THE EFFECT OF CUTTING TREATMENTS
ON THE DRY MATTER PRODUCTION OF
LOLIUM PERENNE L.
AND
DACTYLIS GLOMERATA L.

CON UN RESUMEN

EFECTO DE TRATAMIENTOS DE CORTE
SOBRE EL CRECIMIENTO DE
LOLIUM PERENNE L. Y *DACTYLIS GLOMERATA* L.

M. DEL POZO IBÁÑEZ

Institute for Biological and Chemical Research on Field Crops and Herbage
Wageningen, The Netherlands

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1   INTRODUCTION

Most agricultural crops grow undisturbed for a certain period. Either they are harvested at the end of their life (*e.g.* small grains) or harvesting terminates their life (*e.g.* sugar beets).

Herbage crops, however, differ from these in two respects. Not only is most of the photosynthesizing tissue removed, but this process is usually repeated several times during the growing season. Moreover, the plants that remain at the end of the season must be in a sufficiently good condition to withstand the winter and to be in as good a state next spring as they were the previous year.

It will therefore be readily appreciated that the method of harvesting not only affects the grass crop obtained at that time, but also the subsequent growth and production at following harvests.

This removal of herbage may result in more or less complete defoliation. A greater amount of herbage will be harvested from hard defoliated grasses, but at the same time these plants will be left with a very small portion of assimilating material. Compared with a less severe treatment, lower production can be expected during a subsequent growth period.

In other words, the height of defoliation has a negative influence on total amount of herbage removed, but a positive influence on subsequent herbage production. Since these effects are contrary, it would be interesting to know their relative importance and fluctuations so as to be able to determine what height of stubble left after harvesting will yield the maximum amount of herbage for an extended period.

Since the growing season is of limited duration, an increase in the number of harvests will mean a shorter growth period between subsequent cuts.

Thus the total seasonal yield depends on two factors: the number of harvests and the herbage production at each harvest, which have an opposite effect on each other.

In studying the effects of harvesting on herbage production both the height and frequency of harvesting have to be taken in consideration and a winter season should preferably be included.

Before describing the procedure employed in the present experiments, it would seem advisable to make a brief comparison of the two different ways of harvesting in practice, *viz.* mowing and grazing. Mowing is the practice of cutting a grass with the aid of a certain instrument or machine; this can be directly related to our cutting experiments.

In grazing a new element is introduced, the animal. McMEEKAN pointed out (75) that efficiency of conversion of pasture to animal products depends on three basic factors:

a. The amount, quality and seasonality of the pasture crop;

b. The proportion of this crop actually harvested by the animal;

c. The efficiency of conversion within the animal of the fodder consumed.

Of all these three points only the first two are related to the grass output dealt with in the present work.

Following VOISIN's definition (110) grazing is the "meeting of the animal and the pasture". The grazing system is therefore the way in which these meetings are arranged.

There are three main grazing systems: continuous, rotational and strip-grazing. All these different systems consist of a number of grazing periods of a certain length intercalated in other regrowth or resting periods. They can therefore be defined by the values of the following variables:

1. instantaneous stocking rate;
2. length of the grazing periods;
3. length of the resting periods.

| Grazing system | Inst.stock.rate | Length of the | |
		Grazing period	Resting period
Continuous	light	the season	0
Rotational	heavy	1–7 days	15–45 days
Strip	very heavy	$\frac{1}{2}$–1 days	15–45 days

Instantaneous stocking rate is the number of animals grazing per unit of surface at any given time. The result of multiplying this instantaneous stocking rate by the length of the grazing period has been termed the grazing intensity (110).

This grazing intensity determines the height of the stubble left when animals are moved to another paddock. For this reason results obtained by cutting can also be referred to grazing practices. But plant defoliation is not the only effect produced by grazing animals. There are additional losses due to fouling by excreta, trampling and poaching, particularly in wet weather. However, there seems to be a close correlation between production under clipping and grazing, as was found by BRYANT and BLASER (30) who compared yields and stands of orchardgrass under clipping and grazing with different defoliation intensities. Higher yields were obtained under clipping than under grazing.

It seems therefore, that on the whole the reaction of the grass plant to grazing seems comparable to the effect of cutting.

In view of all this the purpose of the following series of experiments was to compare the effects of different heights and frequencies of defoliation both under indoor and field conditions. The indoor experiments make it possible to vary several internal and external factors, and the field experiments were performed to compare results with those obtained under controlled conditions and to do some preliminary work on the effect of the winter season.

2 REVIEW OF THE LITERATURE

2.1 DEFOLIATION AND GRASS PRODUCTION

A classification of herbage species was made by KLAPP (62, 63) who gave a list of 14 species from the least to the most resistant to clipping. *Dactylis glomerata* and *Lolium perenne* were placed seventh and thirteenth respectively in this list. KLAPP suggested that this resistance to defoliation is related to the botanical characteristics and growth habit of the species.

It has been repeatedly found (4, 37, 78, 80) that cutting reduces the rate of tillering and dry matter production in comparison with undefoliated plants. These experiments were usually carried out with single plants and for short periods of time. Most probably the plants in these experiments never suffered from a lack of nutrients and water or from mutual shading, unlike the sward conditions and long periods (50, 61) in which the uncut plants failed to produce the maximum amount of herbage.

But if repeated cutting is necessary in practical farming for good grass production the problem is, how intense and frequent should such cutting treatments be.

When regrowth was studied after a single defoliation the greatest production was found in plants cut highest (BURKE and WOOD, 32; HARRISON and HODGSON, 48; MITCHELL and COLES, 81).

BAKER (14), working on *Lolium perenne*, found that the reduction in herbage weight in the field caused by a single defoliation tended to disappear after a time, but that the difference increased when plants were cut several times.

JOHNSON and DEXTER (56) found that in quack grass 6 inches was the optimal cutting height in a repeated cutting experiment (heights ranging from ground level to 8 inches), but that after the first cut a height of 3 inches was the best.

Thus the effect of a certain clipping height is altered by repeating the process. Moreover, when a certain range of intensities is studied, the optimal cutting height depends on the length of the experimental period.

Some field experiments with single plants cut repeatedly indicate the preference of a lenient treatment (CRIDER, 37; STAPLEDON and MILTON, 103).

When experiments were carried out under sward conditions and the treatments repeated for a certain time the most diverse and contradictory conclusions were obtained.

