emergence. At these times, air temperatures were high but, more important, there was very little rain. When rain did fall, at the time of the June sowing,

emergence was very rapid. Holcus lanatus seeds can germinate relatively well in up to 50% sea water (Rozema, 1975). This may help to account for its vigorous establishment on sites subject to salt spray, like Lundy Island (Gillham, 1955).

Light. Seeds of H. lanatus will germinate readily in the light at normal growing temperatures, but far fewer seeds germinate if they are kept in the dark. (Grime and Jarvis, 1975). However, if the seeds are tested in the dark at diurnal fluctuating temperatures of 22°C and 10°C they germinate nearly as well as in the light (Thompson, Grime and Mason, 1977).

Holcus lanatus seedlings grow much more slowly in shade than in full light. Work by Hart and McGuire (1964) showed that seedling dry weight, six weeks after sowing, declined considerably with increasing levels of shade.

VEGETATIVE GROWTH

Shoots. Controlled environment studies at 7°-35°C in New Zealand showed that H. lanatus followed similar curves in shoot dry weight and tiller number to L. perenne and Dactylis glomerata (Mitchell and Lucanus, 1962). The maximum weekly relative growth rates of 132 species of flowering plants were measured at Sheffield (Grime and Hunt, 1975). Holcus lanatus was one of only 10 species which had maximum relative growth rates of more than 2 g/g/wk.

Runners. Holcus lanatus regenerates vegetatively by developing new shoots and roots at its nodes. A blanketing mass of runners builds up. This growth habit is responsible for the spongy feeling of the turf and for the smothering nature of the species. Semi-prostrate or prostrate rosette shoots, called 'mops', may also form at the end of the runners (Arber, 1934). These mops of shoots, which are found in hedgerows, will root readily if they come into contact with moist soil.

In an established sward, H. lanatus grows in large spreading clumps. This growth habit was investigated by Turkington (1975) who sampled such a sward throughout the year, using a point quadrat. He noted the first leaf which the point touched and also the species of any plant which touched this leaf nearest to the sampling point. This method revealed that H. lanatus has a high proportion of intra-specific contacts throughout the year and therefore must be growing in large patches. This growth habit has also been shown in a survey of the grassland around Sheffield (Grime and Hodgson, personal communication). Holcus lanatus plants formed runners in autumn and if the plants were cut regularly in spring, the plantlets on the runners established better (Watt, unpublished data).

Roots. Holcus lanatus has a greater competitive ability than Dactylis glomerata when the species are grown in 50:50 mixture (Remison, 1976). This is due mainly to its aggressive root competition. In a further experiment, H. lanatus, D. glomerata, Lolium perenne and Anthoxanthum odoratum were grown in glass-sided boxes. In comparison with these three other species, the roots of H. lanatus were the deepest, longest, most finely divided and quickest growing with the longest root hairs. Such a manner of root growth would be most advantageous in low nutrient status soils.

Holcus lanatus roots in the top 100 mm of soil absorbed most phosphate, whereas at 900 mm there was very little activity (Boggie, Hunter and Knight, 1958). Thus, although H. lanatus plants can root deeply, they extract a large proportion of their nutrients from the surface layers of the soil where competition is most severe.

RESPONSE TO ENVIRONMENT

Temperature. Holcus lanatus grows relatively well at low temperatures, e.g. 10°C (Mitchell and Lucanus, 1962). But, after a severe frost in the

Netherlands it was killed and replaced by Phleum pratense and Poa trivialis in a mixed sward (Vries and Hart, 1941).

Holcus lanatus leaves are produced most rapidly at about 30°C (Mitchell and Lueanus, 1962). But, at 35°C growth is poor (Mitchell, 1956) and leafy shoot production stops when the temperature is below 5°C (Beddows, 1961).

Holcus lanatus gives a greater yield of shoot dry weight in the early spring than does Lolium perenne (S23) (Haggar, 1976a). This suggests that it can begin to grow at colder temperatures. This has also been found in reseeding trials on hill land (Herriott, 1975; Thomas, 1936).

Light. Holcus lanatus is more efficient than Dactylis glomerata at intercepting light. This was shown by Remison (1976) who grew the two species both in monoculture and together with separate root systems. The shoot dry weight yield per plant of H. lanatus was 16% greater when it was in shoot competition with D. glomerata than when it was grown in monoculture. Similarly when H. lanatus and Lolium perenne were grown together in regularly cut swards, H. lanatus with its wider leaves intercepted more light per unit area than L. perenne (Riveros, 1963).

Moisture. Many people have observed that H. lanatus is often found growing on wet sites (Armstrong, 1945; Burbidge, 1966; Grant and Brock, 1974). A pilot survey of grassland in south east England indicated a tendency for H. lanatus both to invade swards earlier and to spread more rapidly in them if they are on heavy, badly drained sites (Morrison and Idle, 1972).

These findings may be confounded with other factors. For example, the number of animals in a wet field may be lower than in a well-drained field and the H. lanatus will, therefore, not be trampled on so much. There may also be an interaction with pH which tends to be low in badly drained basic soils (Nichol and Turner, 1957). Thus, the observations that H. lanatus had a negative relation with soil oxygen content (Rogers and King, 1972) may be interpreted in terms of wet soil, low pH, low stocking rate or other related factors.

Holcus lanatus is well adapted to wet conditions. The roots have a radial cortex with many small irregular air spaces (Jacques and Munro, 1963), which may increase the efficiency of nutrient uptake when the soil water level is high and aeration is restricted (Soper, 1959). The wetter the soil conditions in which H. lanatus grows, the more fine roots the plant produces on the soil surface and the more adventitious roots are formed around the edge of its clump (Watt, unpublished data). However, it has also been noted that a high water table restricts its vertical root penetration into the soil (Troughton, 1957).

Drought can severely affect H. lanatus. During the very dry summer of 1911, Stapledon (1912) found it unproductive on the Cotswolds, but although the plants became stunted, few died. The tendency of H. lanatus to develop surface roots has been thought to make it vulnerable to drying out (Beddows, 1961). In contrast to this evidence, Baker (1962) states that H. lanatus is a common weed of the drier areas of England. It seems that H. lanatus can tolerate very wet conditions, but prefers a moist soil and can survive a moderate drought, although various ecotypes may have developed in different environments.

pH. Holcus lanatus is found growing in a very wide range of pH. In an experiment in which it was grown in mixture with other grasses on soils of widely different pH levels H. lanatus composed 44% of the total shoot dry matter yield at pH4 and 38% at pH8 (Remison, 1976).

In a survey of Dutch grassland, Kruijne and De Vries (1963) found that the percentage occurrence of H. lanatus decreased with increasing pH over the range 4 to 8. This tendency for H. lanatus to grow better on acid soils was confirmed in work by Hart and McGuire (1963). They sowed a mixed sward which included H. lanatus. When they applied lime at 15 t/ha, as compared to 5 t/ha, the amount of H. lanatus in the total shoot dry weight yield declined significantly.

There is conflicting evidence about the ability of H. lanatus to tolerate very low pH levels. On the one hand, a survey of grassland round Sheffield showed a dramatic decrease in the amount of H. lanatus present when the soil pH was below 4 (Grime and Lloyd, 1973). The authors suggested that the plant might not be able to tolerate the free aluminium ions which occur at this pH level. However, in the Park Grass experiment at Rothamsted, H. lanatus dominates a high nutrient plot in which the soil is pH 4 (Rothamsted Experimental Station, 1974).

In contrast to this work, a survey of hill pasture has shown that H. lanatus has a slight positive correlation with soil pH (Rogers and King, 1972). Adaptation to pH level is shown in the Park Grass experiment where plants taken from unfertilised, pH 5 plots gave their maximum yield in pH 5 soil, whereas plants from well fertilised pH 7 plots gave their maximum yield in pH 7 - 8 soil (Remison, 1976).