Increases in herbage production were found with increases in cutting height by AHLGREN (1), GRABER and REAM (45), JACQUES and EDMOND (54), JÄNTTI and HEINONEN (55), JUSKA and HANSON (58) and WRIGHT (130). BROUGHAM related the pasture growth to the leaf area index (leaf area per unit area of ground) and in a 9-week regrowth period found an increasing rate of herbage production (21) which became

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constant some 3–4 weeks after the initial cutting. This period of constant rate of production seems to coincide with total light interception. When the grass was cut to 1, 3 and 5 inches (22), both the complete light interception and the maximal and constant herbage production rate were reached respectively 24, 16 and 4 days after cutting. In a more extensive research it was postulated (24) that erect growing plants have a higher optimal height of defoliation than prostrate ones, so that the latter are able to tolerate a more severe clipping treatment. This was also dependent on the time of the year in which the cutting treatments were carried out (25).

In an experiment on repeated cutting HIROSE and coworkers concluded (50) that 3–4 mowings per year was the best treatment, the optimal cutting height for cocksfoot being 9–12 cm and for perennial ryegrass 6–9 cm. HUOKUNA (52), working with cocksfoot, obtained inconsistent results which may be explained by considering the frequency of cutting in each case. He suggested that for each species there is a definite minimum height of stubble which can be left after cutting without any damage to the plants; the best average cutting height seems to be the 4–5 cm.

BURGER et al. (31) and BRYANT and BLASER (30) found a decrease in yield when the cutting height was raised.

In all these experiments it should be noted that the intervals or range of intervals used between cuts were different (52).

A diversity in results was also found when studying the effect of cutting frequency (length of the interval). TYLER and ELLIS DAVIES (109) obtained more forage production from three cuts a year than from two cuts with lucerne and lucerne/grass mixtures. In some cases a certain frequency of cutting intermediate in the range used was found to be more efficient (HIROSE and co-workers, 50; KENNEDY and RUSSELL, 61).

However, on this question the majority of authors report that the longer the regrowth interval the higher is the production obtained (CARTER and LAW, 33; CHAMBLEE et al., 34; GERNERT, 43; GRABER et al., 44; HIEPKO, 49; JAQUES and EDMOND, 54; PARSONS and DAVIS, 84; PETERSON and HAGAN, 87).

It should be realised that most experiments were clipping experiments. It can hardly be assumed that grazing after such very long intervals would give the best cattle productions since under such conditions losses from trampling, etc., would increase to high values. Moreover, it is a well-known fact that the quality of grass decreases with the stage of growth, owing to the lower protein content (ARMSTRONG, 13) and lower digestibility of the organic matter (MINSON et al., 77).

It is therefore postulated that all these disparate results are primarily due to the fact that every research worker used his own species or mixture. This creates differences in rate and habit of growth which are further complicated by the unequal adaptation of the different cultivars to the environment.

Secondly, both climatic and soil conditions were very diverse. Moreover, fertilizer treatment might have a considerable influence on the results. Some research workers even state that the results reported were only found under certain fertilizer treatments (116) or in certain years when the experiment was carried out (37, 61, 87, 103). In

other words, the results were influenced by all variables conditioning the rate of growth of a plant.

In order to compare the results of the different workers in this field the specific experimental conditions should be known.

With a view to improving results some of our experiments on differential cutting treatments were carried out under constant conditions.

2.2   THE PLANT RESERVES

The assimilated material formed by the plant can be used for respiration, building new material, or accumulated somewhere in the plant, usually in the form of polysaccharides. Such a high local concentration of carbohydrates is usually designated as plant reserves, although some criticism has been levelled at this term (MAY, 73) in that it "connotes provision for the future and signifies teleological thinking".

Reserves in grasses are sugars, fructosan and starch. It has been suggested (DE CUGNAC, 38) that fructosan-containing grasses are mostly from temperate, cool regions. It has been found that a higher proportion of these substances is accumulated in the lower parts of the stems (ALBERDA, 4 and 8; BAKER, 15; SPRAGUE and SULLIVAN, 96 and 97).

Much research has been devoted to the study of the seasonal changes in carbohydrate content in different grasses (ALBERDA, 2 and 5; HIEPKO, 49; WAITE and BOYD, 111 and 113; WEINMANN, 117). Although there are some differences between the results obtained by all these authors, possibly owing to differences in environment and species, it can be stated as a general rule that the total of available carbohydrates decreases in both concentration and amount during the period of intensive growth, more particularly during the spring, and increases during maturation, thus indicating their function as "reserve substances" (WEINMANN, 121). MAY (73) also concludes that carbohydrate content is inversely related to herbage growth.

But ALBERDA (5) concludes that "the influence of reproductive development on the carbohydrate reserves is of little importance compared with the influence of defoliation either by cutting or by grazing". The author arrives at this conclusion (3 and 5) after experiments in which cutting was performed at different stages of inflorescence development. He distinguished two kinds of carbohydrate fluctuations, viz. a long-term one due to seasonal variation, and a short-term one due to cutting or grazing.

Cutting is always reported (ALBERDA, 4 and 8; SULLIVAN and SPRAGUE, 96 and 98; WAITE and BOYD, 112) as the cause of an immediate and considerable drop of the reserves. However, after being cut the plant is able to accumulate new reserves and recover the initial level provided suitable growing conditions are allowed.

It has been generally reported that the temperature is inversely related to carbohydrate content (ALBERDA, 4; KENDALL, 60). Nitrogen fertilization also decreases the carbohydrates accumulated (ALBERDA, 8; SPRAGUE and SULLIVAN, 98).

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Repeated cutting, especially at a low height and a high frequency of defoliation, decreases the reserve level (GRABER *et al.*, 44; WEINMANN, 116).

When we consider the reserves from the viewpoint of all this previous research, it can be seen that these carbohydrates are influenced by development, growth and environmental conditions, but that cutting and fertilizing can change their level more than any natural variation.

2.3 THE RESERVE LEVEL AS AN IMPORTANT FACTOR FOR REGROWTH

Hitherto we have considered the reserves as the result of a series of possible variables. But this does not mean that these reserves are necessarily of importance to the plant, especially under adverse circumstances. Two main questions arise, *viz.*:

a. When and how efficiently can these reserves be used?
b. What does the reserve level of a plant mean in relation to further growth under more or less adverse conditions?

This is particularly important when considering the regrowth of grasses after cutting or grazing. GRABER *et al.* (44), in work on alfalfa and three grass species, stated that "new top growth, especially in the early stages, are initiated and developed largely at the expense of previously accumulated organic reserves, that their quantity and availability sharply limit the amount of both top and root growth that will occur, and that progressive exhaustion of such reserves by early, frequent and complete removal of top growth results ultimately in the death of the plant regardless of the most favourable climatic and soil environment". More recently this theory has been supported by other authors (WEINMANN) who attach great importance to the reserves.

This has lately been subjected to much criticism by MAY (73) and MAY and DAVIDSON (74), who assumed that the regrowth of a sward is usually a function of the green tissue left in the field. MAY (73) concludes "that a percentage decrease in non-structural carbohydrate can be largely accounted for by its use as respiratory substrate and that the remainder would be available for translocation and synthesis at new growing points".

Further research (WARD and BLASER, 114) on cocksfoot showed that carbohydrate reserves were used for respiration and/or synthesis of new tissue. Plants placed in the dark after defoliation gave new growth at the expense of carbohydrate reserves in the stubble. The level of reserves influenced the regrowth of plants during the first 25 days. The leaf area after clipping showed its influence on subsequent plant growth during the whole experimental period.

Also A. G. DAVIES (40) was able to demonstrate that the level of carbohydrates in the stubble has a definite influence on the dry matter production after cutting.

Finally, comparative experiments (12) showed that the reserve carbohydrates have

an effect on the initial rate of growth of cocksfoot, but that the initial amount of leaf plays a more important part in the regrowth of ryegrass.

More information should be obtained on the influence of environment and clipping treatments on the accumulation of reserves and on the part played by these substances in the regrowth of grasses and subsequently in grassland production and management.

3   SCOPE OF THE EXPERIMENTS

Two kinds of experiments were carried out, *viz.* field experiments and indoor experiments under controlled conditions.

A two-year field experiment was planned as the basis for the indoor experiments. It was intended to study the effect of height of cutting and interval between cuts on the growth of grasses. Rows of perennial ryegrass and cocksfoot sown in the spring of 1961, were submitted to three different cutting heights and these defoliations were repeated at three different intervals between cuts, both in 1961 (July and August) and in 1962 (May, June and July).

During the first year differences occurred in the rapidity of establishment after sowing and during the second earliness of the cultivars had an effect on the herbage harvested at the first cut as well as on subsequent grass production. The importance of the date of the first cut was then realised in comparing the 1961 and 1962 results. Moreover, the plant material had been vernalized in the second year of this experiment, whereas in the first year both grasses were fully vegetative.

A new experiment was therefore planned in order to study the effect of repeated cutting treatments, started at different dates, on vernalized and unvernalized material of both perennial ryegrass and cocksfoot.

To make a more detailed study of the background of grass responses to cutting a more accurate technique was required than that of the field experiments. Further research was therefore carried out under constant environmental conditions.

Of the different climatic conditions of importance in grass growth, only temperature was studied. With one exception all experiments were performed at four temperatures ranging from 15° to 30°C.

Several kinds of experiments were carried out under these controlled conditions. In order to ascertain the effect of the cutting height on growth, an experiment was performed in which the regrowth of plants of both species, initially cut to different heights, was studied.

When the plant is cut, most of the assimilating tissue is removed. The quicker new leaves are formed the faster dry matter production will be resumed. To study whether the distribution of newly formed dry matter was changed after cutting an experiment was carried out in which this distribution between plant parts was determined in undisturbed growing plants in comparison to plants cut to two different heights. This was the only indoor experiment carried out at a single constant temperature.

To examine whether the reserve status of the plant after cutting had any effect on subsequent dry matter production different reserve levels were created in a short time so as not to change the leaf area left after cutting. Dry matter production and reserve level were followed at different temperatures.

Finally, an experiment was carried out in order to obtain some information on the growth of grasses under repeated cutting (fixed height and interval of clipping). It was performed at four temperatures and the effect of different day and night temperatures was studied at the same time.

Before giving an extensive description of each kind of experiment it is necessary to define some terms used in the following pages and which are often employed in the literature with different and confusing meanings.

The term *growth* (*viz.* growth of the whole plant or parts of the plant) is only used in the sense of a visible increase in size. This usually also means an increase in fresh weight but not necessarily in dry matter.

In all cases where a definite increase of plant organic material is meant, the term *production* (of dry matter) is used.
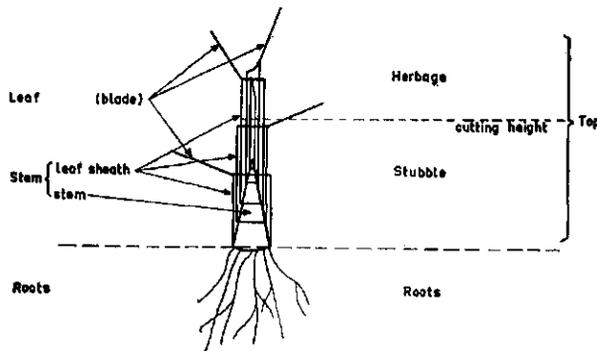

FIG. 1. Schematic division of the plant into different parts.

The usual morphological names of the grassplant are given on the left of Figure 1 and on the right the names of the plant parts used in agricultural experiments and practice.

4 MATERIALS AND METHODS

4.1 FIELD EXPERIMENTS

4.1.1 Influence of height of cutting and interval between cuts on herbage production (Field experiment I).

As stated previously with this experiment we tried to study the effect of different intensities and frequencies of cutting on the growth of *Lolium perenne* and *Dactylis glomerata* in the year of sowing and a year later.

Two plots of the same dimensions (50 × 8 m) were sown on May 3 with *Lolium perenne* (Mommersteeg's Engels raaigras) and *Dactylis glomerata* (Mommersteeg's Kropaar) in rows separated 0.50 m running lengthwise. To obviate border effects, 5 m of each row was omitted from the experiment proper at both ends; for the same reason, the three outer rows on both sides were also unused. The rest was divided into 5 blocks of nine 8 m rows.

During the first part of the experiment proper the cutting treatments were carried out between 28.6.61 and 27.8.61.

Three heights of cutting, *viz.* 2½, 5 and 10 cm above the soil, were used in combination with three different frequencies or periods of regrowth, *viz.* 10, 15 and 20 days.

Two wooden laths of the required height were placed on either side of the row to be cut and pressed together. The tops could then be cut with a scythe and harvested.

Establishment and early growth was much better and uniform in perennial ryegrass than cocksfoot. Actually when cutting treatments started, stands of cocksfoot were rather poor and some bare spaces could be found in the rows. This obliged us to make a slight change in the sampling method in the case of cocksfoot.

The original plan was to sample every 5 days for production rate determination. This was possible with *Lolium perenne*. However, with *Dactylis glomerata* initial growth was so slow and irregular that larger samples had to be taken. This reduced the amount of material left for the 1962 experiments, and so the cutting schedule had to be modified, *i.e.* for treatments 1 and 3 (10- and 20-day intervals), samples were taken every ten days and for treatment 2 (15-day interval), samples were taken on the day of cutting and on the seventh day following.