From work in New Zealand, Davies (1944) considered that the optimum soil pH for the growth of the species is 5 to 7.5 but the grass is a notable colonist on areas of greater acidity. This compares with the narrower optimum range for ryegrass of pH 6 to 7. Similarly, in a survey of a wide range of habitats round Sheffield, H. lanatus grew on soils with pH levels of 3.5 to 8.0 and was most abundant at pH 5 to 6. Lolium perenne was only found growing between pH 4.5 and 9.0, with a peak at pH 6 to 7 (Grime and Hodgson, personal communication).

Allelopathy. There are now several pieces of experimental evidence which support the hypothesis that H. lanatus plants can have an allelopathic effect on other plants in a sward. In one experiment Newman and Rovira (1975) tested eight plant species, all common in permanent neutral grassland, with leachate from each other's and their own roots. They found that H. lanatus caused the greatest overall reduction in the shoot dry weight of the other species to which its leachate was applied. Also, H. lanatus grew

better with leachate from its own roots than with that from other species. This work was done under artificial conditions and the results may not be relevant to the field; but, it may help to account for the way H. lanatus can dominate permanent grassland.

Recent work at Sheffield (Al-Mashhadani and Grime, personal communication) supports this finding. Seedlings of Rumex acetosa and H. lanatus were grown in sand removed from beneath monocultures of H. lanatus. The growth of these seedlings was severely depressed compared to the controls although excess nutrients were added. At the Weed Research Organization, leachates from H. lanatus seedlings and established plants have also significantly decreased the shoot dry weight of L. perenne seedlings growing in sand culture (Firth, personal communication).

There is, therefore, considerable evidence that H. lanatus may exert an allelopathic effect on many species but much more work is needed to find out whether this happens in a sward.

PREDATORS AND FUNGAL INFECTIONS

Animals. Many animals, besides domesticated livestock, feed on H. lanatus. The amount of H. lanatus present in swards increased in 1954-57 following the drastic decline in the rabbit population due to myxomatosis (Thomas, 1960). The species can also become abundant in chalk grassland if rabbits are excluded (Tansley, 1939). Mortimer (1976) placed H. lanatus seeds on the soil surface some of which was covered with netting to protect the seeds from vertebrates. When seeds were unprotected the number of plants which became established was 50% less than when vertebrates were excluded. This was mainly due to vole damage.

Invertebrates also feed on H. lanatus, for example Grey field slugs (Agriolimax reticulatus) (Pallant, 1972). The flowering and seed production of H. lanatus form an essential part in the requirements of a stage in the

life-cycle of an heteropteran, Leptopterna dolabrata (McNeill, 1973).

Studies of shoot fly larvae present in micro-plots of pure swards of 10 grasses showed that H. lanatus was also the preferred host of Opomyza petrei (Mowat, 1974).

Fungi. A number of fungi can infect H. lanatus. These are listed by Moore (1959); Beddows (1961); Wilson and Henderson (1966). One of the commonest infections is crown rust (Puccinia coronata var. holci). The orange spores of this fungus are commonly found on the older leaves from August to October and decrease their palatability (Corkhill, 1956; Ivins, 1952). Holcus lanatus can also act as a host for carrying over take-all (Gaumannomyces graminis) to wheat (Walker, 1945). Thirty five percent of the H. lanatus plants examined were infected. Ergot (Claviceps purpurea) can also be found on H. lanatus (Jenkinson, 1958).

Holcus lanatus litter provides a substrate for Pithomyces chartarum which causes facial eczema in sheep in New Zealand (Sinclair, 1961). This fungus produces a toxin called sporidesmin, which can affect H. lanatus germination (Wright, 1969). The fungus occurs in Britain, but it is not known whether it produces sporidesmin here (Lacey and Gregory, 1962).

In a study of grasses growing on coal tips, Daft and Nicolson (1974) found H. lanatus plants which were infected with a vesicular-arbuscular mycorrhiza. Such infections have been shown to increase phosphate uptake from many plants in low phosphate soils (Hatch, 1937; Nye, 1966). In the case of H. lanatus, therefore, the presence of mycorrhizal fungus and also the plant's rapid and extensive root growth may be reasons why it can tolerate low phosphate soils.

PERENNIALITY AND SENESCENCE

Holcus lanatus is classified as a perennial species (Hubbard, 1968). In a study of specimens from all over Europe, Bocher and Larsen (1958) found

that spaced plants lived for only a few years and tended to die after luxuriant flowering. They referred to the species as a pauciennial. They suggested that in dense, natural vegetation, plant competition restricts its growth and flowering, thereby making the species perennial. Vigorous plants collected from meadows tended to be perennial whereas plants from dry or open habitats were shorter lived. Holcus lanatus appears to have adapted its life cycle to suit a wide range of habitats. The way in which a clump of H. lanatus dies from the middle outwards has been described by Kruijne (1968).

SIGNIFICANCE IN GRASSLAND

ESTABLISHMENT

Ingress into swards. The height at which a sward is cut has a great effect upon the establishment of H. lanatus from seed. Hart and McGuire (1964) sowed H. lanatus seeds into a number of sward types in Oregon in July. The swards were cut during summer and autumn, either two or three times at either 50 or 100 mm above ground. At 50 mm height there were between 200 and 300 H. lanatus plants/m² the following spring; but at 100 mm there were less than ten. The authors suggest that the establishment of seedlings was limited by low light.

Inverting a sward allowed H. lanatus seeds to germinate more quickly than in a closed sward at Bangor but it did not alter the number of plants which germinated and established. About 5% of the seeds sown on either inverted or undisturbed swards were present as established plants a year later (Mortimer, 1976).

Competitive ability. Once H. lanatus has become established in a sward its high relative growth rate puts it at a competitive advantage (Grime and Hunt, 1975). In a triangular model which classifies vegetation with respect to competition, stress and disturbance, H. lanatus lies in the competitive

sector (Grime, 1974). Other factors which identify H. lanatus as a 'competitive' plant are its ability to spread laterally, and to deposit a layer of litter on the ground and its potentially tall growth habit (Grime and Hunt, 1975).

YIELD

Total yield. Work at Oxford (Haggar, 1976a) compared the productivity of H. lanatus and other indigenous grasses with L. perenne (S23) in monoculture swards. There was no significant difference between the total dry matter yields of L. perenne and H. lanatus under good growing conditions (400 kg/ha N, 180 kg/ha P and K).

In the following year of the experiment, under poorer conditions, the total dry matter yield of H. lanatus was significantly greater than that of L. perenne.

In the final year of the experiment fertilizer was applied to the plots in three equal dressings. Harvests were made in June, August and September. The total yields are shown in Table 1.

Table 1 Dry matter yields of H. lanatus and L. perenne (kg/ha) at two N levels. From Haggar, 1976a.

Species	kg/ha N	
	60	180
<u>H. lanatus</u>	7,118	10,745
<u>L. perenne</u>	3,319	7,385

Thus, H. lanatus yielded at least as much as L. perenne under conditions of high soil fertility and had a considerably greater yield when inputs of nitrogen and moisture were lower.

In experiments at the Grassland Research Institute there was no significant difference between the annual yields of irrigated, well-

fertilized plots of H. lanatus and L. perenne (S24) which were harvested monthly. The dry matter yield of L. perenne was 8,240 kg/ha and of H. lanatus 8,970 kg/ha (A.J. Corrall, personal communication). These results confirm earlier work by Stapledon and Milton (1932) in which the annual yield of H. lanatus compared favourably with that of L. perenne either with or without nitrogen.

Seasonal distribution. Holcus lanatus is one of the earliest grasses to start growth in the spring. At Oxford, it produced a greater yield than L. perenne (S23) during the early spring (Haggard, 1976a). The two species were of similar productivity during May but H. lanatus was again more productive during July. The autumn growth of both was similar.

On hill land, H. lanatus is again one of the earliest grasses to start growth in the spring and its aftermath growth in a reseeding trial there was also outstanding (Herriott, 1975).

RESPONSE TO MANAGEMENT

Fertilizers. Holcus lanatus established much better from seed on an infertile site if total fertilizer was applied (Miles, 1974, a and b). Also, within four years of starting to fertilize a cotton grass (Eriophorum vaginatum) site regularly the area became an H. lanatus dominant sward (Bradshaw, 1969).

A survey of Dutch grassland found a greater amount of H. lanatus present on low K soils (Kruijne and de Vries, 1963). Holcus lanatus is abundant on low K plots in both the Park Grass Experiment (Brenchley and Warington, 1958) and in work by Castle and Holmes (1960). Also, it did not respond to the addition of K fertilizer to a permanent sward at the Grassland Research Institute (Norman, 1955).

The addition of P fertilizer did not alter the amount of H. lanatus present in a mixed sward in Oregon (Hart and McGuire, 1963). This is in agreement with a survey of Dutch grassland which showed that the percentage frequency of H. lanatus was independent of the amount of P in the soil (Kruijne and de Vries, 1963). Also, work at Sheffield has shown that H. lanatus seedlings in nutrient solution can grow equally well in considerable dilutions of the original P concentration, as long as high flow rates are maintained. (Unit of Comparative Plant Ecology, N.E.R.C.).

Some experimental work has shown that H. lanatus responds well to N fertilizer. The amount of H. lanatus in a mainly Agrostis/Festuca sward increased most in plots which were given N fertilizer at the rate of 330 kg N/ha/yr and were grazed frequently (Elliott et al., 1974). Also, H. lanatus has a high response to N applied in July (Haggar, 1976a).

On the other hand, when fertilizer N was applied to a mixed sward for five years the amount of H. lanatus present declined while the amount of L. perenne increased (de Vries and Kruijne, 1960). Similarly, when the amount of N applied to a mixed sward in Oregon was increased from 0 to 100 kg/ha/yr the amount of H. lanatus in the sward was significantly less (Hart and McGuire, 1963). Holcus lanatus yielded more than L. perenne at low N levels (Hedde, 1967) and became dominant on low N plots in an experiment in which a range of fertilizer treatments was used (Castle and Holmes, 1960).

Thus, H. lanatus can tolerate low levels of N, P and K. Studies in cation-exchange capacity of root systems suggest that it is at an advantage over other grasses when these elements are limited (Jackman, 1960). It can produce more shoots than L. perenne under low nutrient conditions, but, if the N level is increased, the response of the species depends on what other species are present and how the sward is managed.

Irrigation. During the drought of 1976, young H. lanatus plants, which had been transplanted into the field in March, suffered badly. They wilted before Lolium perenne plants, transplanted at the same time (Watt, unpublished data). However, H. lanatus plants, which arose from seed sown in the spring and summer of 1975 withstood this drought extremely well (Watt, 1976). The plants had presumably been able to develop deep enough roots during that time to be able to survive without irrigation.

Defoliation. Under a lax cutting regime H. lanatus can dominate L. perenne in a mixture (Riveros, 1963; Froud-Williams, 1974; Watt, unpublished data).

Holcus lanatus is not well adapted to very frequent close defoliation. It was suggested that one of the reasons why H. lanatus, sown as a nurse species for L. perenne on hill land declines after a few years is because of its poor root growth under intensive sheep grazing (Sithamparanathan, 1963).

Some of the early experimental work on grassland showed that the growth of H. lanatus was favoured by resting it from grazing between mid-April and mid-May and by lenient grazing for the rest of the year (Jones, 1933a). When a sward was subjected to controlled grazing plus N and P fertilizer for one year, the amount of H. lanatus present fell from 56% to 33% (Jones, 1933b). He observed that on swards with uncontrolled grazing, H. lanatus tended to be avoided by the sheep until they had nothing else to eat in January and February. The dead shoot material protected the young shoots in the spring and made it difficult for the sheep to eat them.

Treading. When a sward is grazed, the plants in it are also trodden by the animals. Holcus lanatus is very susceptible to damage by trampling (Davies, 1938). The effect of animal treading on a range of grassland species under various conditions has been studied by D.B. Edmond. His extensive work has been reviewed by Brown and Evans (1973). In this work, H. lanatus was consistently the grass least tolerant of treading.

QUALITY

Chemical composition. Chemical analyses of H. lanatus at various stages of growth have shown that it can supply useful amounts of the more important minerals (Fagan and Milton, 1931; Thomas and Thompson, 1948) and that as hay it compares favourably with perennial ryegrass (Aston and Morgan, 1953). The fibre content of samples from plots of H. lanatus, which were cut monthly, ranged between 23% of the dry matter at the end of April to 35% at the end of July (Fagan and Milton, 1931).

Work at the Grassland Research Institute showed that mean nitrogen content of H. lanatus was 2.3% compared with 1.84% for L. perenne. These figures were derived from fortnightly harvests during May and June (Corrall, personal communication). The total yield of nitrogen provided by the grass during the growing season is similar to that provided by L. perenne (Haggar, 1976a).

Although H. lanatus has a high content of molybdenum, zinc and chloride compared with other grasses (Fleming, 1965) it is very low in iodide. In one comparison, H. lanatus contained only 7 mg iodine/100 g dry weight, whereas L. perenne had 146 mg/100 g dry weight (Butler and Johnson, 1957). In New Zealand, goitre in lambs is associated with herbage containing less than 30 mg iodine/100 g dry weight. Cyanogenesis occurs in H. lanatus (Devetak, Jovančević and Milinković, 1971), but this does not seem to be a problem for livestock.

Holcus lanatus has a relatively high sodium and potassium content (Griffith and Walters, 1966) but it contained much less protein and copper than Lolium multiflorum when the grasses were analysed at the hay stage (Rasheed and Seeley, 1966). However, work in Eire showed that H. lanatus contained similar amounts of copper to L. perenne (O'Toole, 1962).

Palatability. Holcus lanatus is palatable when the first shoots appear in the spring (Garner, 1963). However, it becomes unpalatable as it comes up to flower in the summer. Garner suggests that the hairs on the plant contribute to its unpalatability and that the amount of lignification provides the link between palatability and digestibility. Ivins (1952, 1964) maintains that the grass is relatively unpalatable throughout the year.

A study of the palatability of a range of grasses was carried out by Stapledon and Milton (1932). The H. lanatus seed was obtained from commercial ryegrass seed cleanings. These plants entered the stage of pseudostem erection in April - much earlier than indigenous ones. The culms were rejected by the grazing animals. Volunteer indigenous and leafier H. lanatus plants were much better grazed. In July, after flowering, the plots were very well grazed. As the aftermath of H. lanatus is almost all leaf (90% of the panicle shoots are removed in a hay cut), it is usually well grazed.

This difference in palatability between culm and leaf suggests that it is probably the lignification in the culm that causes unpalatability, as opposed to the hairs which occur on the leaves as well as the culm.

Digestibility. The mean digestibility of grass cut monthly in 1972 was significantly greater for H. lanatus than for L. perenne (Haggar, 1976a). The mean D value for H. lanatus was 69.0 and for L. perenne, 65.4. This compares with figures from the Grassland Research Institute of 68.5 and 68.7 respectively (Corrall, personal communication).

In 1973, the digestibility of the primary growth of H. lanatus and L. perenne were compared. Both grasses had a D value above 75 until 8 May. After this date H. lanatus had a D value about 5 units lower than L. perenne (Haggar, 1976a)

The dry matter yield of primary growth was multiplied by the D values of these species, to calculate the yield of digestible organic matter.

Despite the relatively high digestibility of L. perenne from May onwards, H. lanatus had a higher yield of digestible organic matter throughout the whole period 10 April to 5 June (Table 2).

Table 2 Dry matter yields of H. lanatus and L. perenne at 65 D value. From Haggar (1976a).