In sampling, the whole shoot down to the roots was taken. In the case of *Lolium*, each sample consisted of 25 cm of row. In the case of *Dactylis*, each sample was 60 cm long. In both cases 10 cm was left between samples.

Fresh weights were determined after washing and blotting with filter paper. A subsample of 100 tillers was then taken, cut into two portions of the appropriate treatment height and the fresh and dry weight determined of both portions. From these

data it was possible to calculate the dry weight and the number of tillers of the whole sample.

The samples were dried in flat trays in a forced draft oven at 70°C overnight, followed by heating to 105°C for half an hour.

During September 1961, warm temperatures and suitable conditions for grass growth were recorded. At the beginning of October there was an abundant top growth and it was decided to clear up the whole plot by mowing all rows to the medium cutting height used in the experiment (5 cm).

The winter of 1961–1962 could be termed an average Dutch winter (see Fig. 2).
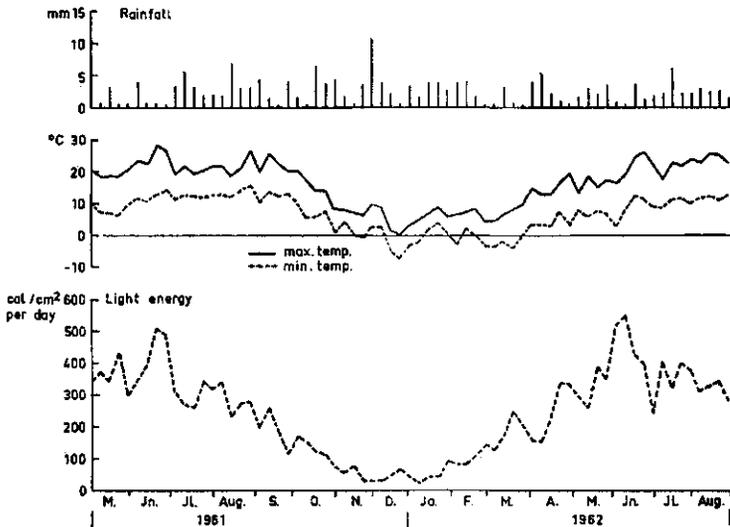
FIG. 2. Climatic conditions during the field experimental period.

In the spring *Dactylis* grew earlier than *Lolium*, so that the situation of the preceding season was reversed. At the beginning of cutting treatments cocksfoot exhibited a better herbage growth than ryegrass, although the rows appeared to be fairly uniform for both species.

Cutting treatments started on 14th May and were completed by 25th June.

The lay-out was then the same as that described above for 1961, only the cutting frequencies being changed. In order to facilitate the work schedule the intervals of 10, 15 and 20 days in 1961 were changed to become one, two and three weeks respectively in 1962. Cutting heights, number and disposition of the treatments, and replications were the same as in the preceding year.

The method of sampling was also slightly modified. 25 cm samples of both species were taken weekly. Laboratory handling was unchanged.

Environment. Both field experiments were carried out on a sandy soil, an analysis of

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which, made in the autumn of 1960 and the autumn of 1961, gave the following data:

	1960	1961
humus %	3.7	3.6
pH-KCl	4.4	4.5
P.Al $\left(\dfrac{1}{1000}\%\right)^*$	15	15
K $\left(\dfrac{1}{1000}\%\right)^{**}$	10.4	8.7
MgO (mg/kg)***	34	50

* Method of acetate lactate
** K soluble in HCl
*** MgO soluble in NaCl

Before sowing in 1961, this field was supplied with 60 kg/ha of N, as ammonium nitrate, 120 kg/ha P_2O_5, as basic slag, and 120 kg/ha K_2O as potassium sulphate. During the treatments 100 kg/ha of ammonium nitrate and 60 kg/ha of potassium nitrate were added, both on 11th July and 9th August, 1961.

In the early spring of 1962, they received the following manurial treatments: 150 kg/ha P_2O_5, as basic slag, and 500 kg/ha as calcium carbonate. During the experiment proper 100 kg/ha ammonium nitrate and 60 kg/ha potassium nitrate were given in addition.

Fig. 2 shows the rainfall, maximum and minimum temperature and light energy at Wageningen during the period of the field experiments (data supplied by the Department of Physics and Meteorology of the Agricultural University, Wageningen).

4.1.2 Effect of date of first cut on production by vernalized and unvernalized plants
      (Field experiment II).

Tillers from field experiment I which had been outside throughout the winter were cleared of dead material and the roots cut to 1–2 cm from the base of the tiller. At the same time seed of the same provenance was sown in the greenhouse on 19th March, 1962.

These vernalized and unvernalized tillers were thus ready for planting in the field on 26th April, 1962, in bunches of 5 tillers, in rows 50 cm apart, the plant spacing being 40 cm.

The cutting scheme consisted in clipping the groups of grasses for four weeks to a height of 5 cm every fortnight. Treatments were planned to start at the time of heading and one week and three weeks later, respectively. With perennial ryegrass this was done on 15.6.'62, 22.6.'62 and 6.7.'62 and with cocksfoot on 8.6.'62, 15.6.'62 and 29.6.'62. Moreover some plants were allowed to grow undisturbed. There were five replications of each treatment. The experiment was completed on 3.8.'62.

All treatments were sampled once a week. Samples consisted of two plants per replication, *i.e.* ten plants per treatment. The samples were handled in the laboratory as described above.

The plot was situated close to the other field experiment, so that the same soil characteristics, manuring treatment and climatic conditions are applicable.

TABLE 1. Field experiments. Conditions

FIELD EXPERIMENT I
(cutting height and interval between cuts)

Seeding date		3.5.'61	
First year (1961)			
first cut		28.6.'61	
end of cutting treatments		27.8.'61	
cutting heights		2½, 5 and 10 cm	
intervals between cuts		10, 15 and 20 days	
Second year (1962)			
first cut		14.5.'62	
end of cutting treatments		25.6.'62	
cutting heights		2½, 5 and 10 cm	
intervals between cuts		1, 2 and 3 weeks	

FIELD EXPERIMENT II
(vernalization and date of first cut)

Seeding date of unvernalized material in the glasshouse		19.3.'62	
Date of planting tillers in the field		26.4.'62	
Lolium perenne			
date of first cut	15.6.'62	22.6.'62	6.7.'62
date of last sampling	13.7.'62	20.7.'62	3.8.'62
Dactylis glomerata			
date of first cut	8.6.'62	15.6.'62	29.6.'62
date of last sampling	6.7.'62	13.7.'62	27.7.'62

4.2 INDOOR EXPERIMENTS

4.2.1 *Growing conditions*

The indoor experiments reported here were carried out in the Phytotron of the Institute for Biological and Chemical Research on Field Crops and Herbage, Wageningen. A complete description of this unit has been given by ALBERDA (6).