Species	Date of reaching 65 D value	D.M. yield kg/ha at 65 D value
<u>H. lanatus</u>	18 May	2,700
<u>L. perenne</u>	1 June	3,400

Thus, H. lanatus does not provide as much bulk as L. perenne at 65 D value and it is therefore not as suitable for conservation.

Animal Production. There is relatively little experimental evidence comparing the liveweight gain of animals grazing H. lanatus with those grazing other species. The evidence available suggests that animals gain at least as much weight on H. lanatus swards as on L. perenne swards. In an experiment in Eire, swards of both monoculture L. perenne and H. lanatus were established, each containing some Trifolium repens. For three years the area was stocked at 25 sheep/ha and no nitrogen was applied. Over this period the liveweight gains of the sheep on the H. lanatus plots were significantly greater than those on the L. perenne plots (Moloney, 1962, 1963, 1964; Murphy, 1965). Work at the Weed Research Organization has shown that there was no significant difference between annual beef production from swards containing either 24% or 55% H. lanatus (Haggar et al. in press).

USES

Hill land. In Scotland, an experiment was set up to compare the yields of pure stands of grasses and legumes at high levels of fertilizer. Holcus lanatus, L. perenne and Festuca rubra were clearly the highest yielding

grasses. Holcus lanatus was among the earliest species to start growth in spring and was outstanding in its aftermath growth. This is important on hill land where the growing season is short (Herriott, 1975).

Similar experiments have been carried out using very little fertilizer. It was concluded that only H. lanatus and F. rubra were suitable, in terms of yield and persistency for sowing under low fertility conditions (East of Scotland College of Agriculture, 1973).

Areas which grew Nardus stricta and Molinia caerulea or areas which were covered with deep peat were reseeded with H. lanatus (Hughes and Nicholson, 1961 a and b). The grass established well and gave a high dry matter yield. Holcus lanatus was sown in ploughed up peat by Hunt (1964). It proved persistent and gave a high yield in the fifth year with no nitrogen fertilizer.

It has been suggested that H. lanatus could be used as a 'nurse' species for sown L. perenne and Trifolium repens on hill land (Thomas, 1936; Davies, 1940). They suggested that H. lanatus establishes rapidly and is most aggressive during the seeding and following year, this allows more stock to be carried, consolidates the soil and speeds up the fertility cycle. In addition, H. lanatus protects the slower growing L. perenne and T. repens from overgrazing. Holcus lanatus will not respond as much as L. perenne to high fertilizer levels. So, with close grazing, lime and high levels of fertilizer, the sward should change from H. lanatus dominance to L. perenne and T. repens dominance. This type of management was carried out by Sithampanathan (1963). His results support this theory (Table 3).

Table 3 The amount of H. lanatus and L. perenne in a hill sward at different times after seeding. From Sithampanathan (1963).

Species	% of sward	
	1 year after seeding	3 years after seeding
<u>H. lanatus</u>	86	29
<u>L. perenne</u>	14	55

Massey Basyn. This is a variety of H. lanatus, bred in New Zealand to increase the productivity of hill land (Munro, 1961; Jacques, 1974; Jacques et al., 1974). It had similar dry weight yields to Ruanui, Manawa and Ariki ryegrasses and lambs grazing it had the same liveweight gain as those on Ruanui ryegrass (Watkin and Robinson, 1974) although they weighed less at birth.

In recent work at Oxford, the growth of individual plants of Massey Basyn was compared with that of indigenous H. lanatus plants (Watt, unpublished data). The New Zealand variety was taller, had wider leaves and had a greater fresh weight at harvest than the indigenous H. lanatus, which suggests that it might also be more productive than some indigenous English H. lanatus plants.

The species varies greatly in its response to environmental factors, which suggests that it could be selected to suit the low input systems of the future.

Reclamation. Holcus lanatus has proved useful in stabilising eroding areas in the Farne Islands (Hormung, 1976) and Massey Basyn stabilised denuded slopes in New Zealand better initially than Festuca rubra or Agrostis tenuis but by 3 years it had largely disappeared (Dunbar, 1974).

South America. Holcus lanatus is tolerant of acid, low phosphate soils and has therefore proved to be a valuable species on the Falkland Islands (Davies et al., 1971). Most of the soils on these islands are acid peats (pH 3.9 - 5.4) which are very low in phosphate. By 1971, over 6,000 ha of scrubland had been ploughed or rotavated and sown, mainly to H. lanatus, which has raised their value for sheep and cattle production considerably.

Holcus lanatus is also quite widely used for pasture and hay in Chile, cultivated as an annual for winter fodder in Southern Brazil and considered outstanding for higher altitudes in Hawaii (Whyte, Moir and Cooper, 1959).

WEED STATUS IN HERBAGE SEED CROPS

Holcus lanatus is a widespread weed of herbage seed crops and it can decrease the yield of these crops considerably (Harkess and Hope, 1974). The grass was classified as an injurious weed under the Seed Regulations of 1922 but it is not now so listed because of improved seed cleaning methods (Gill and Vear, 1969). However, one third of the Italian ryegrass and half of the perennial ryegrass seed tested in Northern Ireland contained more than the allowed limit of H. lanatus seeds (Ministry of Agriculture, Northern Ireland, 1968a).

CONTROL

Management. A survey of the literature suggests that to check the spread of H. lanatus in a ryegrass sward the land should be well drained (Morrison and Idle, 1972) and limed if acid (Hart and McGuire, 1963). The sward should be cut or grazed regularly to prevent H. lanatus dominating L. perenne (Riveros, 1963). Regular grazing keeps H. lanatus in a vegetative and palatable condition (Garner, 1963) and damages it by trampling (Brown and Evans, 1973).

Herbicides. Holcus lanatus seedlings have been controlled in a L. perenne seed bed by spraying pre-emergence with ethofumesate at 2 kg a.i./ha in August (Hammond et al., 1976). A number of herbicides have shown different degrees of selective control of established H. lanatus in ryegrass. Dalapon applied at 3.4 kg a.e./ha in July has given good results (Allen, 1969) and this herbicide is recommended in the Weed Control Handbook (British Crop Protection Council, 1972). Asulam applied at 3.4 kg a.i./ha in summer or autumn reduced the amount of H. lanatus without affecting the ryegrass (Blair and Holroyd, 1973). A very low dose of paraquat can also be useful e.g. 0.14 kg a.i./ha has given similar results (Sharp, 1968). Linuron applied at 2.2 kg/ha in March has shown very good selectivity against

H. lanatus in a timothy (Phleum pratense) seed crop in Scotland (Harkess and Hope, 1974). Propyzamide applied at 1.1 kg a.i./ha in July has also given promising results (Fisher and Faulkner, 1975; Haggard, 1976b). Metribuzin at a very low dose (0.37 kg a.i./ha) has shown good selectivity in initial pot experiments (Watt, unpublished data).

CONCLUSION

Holcus lanatus is a very adaptable and competitive grass. Its shoots and roots can grow very vigorously and it has ecotypes which allow it to tolerate a wide range of environmental conditions. It can reproduce well both by seed production and by runners. A weak point is its susceptibility to damage by treading.

In lowland ryegrass swards, H. lanatus has been regarded as a weed because livestock reject it when flower shoots are formed (Stapledon and Milton, 1932). Beef cattle have however made better animal liveweight gains on pure H. lanatus swards than on pure L. perenne swards (Moloney, 1962, 1963, 1964; Murphy, 1965). This suggests that the reputation of H. lanatus as a weed may have arisen from estimates of its productivity under low nutrient conditions rather than under the same nutrient conditions as are applied to sown species.

On hill land, H. lanatus is a valuable and persistent species (Hughes and Nicholson, 1961 a and b; Herriott, 1975). It has been sown both to prevent soil erosion (Dunbar, 1974; Hornung, 1976) and to provide fodder on acid, low nutrient soils (Davies, et al., 1971).

More information is required about animal production from swards of H. lanatus under various management systems. Because of the large amount of variability in the species, it should be possible to breed improved cultivars of H. lanatus for specific purposes, e.g. for beef production under high or low input systems or for the reclamation of spoil tips. Herbicides in

current use in grassland have their limitations and new herbicides for the selective control of H. lanatus in ryegrass herbage seed crops are needed.

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THE EMERGENCE, GROWTH, FLOWERING AND SEED PRODUCTION OF

HOLCUS LANATUS L. SOWN MONTHLY IN THE FIELD

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Summary. This report describes a growth study of spaced plants of Holcus lanatus, arising from seed sown monthly in bare soil in 1975. No artificial watering was used and seedling emergence was low during the hot, dry summer. At other times of the year seedling emergence was usually very rapid. There was a large difference between the growth of plants from seed sown in June and those sown in July. The June sown plants produced more than five times as many tillers per plant, 200 days after sowing, and more than twice as many seeds per plant, as the July sown plants. But, the July sown plants produced more seeds per panicle than the June sown plants.

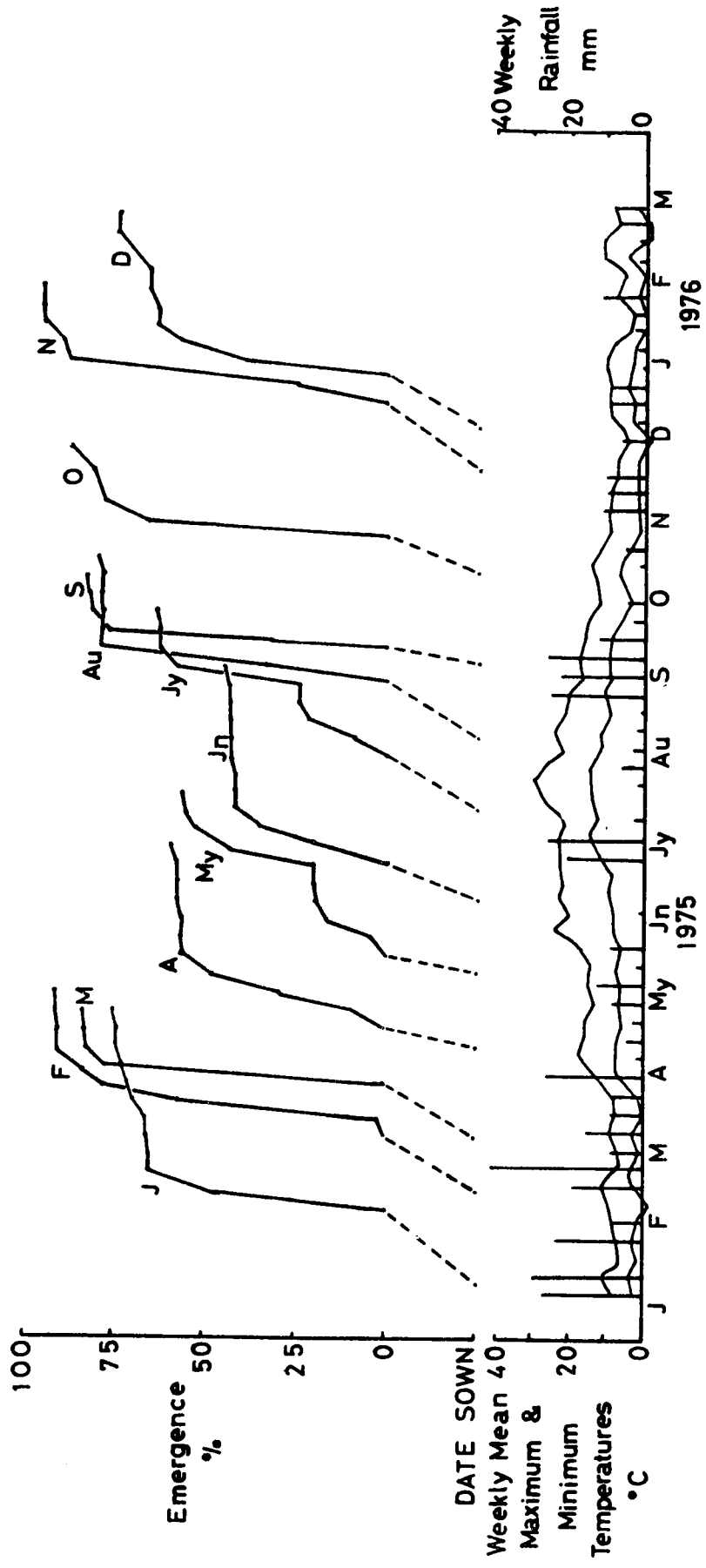
Résumé. Ce travail présente un compte-rendu d'une étude de la croissance de plantes espacées de Holcus lanatus provenant de semis en sol nu à intervalles d'un mois en 1975. Aucun arrosage artificiel ne fut apporté, et la levée des plantules fut irrégulière pendant cet été chaud et sec. A d'autres époques de l'an la levée des plantules se trouvait généralement bien rapide. Il y eut de grandes différences de croissance entre les plantes provenant du semis de juin et celles du semis de juillet. Deux cent jours après le semis, les plantes semées en juin produisaient cinq fois plus de talles/plante que celles semées en juillet - et plus du double de semences. Mais le rendement de semences/panicule était supérieur chez le semis de juillet.

INTRODUCTION

Little is known about how environmental factors affect the emergence, growth, flowering and seed production of Holcus lanatus (Yorkshire Fog) sown at various times of the year in the field. The laboratory test recommended by the Association of Official Seed Analysts (1970) is that seed should be germinated under alternating conditions of 16 hr dark at 20°C and 8 hr light at 30°C, in moist conditions. McNeill (1973) at Ascot, Berkshire, found H.lanatus flowering from late May onwards. And, Mortimer (1974), working at Bangor, Gwynedd, found H.lanatus shed seed from June to September with a peak during the first two weeks of July. He sowed seed which was 64.8% viable on the soil surface in October 1970. Only 24% of the total seed sown germinated and the maximum number of seedlings occurred in November. By the following May only 11% of the seed sown had given rise to established plants. Böcher and Larsen (1958) found that H.lanatus plants grown from northern European seed needed to be vernalised before they would flower.

This report presents the results of an experiment designed to study the emergence, number of tillers, dry weight of shoot growth, time and duration of flowering and the seed production of H.lanatus sown monthly in 1975 in the field.

Figure 1. Emergence (% of viable seed sown) of *H. lanatus* sown each month during 1975 and also weekly rainfall (mm) and weekly maximum and minimum air temperatures ($^{\circ}\text{C}$).



METHOD AND MATERIALS

The site (6m x 1.2m) was on a sandy loam soil at the Weed Research Organization, Oxford. The top 75 mm of soil was removed and placed in a 'Camplex' electrical soil sterilizer. It was heated to 77°C and then left until the soil temperature stopped rising, before it was returned to the site. This technique is recommended by the manufacturers and it killed any seed present in the soil.

Holcus lanatus seeds, collected the previous summer at WRO were sown monthly during 1975. The seeds were stored at room temperature before sowing. Each plot measured 1m x 0.3m and 100 seeds per plot were sown, 2mm deep at 30mm spacing in 4 rows each 50mm apart. The same number of seeds was sown every month into a freshly prepared seed bed with a fine tilth. Laboratory tests showed that the unsown seeds remained about 60% viable throughout the year. The experiment was of an unrestricted random design with two replicate plots for each monthly sowing.

After sowing, each plot was protected from birds by plastic netting. Every week, the number of seedlings which had emerged on each plot was recorded. As each month's seedlings grew, they were thinned at intervals, to prevent intra-specific competition. At each thinning the tiller numbers and shoot dry weights of the harvested plants were noted. One plant was selected at random and left to grow on in each plot; the number of panicles was recorded each week. The time at which anthesis occurred was recorded by scoring the plants each week for the proportion of flowers which had produced anthers.