The experiments proper were performed in growth rooms with artificial light; previously the plants were grown in a greenhouse at 20°C $\pm$ 2°C, using normal daylight with additional illumination with 400 watt, high-pressure mercury vapour lamps during winter months.

The growth rooms are also provided with 400 watt high-pressure mercury vapour lamps (Philips HPL) giving a light intensity of 5×10^4 ergs cm^{-2}sec^{-1} at the height of the pots in which the plants were cultivated (about 40 cm below the lamps). The temperature in the rooms can be held at the selected value $\pm$ 0.3°C.

Tillers of a tetraploid clone of perennial ryegrass were planted in bunches of 7 tillers

each in four holes of a hardboard disc placed on top of a 1-litre glass jar, which had an outer coat of aluminium paint. Clonal material was also used for *Dactylis glomerata* and planted in bunches of 4 tillers per hole.

The entire roots of the tillers were cut off; they were first cultivated in tap water until some new roots were formed and then transferred to a Hoagland solution of half strength of the following composition:

KNO_3	126.4	mg/l
$MgSO_4 . 7H_2O$	123.2	,,
$Ca(NO_3)_2 . 4H_2O$	295.2	,,
KH_2PO_4	34.0	,,
H_3BO_3	2.86	,,
$MnCl_2 . 4H_2O$	1.81	,,
$ZnSO_4 . 7H_2O$	0.22	,,
$CuSO_4 . 5H_2O$	0.08	,,
$H_2MoO_4 . H_2O$	0.09	,,

Furthermore, 1 ml per litre of a solution of iron EDTA chelate was added whenever the nutrient solution was renewed.

The plants were kept in the greenhouse until they grew vigorously, and then used for the experiment.

During the pretreatment the nutrient solution was changed twice a week, and during the experiment proper three times a week. To avoid differences in light intensities, wind velocity, etc., the trolleys on which the plants were placed were shifted daily to another position in the growth room and the plants were given another position on the trolley whenever the solution was renewed. In this way a position effect on the growth rooms was avoided.

The time and duration of each indoor experiment is given in table 2.

TABLE 2. Indoor experiments. Conditions

Experiment	Date of beginning	Duration (days)	Number of	
			cuts	sampling dates
Gl	22. 1.'62	31	1	5
Gd	24.11.'61	32	1	5
Rl	30. 3.'62	25	1	5
Rd	6. 8.'62	25	1	5
Dl	24. 1.'63	32	0-1	5
Dd	17. 4.'63	40	0-1	4-5
Ml	26. 9.'62	126	7	7

4.2.2 Effect of cutting height and temperature on regrowth (exp. Gl and Gd).
The aim of these two experiments was to follow the growth of *Lolium perenne* and *Dactylis glomerata* grown at different temperatures and cut initially to different heights.

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The temperatures used were 30, 25, 20 and 15°C. The cutting heights were 10, 5 and 2½ cm.

After the plants had been clipped to the required height several samples were taken during the experimental period, in order to obtain information on the final status and to follow the dry matter production and chemical composition.

Each sample consisted of five pots. The plants were cut at the height to which they had been clipped at the beginning of treatments, and the fresh and dry weight of roots, stubble and herbage were then determined.

4.2.3 *Effect of reserve level and temperature on regrowth* (exp. Rl and Rd).

The aim was to study the regrowth curves of grasses cut to the same height but having different levels of total soluble carbohydrates.

In order to obtain a low reserve level, plants were placed in the dark at 30°C for three days with aeration of the nutrient solution. For a high reserve level, plants were placed in continuous light at 10°C for three days without aeration.

This enabled us to produce plants with the following reserve levels in the stubble:

Reserve level	TSC in stubble as per cent of dry matter	
	Lolium perenne	*Dactylis glomerata*
low (L)	7.8	12.3
high (H)	23.4	25.7

Although there were some fairly considerable differences between the two reserve levels, the levels reached were far from extreme. With *Lolium perenne* the reserve level may occasionally rise to values around 40 per cent of the dry weight and with *Dactylis* a reserve level of 12 per cent is still fairly high.

After this pretreatment all plants were cut down to 5 cm and the plants of both species were divided into four groups to be placed at 30, 25, 20 and 15°C respectively. Sampling was also repeated several times during the growth period.

4.2.4 *Dry matter distribution in undisturbed and cut plants* (exp. Dl and Dd).

This experiment was designed to study the distribution of the dry matter formed between roots, stems and leaves in both species, together with the influence of cutting on this distribution.

Clones of both *Lolium* and *Dactylis* were cultivated in the usual way in the greenhouse. Afterwards they were placed in a growth room at 20°C.

The material was divided in four groups. Two groups of plants were allowed to grow undisturbed and only the method of harvesting was different; they were sampled for the first time on 29.1.'63 for *Lolium* and on 17.4.'63 for *Dactylis*.

A third group was cut to a height of 2½ cm on 4.2.'63 for *Lolium* and on 29.4.'63 for *Dactylis*. The fourth group was cut to 10 cm on the same dates. From this date onward they were sampled together with groups 1 and 2 as follows:

At each sampling the plant material of five pots per group was used. The roots were cut off and taken as a plant portion. The tops of the first and third groups were cut to a height of $2\frac{1}{2}$ cm and in both portions the leaf blades were cut and designated "leaves". The remaining stem + leaf sheath was termed "stem" (see Fig. 1). The tops of the second and fourth groups were cut to a height of 10 cm. The stems and leaves were separated in the same way.

Portion	Group 1 and 3	Group 2 and 4
1	roots	roots
2	stems below $2\frac{1}{2}$ cm	stems below 10 cm
3	leaves below $2\frac{1}{2}$ cm	leaves below 10 cm
4	stems above $2\frac{1}{2}$ cm	stems above 10 cm
5	leaves above $2\frac{1}{2}$ cm	leaves above 10 cm

The fresh and dry weights of these portions were then determined and the tillers counted. With regard to this material it should be noted that *Lolium perenne* headed and flowered. This is why these results cannot be readily compared to similar results obtained in experiment Gl in which the material was kept completely vegetative.