The maximum height of the plants above the ground was measured on 15 June after which the plants were cut down to ground level on 29 June and their fresh and dry weights were recorded. Twenty panicles (which appeared to have shed little, if any, seed) were selected from each plant at random at the time of harvest. Their fresh weight was recorded and they were kept in linen bags at ambient temperature for 16 days. Then the seed was removed from the rachis and weighed. Two sub-samples, each of 100 seeds were taken from each sample and weighed. The mean number of seeds produced on each plant could then be estimated.

The term 'seed' refers to the caryopsis surrounded by the lemma and palea. Groups of plants are referred to by the months in which they were sown. Weekly rainfall and weekly mean maximum and minimum air temperatures were recorded at a nearby meteorological site and are shown in Figure 1. Monthly mean rainfall figures for 1975 are presented in Table 2. No artificial watering was used.

RESULTS

Germination and emergence

Under favourable conditions, the seeds germinated rapidly and started to emerge between one and two weeks after sowing (September). But when it was dry and/or cold, emergence was delayed (July) (Table 1). In Figure 1, weekly maximum and minimum air temperatures and weekly mean rainfall are plotted to help explain these differences. Once emergence had begun it continued rapidly for all sowing dates, although April, May, June and July sowings emerged more slowly than those of other months. The May and July sowings emerged in two batches. Most months' sowings produced between 75% and 95% emergence of viable seeds, but, far fewer seedlings emerged from April to July sowings.

Plant growth

The tiller numbers of plants of the 12 sowing dates at various times after 50% emergence of their seedlings are shown in Figure 2. The January to June sown plants all increased rapidly in tiller numbers between 100 and 200 days after the date of 50% seedling emergence. The plants from the July sowing onwards tillered to a much lesser extent. The maximum height of the plants above the ground was measured on 15 June 1976. All the plants were more than 500 mm tall, with the exception of those

Table 1

<u>Emergence of <i>Holcus lanatus</i> seed</u>			
<u>Month of sowing</u>	<u>Maximum % emergence of viable seeds</u>	<u>Number of days to maximum emergence</u>	<u>Number of days to 50% emergence</u>
Jan	75.0	105	35
Feb	91.7	77	35
Mar	84.2	49	24
Apr	59.2	77	21
May	56.6	70	45
Jun	44.2	98	22
Jul	63.3	77	52
Aug	79.2	70	31
Sept	81.6	28	10
Oct	88.3	56	17
Nov	95.8	56	31
Dec	75.8	70	31
L.S.D. (p=0.05)	25.3	16.9	16.3

Table 2

<u>Month</u>	<u>Monthly rainfall mm</u>		
	<u>1975</u>	<u>Mean 1965-1974</u>	<u>1975 versus 10 year mean</u>
Jan	64.9	53.8	+ 11.1
Feb	34.4	43.2	- 8.8
Mar	85.1	31.7	+ 53.4
Apr	45.6	43.6	+ 2.0
May	39.7	55.5	- 15.8
Jun	9.5	63.2	- 53.7
Jul	48.0	53.6	- 5.6
Aug	18.4	59.3	- 40.9
Sep	85.9	51.9	+ 34.0
Oct	16.8	51.1	- 34.3
Nov	34.0	58.8	- 24.8
Dec	18.8	46.4	- 27.6

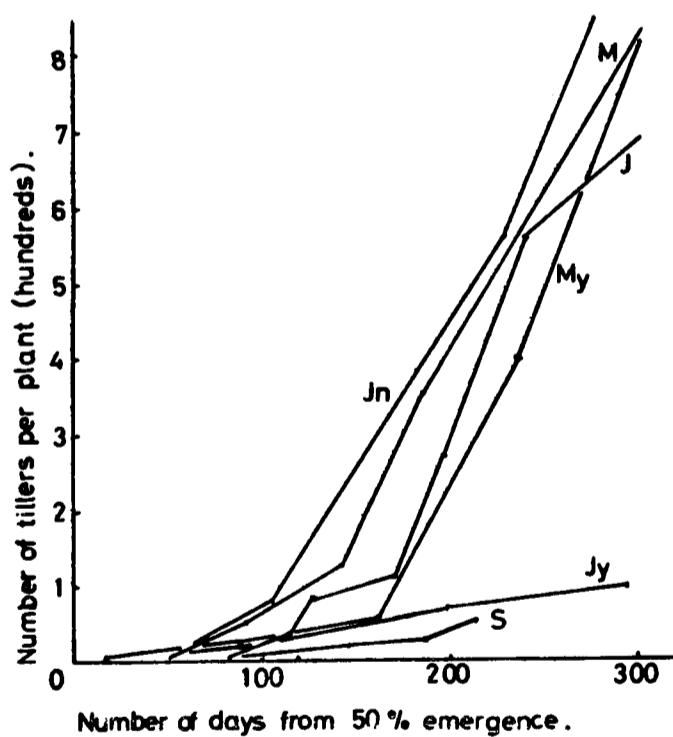
from the last three sowing dates, October, November and December 1975 which were 435, 240 and 130 mm tall respectively. The plants were harvested to ground level on 29 June 1976 and the shoot dry weights are recorded in Table 3. The January to June plants all weighed more than 300 g, whereas plants from July sowings onwards all weighed less than 150 g.

Table 3

Shoot dry weight, number of panicles and
number of seeds per plant and per panicle for each sowing date

Month of sowing in 1975	Number of days from 50% emergence to harvest	Dry wt.g on 29 June 1976	Mean total number of panicles per plant	Estimated mean seed numbers per plant	Mean seed numbers per panicle
Jan	487	339.3	403.5	128,130	307.1
Feb	452	349.4	495.5	138,983	265.8
Mar	441	627.5	754.5	242,665	321.6
Apr	410	437.7	535.0	171,697	316.2
May	357	331.9	500.0	146,811	293.6
Jun	352	457.0	759.5	236,078	310.8
Jul	288	134.7	184.5	89,148	483.2
Aug	281	108.7	133.5	83,680	677.6
Sep	271	77.0	119.0	75,837	469.9
Oct	232	7.2	17.5	3,639	207.9
Nov	179	12.9	5.0	2,222	444.4
Dec	163	2.1	0	0	0
L.S.D. (p = 0.05)	6.1	339.9	281.1	87,748	274.5

Figure 2. Tiller numbers present after 50% emergence of *H. lanatus* seed sown on a selection of the sowing dates.



Panicle Production

A large number of panicles was produced by all the early sown plants, (Table 3). There was a sharp drop in the number of panicles from 759 per plant for the June sowing to 184 per plant for the July sowing. This decline continued throughout the later sowings with the October plants producing very few panicles. Only one of the November plants produced any flowers and the December plants did not flower at all. The mean time at which 50% of the panicles had emerged was during the first week in June for all plants with the exception of October and November sowings in which it did not occur until 13 and 15 June respectively. Likewise, the estimated mean time at which 50% anthesis occurred was between 10 and 14 June for all plants except the October and November ones. In these it did not occur until 23 and 29 June respectively.

Number of seeds per plant

In general, the plants produced a very large number of seeds with a maximum of 240,000 seeds per plant from the March sowing. Large numbers of seeds were produced by the January to June sown plants but the numbers declined from the July sowing onwards. However, the July, August and September sowings all had a larger number of seeds per panicle than the earlier sowings. Even the relatively very small plants from the October and November sowings produced more than 2000 seeds per plant.

DISCUSSION

The very hot and dry summer of 1975 and the very mild winter of 1975/76 must be taken into account when considering these results. May and June were unusually dry (Table 2). The number of seedlings which emerged from sowings during these months was low. Air temperatures were high in June, July and August and what little rain there was evaporated quickly and plants wilted. Many April seedlings died when they had only just emerged or had only one or two leaves. Both the May and June sowings emerged in two batches, the second batch in each case co-inciding with rainfall after a dry period. The relatively mild weather in January 1976 allowed the November and December sowings to emerge rapidly. A low total number of seedlings emerged from the April to June sowings. As the viability of the seeds was approximately the same for all sowings, it seems likely that many seedlings died between germination and emergence. With the exception of these summer months during which seedling emergence was slow, *H. lanatus* seedlings emerged rapidly. This is consistent with the seed being non-dormant. Mortimer (1974) found a peak in seedling numbers in early September from *H. lanatus* seed sown at the natural time in summer. This experiment however, shows a peak in seedling numbers in late September - early October for summer sowings. The exact time of the peak may depend on the amount and timing of autumn rain.

There is a great difference in the number of tillers produced by plants from June and July sowings at any given time after 50% seedling emergence (Figure 2). In order to begin tillering a grass must have reached a certain stage of growth. After that, the degree to which it tillers depends to a large extent on environmental conditions. The June sowing reached 50% seedling emergence on 10 July whereas the July sowing did not reach this level until 14 September. At the thinning on September 11, the July sown plants which had emerged were only just beginning to tiller whereas the June sown plants already had 11 tillers. This difference in plant growth stage in early autumn was probably very important in determining the absolute increase in tiller numbers in both groups of plants over the winter. By February 20, 1976, the June plants had 500 tillers compared to the July plants 60 tillers. This large difference between the June and July sowings was also reflected in both plant dry weight on 29 June 1976 and in panicle numbers. The larger number of tillers formed during the autumn and winter by the June plants compared with the July plants meant that a much larger number of tillers on the June plants were

formed in time to be vernalised in the winter and were therefore able to flower in the following summer. Mortimer (1974) found that H.lanatus shed seed from June to September with a peak during the first two weeks of July. In a summer like 1975, the seed shed before mid-June would have been at a great advantage, in terms of subsequent plant growth, over the later shed seed.

The fact that neither of the two December plants and only one of the November plants flowered confirms the statement of Evans (1964) that H.lanatus plants need to undergo a period of vernalisation as vegetative plants before they can flower. There is no record of any effect of day length on the flowering of H.lanatus. Böcher and Larsen (1958) collected H.lanatus seed from all over Europe and sowed it indoors in spring, transplanting the seedlings outside in June. They found that plants from southern Europe flowered in the first year without 'reinforcement' (a long vegetative period before wintering) and before wintering. Plants from northern Europe only flowered in the second year and required 'reinforcement' and overwintering.

Plants from the July, August and September sowings in this experiment produced a larger number of seeds per panicle than plants from the earlier sowings. This indicates that the vernalised tillers on these plants grew well in 1976 and were able to compensate, to some extent, for their low numbers by producing more seeds per panicle. Thus, the direct effect of sowing at different times was on total tiller numbers and numbers of vernalised tillers rather than on seed numbers per plant. The November and December plants were very small and produced little or no seed. But, if they were kept free from competition they would probably produce a large amount of seed in summer 1977. The times of 50% panicle emergence and anthesis were approximately the same for all the plants which flowered except the October and November sowings in which they were delayed by about a week. Thus, there is a gradient in the plants from the various sowing dates from those which flowered at the normal time, through those which flowered late to those which did not flower at all.

The number of seeds produced by plants from the late summer - early autumn sowings is still very large. If there was one H.lanatus plant per square metre in a sward and each plant produced about 100,000 seeds a year, of which 60% were viable, 600 million viable seeds would be shed over a hectare in one year. These figures are based on spaced plants however and would be lower for plants in the competitive situation of a sward. Milton (1948) found 173,000 H.lanatus seedlings per ha. germinated from soil cores taken to a depth of 180 mm on a mainly Agrostis-Festuca sward. This is a large number of seedlings but it represents only 0.02% of the potential annual seed production of H.lanatus plants at a density of one per square metre in a sward. These estimates point to the high mortality of H.lanatus seed in grassland. Mortimer (1974) has worked out a relevant seed population flux diagram. He has shown that the seeds are very vulnerable both when they are on the soil surface and when they become part of the buried seed bank.

Although these results show that H.lanatus seeds have little dormancy, the potential number of seeds which a plant can produce is so large that even a 1% level of innate or enforced dormancy would result in a large amount of buried viable seed. Dormant H.lanatus seeds may be brought to near the soil surface by moles and worms so that, potentially, they may germinate at any time of year. This has been shown by Jalloq (1975) who found a few H.lanatus seedlings germinating from seeds brought up in mole hill soil whereas Mc Rill (1974) found a mean number of 158.2 seedlings germinated per 100 g of worm cast soil, removed from a permanent sward in February and kept moist for one year.

Acknowledgements

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APPENDIX 3

Dry weight determinations

In all cases plant material was placed inside wire mesh trays in an oven set at 100°C for between 16 and 24 hours. The material was weighed to the nearest 0.1g, except in the case of small seedlings and seeds. These were weighed to the nearest 0.0001g.

APPENDIX 4

Statistical analyses

Levels of significance are expressed as follows

*** , highly significant, $p \leq 0.001$

** , very significant, $p \leq 0.01$

* , significant, $p \leq 0.05$

Experiments were analysed by Analysis of Variance. Where increasing levels of an experimental factor were used this was followed by tests for Linear, Quadratic and (if relevant) Cubic effects in the results. Thus, a straight line relationship, significant at $p = 0.01$ is indicated by

LIN **

Evidence of a single peak in the relationship, significant at $p = 0.05$ is shown by

QUAD *

Evidence of a double peak, significant at $p = 0.001$ is shown by

CUBIC ***

An interaction, with significantly different linear trends ($p = 0.05$) is represented by

LIN X LIN *

Where data has been transformed this is indicated on the Figure.

When a least significant difference (LSD) is shown on a figure this is for $p = 0.05$.

APPENDIX 5

Details of observations made on cv. Massey Basyn
and 'local' H. lanatus

OBSERVATION	DATE(S)	HOW OBSERVED
Number of tillers per plant	19 Sep. 3 Oct. 17 Oct. 4 Dec.	Counted on each plant
Proportion of dead foliage	18 Feb.	0-10 score on each plant
Number of panicles per plant	24 May. 31 May. 7 Jun. 14 Jun. 21 Jun. 28 Jun.	Counted on each plant
Angle of foliage	24 May. 31 May. 7 Jun. 14 Jun. 21 Jun.	Visual assessment (using large protractor) of % foliage in classes 0°-30°, 30°-60°, 60°-90° from horizontal and, hence estimate of mean leaf angle
Maximum plant height	8 Jun.	Distance between soil surface and tip of tallest panicle
Leaf length	8 Jun.	Measured 5 random leaves per plant
Leaf width	8 Jun.	Measured at mid-point of 5 random leaves per plant
Leaf length x leaf width	8 Jun.	Mean leaf length x mean leaf width
Proportion of panicles in anthesis	14 Jun. 21 Jun. 28 Jun.	0-10 score on each plant
Panicle fresh weight	28 Jun.	Mean weight of 20 random panicles per plant
Shoot fresh weight	28 Jun.	Weighed for each plant
Panicle length	28 Jun.	Mean length of 20 random panicles per plant
Dry weight of shoot regrowth	15 Jul.	Weighed for each plant
Weight of 100 seeds	16 Jul.	Weight of 200 seeds from each plant 2
Number of seeds per panicle	16 Jul.	Mean weight of seed from 20 panicles mean weight of one seed (from 100 seed weight)
Number of seeds per plant	16 Jul.	(Number of seeds per panicle) x (number of panicles per plant)
Seed viability	11 Aug.	% germination, after 23 days in petri dishes in laboratory, of 4 x 100 seeds