4.2.5 *Effect of repeated cutting and temperature regime on grass production* (exp. Ml and Md).

The aim was to ascertain the effect of repeated cuts on the growth and tillering of grass subjected to different temperature regimes.

Clonal material from the same origin as the other indoor experiments was planted in Mitscherlich pots filled with fine gravel. Six groups of five tillers of this material were planted per pot in the centre and the five vertices of a regular pentagon. For ten days they were allowed to root in the glasshouse in tap water. Subsequently they were flushed with nutrient solution twice daily. For this purpose six pots were placed on each of eight trolleys and connected to a carboy with nutrient solution. These 25 l carboys were hermetically sealed and connected to the six pots of its trolley by means of a plastic tube with rubber connections. The nutrient solution was pressed upwards into the Mitscherlich pots by means of compressed air. As soon as the solution appeared above the gravel the pressure was released.

Once the plants had reached a good size they were cut for the first time and placed under controlled conditions. They were given daily 17 hours of light (from 4.30 p.m. to 9.30 a.m.) and 7 hours of dark. Four trolleys received a constant night and day temperature of 30°, 25°, 20° and 15°C. The other four received the same temperatures during the light hours but during the hours of darkness they were moved to growth rooms 5°C lower than the light temperature.

When moved to another room the plants received nutrient solution from carboys standing at the new temperature. In this way the roots were subjected almost immediately to the same temperature as the tops. The nutrient solution in the carboys was changed three times a week.

Since the salt concentration of the half-strength Hoagland solution was too low (all the nitrogen was taken up in the period between two flushes) a double strength solution was used from the beginning of the experiment proper.

Plants were cut to the same height every three weeks. The fresh weight of the herbage and the number of tillers was determined in each pot and the dry weight per trolley of six pots.

Since it was impossible to harvest all pots in one day at the end of the experiment, one or two were selected from each trolley (depending on the series of plants) of which the fresh weight of the herbage was nearest to the average.

The plant material remaining after cutting was carefully removed from the pots, washed and freed of dead material. Fresh and dry weight of stubble and roots were determined in the usual way.

The herbage removed at every harvest time as well as the plant parts sampled on 27.2.'63 were milled and stored for further chemical analysis.

4.3 CHEMICAL ANALYSIS

Samples taken from both indoor and outdoor experiments were analysed for their content of soluble carbohydrates. The aim was to ascertain the status of the reserve and accumulation of organic matter which if necessary could be used for a further regrowth.

As early as 1931, DE CUGNAC (38), who examined 38 species of *Gramineae*, divided grasses into two groups, *viz.* those accumulating in their vegetative organs sucrose with or without starch (*Graminées sacharifères*), and those accumulating fructosan, usually together with sucrose, but no starch (*Graminées levulifères*). DE CUGNAC listed *Dactylis glomerata* and *Lolium perenne* in the second group, *i.e.* species accumulating no starch. WAITE and BOYD only found starch in the mature seed (111).

Cellulose, hydrolysable pentosan and lignin failed to show any decrease after defoliation in greenhouse gravel cultures of perennial ryegrass (96).

Monosaccharides were found (86, 96, 111) in small quantities and fluctuations were minimal. Sucrose and fructosan have been designated as the main reserve substances in grasses of temperate regions (86, 96, 111). The variations in these two carbohydrates were found to be the same during the life cycle (111, 113) as after clipping treatments (96, 99, 112) and were possibly greater in the case of the more abundant fructosan than in the case of sucrose.

Since the purpose of this work was rather to ascertain the regrowth ability of the plants in relation to their reserves, the whole fraction — monosaccharides + sucrose + fructosan = water soluble carbohydrates (TSC) — was the only one determined.

After drying, the samples were ground and stored for analysis. TSC was extracted by the DE MAN and DE HEUS method (72) with some modifications introduced by BOSMAN (20). Determinations were made by VAN DER PLANK's method (88).

5   RESULTS OF THE FIELD EXPERIMENTS

5.1   Field experiment I. Effect on grass production of cutting height and interval between cuts

The field experiment reported here was carried out in order to obtain some information on the production of perennial ryegrass and cocksfoot subjected to different combinations of heights and frequencies of clipping.

To facilitate the analysis of results, the data for a certain cutting height is presented as the average of all intervals; vice versa, the data for each interval between cuts is given as the average of all cutting heights. This could be done because no interaction was found between cutting height × cutting interval.

5.1.1   Cutting height

Until the first cut, growing conditions were the same for all treatments. The differences in weight at the first cut are therefore only caused by differences in the cutting height. Differences in treatment begin to appear in the following cuts (table 3).

With *Lolium* the herbage production in the second and following cuts was found to be highest at the medium cutting height (5 cm), whereas with *Dactylis* the highest yield was found as plants were cut to 10 cm. The same was found for total herbage production.

There was a shift in optimal cutting height as the experiment proceeded. Table 4 shows the herbage harvested at every cut for plants defoliated every 15 days (medium interval) to the three heights of cutting. For *Lolium*, the highest amount of herbage was harvested from the 2½ cm cut plants at the first cut, from the 5 cm ones at the

TABLE 4. Dry weight (g) of herbage harvested at the different cuts for plants cut every 15 days

Cutting height	Date of cutting				
	28.6	13.7	28.7	12.8	27.8
Lolium perenne					
2½ cm	83.55	82.00	89.82	51.89	43.83
5 cm	71.56	113.18	90.25	66.77	66.75
10 cm	56.67	82.75	84.16	60.57	68.79
Dactylis glomerata					
2½ cm	29.25	51.03	50.20	36.76	44.23
5 cm	24.04	64.44	59.05	50.15	65.09
10 cm	13.76	48.03	66.45	64.67	79.26

second, third and fourth, and from the 10 cm ones at the last cut. For *Dactylis*, 2½ cm appeared to be the best cutting height at the first cut, 5 cm at the second, and 10 cm at the others. A similar pattern was found in results of the other intervals used.