APPENDIX 6

Results of observations made on cv. Massey Basyn
and 'local' H. lanatus

ATTRIBUTE	UNIT	DATE 1975/6	MASSEY BASYN	'LOCAL'	SIGNIFICANCE
Number of tillers per plant	-	19 Sep.	8.6	8.7	NS
	-	3 Oct.	13.4	16.2	NS
	-	17 Oct.	32.0	35.0	NS
	-	4 Dec.	88.1	90.6	NS
Proportion of dead foliage	%	18 Feb.	45 (0.73)	54 (0.83)	(NS)
Number of panicles per plant	-	24 May.	18.0	0.2	NS
	-	31 May.	64.7	12.4	*
	-	7 Jun.	109.1	101.4	NS
	-	14 Jun.	148.9	132.2	NS
	-	21 Jun.	171.7	141.8	NS
	-	28 Jun.	172.6	143.2	NS
Angle of foliage	°	24 May.	(0.79)	(0.65)	(*)
	°	31 May.	(0.99)	(0.90)	(NS)
	°	7 Jun.	(1.05)	(0.96)	(NS)
	°	14 Jun.	(1.10)	(1.10)	(NS)
	°	21 Jun.	(1.18)	(1.14)	(*)
Maximum plant height	mm	8 Jun.	507	384	**
Leaf length	mm	8 Jun.	99	100	NS
Leaf width	mm	8 Jun.	12	10	*
Leaf length x leaf width	mm ²	8 Jun.	1170	970	NS
Proportion of panicles in anthesis	%	14 Jun.	(1.16)	(0.30)	(***)
	%	21 Jun.	(1.23)	(1.12)	(*)
	%	28 Jun.	(1.50)	(1.40)	(NS)
Panicle fresh weight	mg	28 Jun.	430	310	*
Shoot fresh weight	mg	28 Jun.	346.9	300.3	*
Panicle length	mm	28 Jun.	1210	1120	NS
Dry weight of shoot regrowth	g	15 Jul.	10.9	8.0	NS
Weight of 100 seeds	mg	16 Jul.	38.6	33.3	*
Number of seeds per panicle	-	16 Jul.	579	460	NS
Number of seeds per plant	-	16 Jul.	76,634	74,182	NS
Seed viability	%	11 Aug.	72.0 (1.03)	74.5 (1.06)	(NS)

Figures in brackets are transformed (arc sin/)

APPENDIX 7

A. Composition of L.K. Horticultural Compound Fertilizer,
John Innes Base

	%
Nitrogen	5.1
Phosphoric acid, soluble in water	7.2
Phosphoric acid, insoluble in water	1.0
Potash	10.0

B. Composition of Vitafeed 101

	%
Nitrogen	26.0
Potash	26.0
	p.p.m.
Manganese	255.0
Iron	502.4
Zinc	357.1
Copper	255.0
Boron	131.2
Molybdenum	3.45
Magnesium	900.0

C. Fertilizer and other compounds mixed into soil

	mg/kg soil
John Innes Fertilizer	764
Magnesium sulphate	127
DDT (5% powder)	64
Finely divided trace elements	25

APPENDIX 8

Calculation of equivalent stocking
rates of treading treatments

Plots 3m wide to allow room for cattle

$$3\text{m} \times 3333\text{m} = 10000\text{m}^2 = 1 \text{ ha}$$

As 1 cow walks about 2400m/dy (Hancock, 1953)

1 cow passage over the plot $\frac{3333}{2400}$ stocking rate of $\frac{3333}{2400} = 1.4$ cow/ha/dy

Assuming a 28 day paddock system, then, a stocking rate of 1.4 cow/ha/dy will be achieved by:

28 cow passages once every 4 wk.

Actual levels planned:

LOW TREADING

8 passages of 7 cattle every 4 wk i.e. 2.8 cow/ha/dy

HIGH TREADING

24 passages of 7 cattle every 4 wk i.e. 8.4 cow/ha/dy

In practice the intervals between treadings were about 3 months instead of one month due mainly to the poor grass growth during the drought. So, the actual equivalent stocking rates were nearer 1.0 and 2.8 cow/ha/dy for low and high treading respectively.

APPENDIX 9

Details of herbicides used

HERBICIDE	PRODUCT	MAKER	% ACTIVE INGREDIENT (OR ACID EQUIVALENT) OF PRODUCT	RECOMMENDED VOLUME RATE (l/ha.)	HOW IT ACTS
Asulam	Asulox	May & Baker	400g. a.i./l.	≥ 220	Translocated
Dalapon	Dalapon	Boots	72% w/w a.e.	≥ 220	Translocated
Lenacil	Venzar	Bayer	80% w/w a.i.	225-1125	Soil acting
Linuron	Afalon	Hoechst	200g. a.i./l.	300-500	Translocated & soil acting
Metribuzin	Sencorex	Bayer	70% w/w a.i.	≥ 220	Translocated & soil acting
Paraquat	Gramoxone	Plant Protection	200g. a.i./l.	220-550	Contact
Propyzamide granules	Kerb 50W Granules	Rohm & Haas	4% w/w a.i.	-	Soil acting
Propyzamide liquid	Kerb 50W liquid	Rohm & Haas	50% w/w a.i.	220-1100	Soil acting

Abbreviations: a.e. acid equivalent l. litre
a.i. active ingredient % percent
g. gramme w/w weight per weight
ha. hectare

APPENDIX 10

Chemical names of herbicides used

HERBICIDE	CHEMICAL NAME
Asulam	Methyl(4-aminobenzenesulphonyl)carbamate
Dalapon	Sodium 2,2-dichloropropionate
Lenacil	3-cyclohexyl-6,7-dihydro-1H-cyclopentapyrimidine-2,4-(3H,5H)dione
Linuron	N'-(3,4-dichlorophenyl)-N-methoxy-N-methylurea
Metribuzin	4-amino-6-t-butyl-3-methylthio-1,2,4-triazin-5-one
Paraquat	1,1'-dimethyl-4,4'-bipyridylium-dichloride
Propyzamide	N-(1,1-dimethylpropynyl)-3,5-dichlorobenzamide

APPENDIX 11

A. Equation used to calculate the amount of product needed per 100 ml. distilled water:

$$\begin{array}{l} \text{number of g.} \\ \text{or ml. of product} \\ \text{per 100 ml. water} \end{array} = \frac{\text{dose required} \times 0.296 \times 100}{\% \text{ a.i. of product}}$$

where 1. dose is in kg. a.i./ha.

2. 0.296 is the conversion factor for the nozzle

3. a.i. = active ingredient

B. Nozzle, pressure and volume rate:

The nozzle on the laboratory sprayer was a Spraying Systems 'Teejet' 80015E No. 3. It operated at a pressure of 2.11 kg/cm² and moved at a constant speed over the stationary pots. The volume rate was 339.64 l./ha.

C. Visual assessment

Each week, for nine weeks after spraying, the vigour of both species was expressed on a 0-7 subjective scoring scale.

The scale points were defined as:

0 = completely dead

1 = moribund but not all tissue dead

2 = alive, with some green tissue, but unlikely to make much further growth

3 = very stunted, but apparently still making some growth

4 = considerable inhibition of growth

5 = readily distinguishable inhibition of growth

6 = some detectable adverse effect as compared with control - colour difference, morphological abnormality, epinasty or very slight reduction in growth.

7 = indistinguishable from control

(from Blair, 1973)

APPENDIX 1 2

Scores and percentage dry weights of green
H. lanatus and L. perenne in herbicide experiment

SPRAY DATE	SCORE	% DRY WEIGHT WHICH IS GREEN	
		<u>H. lanatus</u>	<u>L. perenne</u>
4 May	6	54.2	-
	7	-	84.1
	8	69.7	78.0
	9	78.9	80.7
25 May	6	50.3	79.0
	7	73.0	72.2
	8	75.6	83.0
	9	72.2	86.2
15 June	6	-	57.5
	7	74.1	81.0
	8	88.5	88.6
	9	87.4	92.6

There was sometimes poor agreement between the score and the percentage of the dry weight which was green material (especially in the case of L. perenne). This is probably because the grass was scored on its external appearance and so a few extra brown leaf sheaths, which weigh very little, will have a disproportionate effect on the score. But, when they are removed, they reveal a green culm underneath.