The sum of the herbage in the second and following cuts and the dry weight increase of the stubble represents the portion of the total dry matter production situated in the tops of the plants, following a certain manner of defoliation. It is termed apparent dry matter production since the roots were not sampled. In both species this apparent dry matter production increased with increasing cutting height.
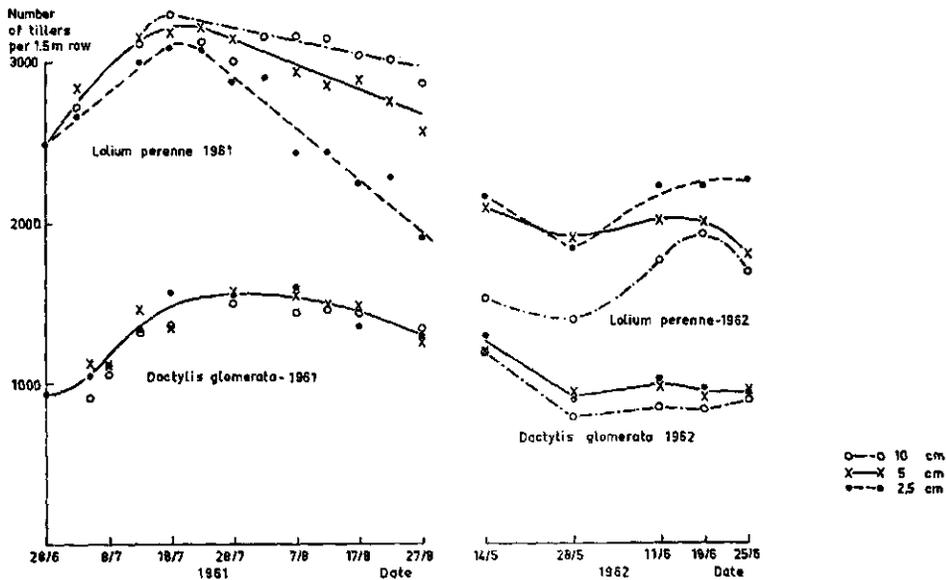
FIG. 3. Tillering of perennial ryegrass and cocksfoot, repeatedly cut to three different heights.

In Fig. 3 the number of tillers per 1.5 m row is plotted against time for all cutting heights. For *Dactylis* no distinct effect of the height of clipping on tillering can be seen. One curve may therefore represent the tillering of the species for the whole period.

For *Lolium* the pattern is quite different. For twenty days following the first cut there was a very rapid increase in the number of tillers at all three cutting heights; only the plants cut to 2½ cm seem to have had a lower rate of tillering. Subsequently this tiller number decreased at different rates, so that on completion of the experiment there was a marked increase in the number of tillers with height of cutting.

The stubble mass increased during the whole experiment as did also the calculated stubble weight per tiller. This increase in the stubble weight per tiller was smaller in shorter cut grass.

In Fig. 4 the percentage of total soluble carbohydrates (TSC) left in the stubble after

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TABLE 3. Dry matter production of *Lolium perenne* and *Dactylis glomerata* under different clipping management during the year of sowing (results are calculated for a 1½ m row)

Treatment[1]	Species[2]	Height of cutting cm	Interval days	Nr. of cuts	Herbage			Stubble			Apparent d.m. prod. g
					first cut g	following cuts g	total g	initial g	final g	increase g	
L.L.	Lp	2½			85.86	293.76	379.62	39.83	62.70	22.87	316.63
L.M.	Lp	5			71.56	336.30	407.86	54.14	111.99	57.85	394.15
L.H.	Lp	10			56.67	308.66	375.33	69.04	207.23	138.19	446.85
D.L.	Dg	2½			29.25	212.64	241.89	22.33	66.68	44.35	256.99
D.M.	Dg	5			24.04	228.25	252.29	27.53	102.41	74.88	303.13
D.H.	Dg	10			13.76	262.37	276.13	37.81	170.10	132.29	394.66
L.1	Lp		10	7	71.36	248.39	319.75	54.34	98.66	44.32	292.71
L.2	Lp		15	5	71.36	299.54	370.90	54.34	121.03	66.69	366.23
L.3	Lp		20	4	71.36	387.47	458.83	54.34	146.45	92.11	479.58
D.1	Dg		10	7	22.35	169.68	192.03	29.22	40.56	11.34	181.02
D.2	Dg		15	5	22.35	241.52	263.87	29.22	113.48	84.26	325.78
D.3	Dg		20	4	22.35	292.06	314.41	29.22	142.28	113.06	405.12

[1] Results are given as a mean of all intervals for the first 6 cases and of all cutting heights in the others.

[2] Lp = *Lolium perenne*; Dg = *Dactylis glomerata*.

defoliation is plotted against time for plants treated with the shortest interval (10 days) at the three cutting heights used.

Initially the TSC content was higher the shorter the stubble left. This is only to be expected, since the reserve level increases in a downward direction. After the first cut this content fell in all treatments. The fall was steeper for the shorter-cut plants; plants clipped more severely needed more reserves to initiate growth. Hence at the second harvest the plants which had been previously cut higher, appeared to have a greater TSC content.
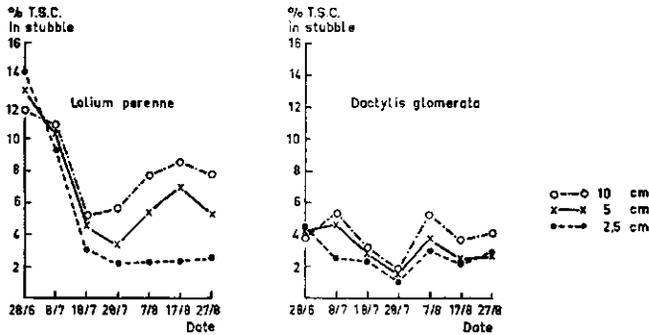

FIG. 4. Soluble carbohydrate content in stubble of plants cut every 10 days to three different heights.

For *Dactylis* the same pattern was found, although variations were always smaller. The TSC content was also lower for cocksfoot than for perennial ryegrass.

The strong fluctuations in TSC content during the experiment were most probably due to changes in climatic conditions since there is evidence that sugar concentrations vary much more smoothly when the plants are repeatedly cut and under constant conditions.

In 1962 no after-effects of the treatment of the previous year could be observed. Only the weight of the first cut increased with decreasing cutting height (Table 5).

This year *Dactylis* grew earlier in the spring and therefore produced much more herbage at the first cut than *Lolium*. This is unlike the first cut in 1961.

In subsequent cuts herbage production was better for both species, in plants defoliated to 5 cm. For *Dactylis* the poorest herbage production was obtained from plants cut to 10 cm. For *Lolium*, as in the preceding year, the poorest was from plants cut lowest.

For *Lolium* (Fig. 3) tillers were more abundant the shorter the plants were cut. The point is that this kind of plant suffered less during the winter (Fig. 7). It could even be stated that the rate of tillering was slightly better for plants cut to 10 cm since it differed less in tiller number from the other two cutting heights towards the end of the experiment.

For *Dactylis* the highest cut rows were less dense from the beginning of the season.

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TABLE 5. Dry matter production of *Lolium perenne* and *Dactylis glomerata* under different clipping management twelve months after sowing. (Results are calculated for a 1½ m row.)

Treatment[1]	Species[2]	Cutting height cm	Interval days	Nr. of cuts	Herbage			Stubble		
					first cut g	following cuts g	total g	initial g	final g	decrease g
L.L.	Lp	2½			73.51	66.81	140.32	73.32	19.46	53.86
L.M.	Lp	5			47.01	101.15	148.16	81.13	34.88	46.25
L.H.	Lp	10			20.63	84.67	105.30	68.42	47.01	21.41
D.L.	Dg	2½			175.12	73.34	248.46	102.48	25.09	77.49
D.M.	Dg	5			111.74	88.44	200.18	118.63	35.28	83.35
D.H.	Dg	10			103.43	70.25	173.68	100.28	63.09	37.19
L.1	Lp		7	7	43.98	75.80	119.78	69.41	26.31	43.10
L.2	Lp		14	4	45.59	84.18	129.77	73.54	31.17	42.37
L.3	Lp		21	3	51.59	92.65	144.24	79.91	43.87	36.04
D.1	Dg		7	7	106.55	64.99	171.54	97.53	25.09	72.44
D.2	Dg		14	4	132.81	78.74	211.55	100.37	35.28	65.09
D.3	Dg		21	3	147.94	88.29	236.23	123.49	63.09	60.40

[1] Results are given as a mean of all intervals in the first six cases and of all cutting heights in the others.
[2] Lp = *Lolium perenne*; Dg = *Dactylis glomerata*.

However, there was no significant difference between the $2\frac{1}{2}$ and 5 cm cutting treatments.

The weight of the stubble decreased in all treatments, and particularly in the first fifteen days.

5.1.2 Frequency of cutting

Table 3 shows that, for both species, the longer regrowth interval resulted in greater herbage production and apparent dry matter production for a 1.5 m row.

For *Dactylis*, cutting frequency had no effect on tillering. But for *Lolium*, tiller
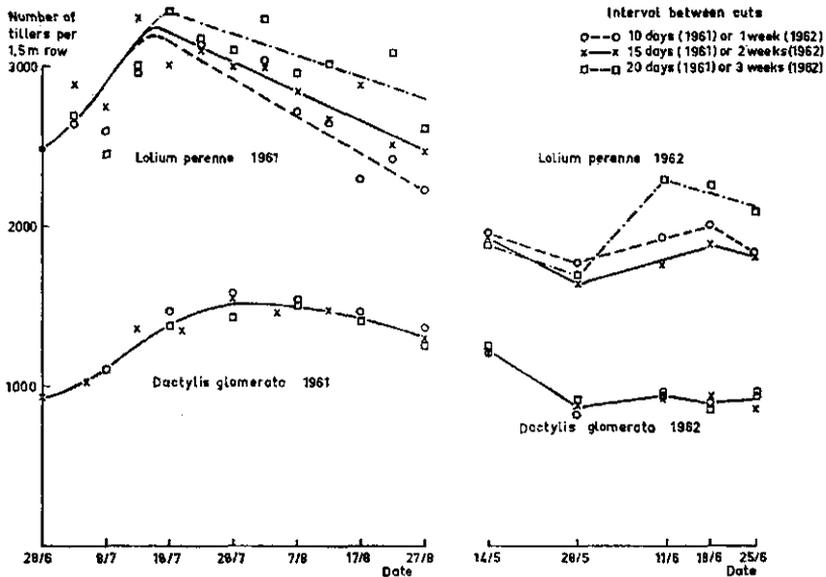
FIG. 5. Tillering of perennial ryegrass and cocksfoot cut with three different frequencies.
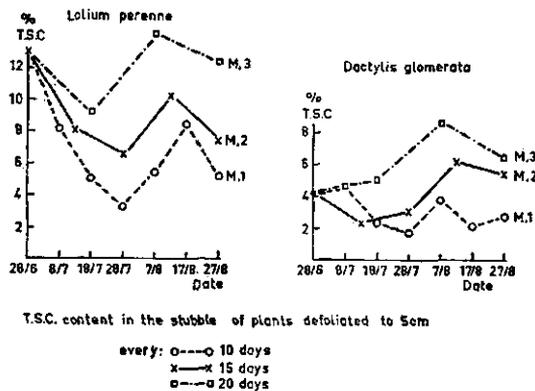
FIG. 6. Soluble carbohydrate content in stubble of plants cut to 5 cm with three different frequencies.

TABLE 6. Stubble weight and tiller numbers before and after the winter period

Treatment	Species	Cutting height cm	Interval days	Stubble weight (g)				No. of tillers	
				per 1.50 m		per 1000 tillers		per 1.50 m	
				end of 1961	beginning of 1962	end of 1961	beginning of 1962	end of 1961	beginning of 1962
L.L.	Lp	2½		62.70	74.39	32.74	34.44	1910	2160
L.M.	Lp	5		111.99	80.91	44.04	38.60	2565	2100
L.H.	Lp	10		207.23	68.04	72.33	44.24	2864	1530
D.L.	Dg	2½		66.68	103.02	44.69	79.92	1355	1288
D.M.	Dg	5		102.41	118.97	69.10	99.14	1490	1210
D.H.	Dg	10		170.10	100.40	116.35	83.60	1425	1185
L.1	Lp		10	98.66	72.41	44.26	35.60	2230	1965
L.2	Lp		15	121.03	76.04	48.96	38.64	2472	1934
L.3	Lp		20	146.45	81.43	55.77	43.04	2610	1890
D.1	Dg		10	40.56	99.08	61.65	80.88	1468	1225
D.2	Dg		15	113.48	100.93	76.73	83.48	1415	1205
D.3	Dg		20	142.28	123.17	101.05	98.30	1410	1230

number increased during the initial 25-day period for all three frequencies. Thereafter it decreased again and the more so for the more frequently defoliated plants (Fig. 5).

As a rule the tillers increased in weight as the experiment proceeded. The increase was greater when the plants were less frequently defoliated.

For the medium clipping intensity the TSC content in the stubble is plotted against time in Fig. 6. In all cases the TSC content was much higher for perennial ryegrass than for cocksfoot; fluctuations due to cutting frequency were also greater for the former species. In both species the less frequently the plants were clipped the higher was the TSC content and the smaller the initial drop.

During winter differences tended to disappear, but not so far as to reach equal stands, since at the beginning of the 1962 season the heavier plants were those cut less frequently in 1961. The first cut in this second year was therefore higher for such plants (Table 5). The same trend was found for the subsequent herbage cuts and consequently for the total also.
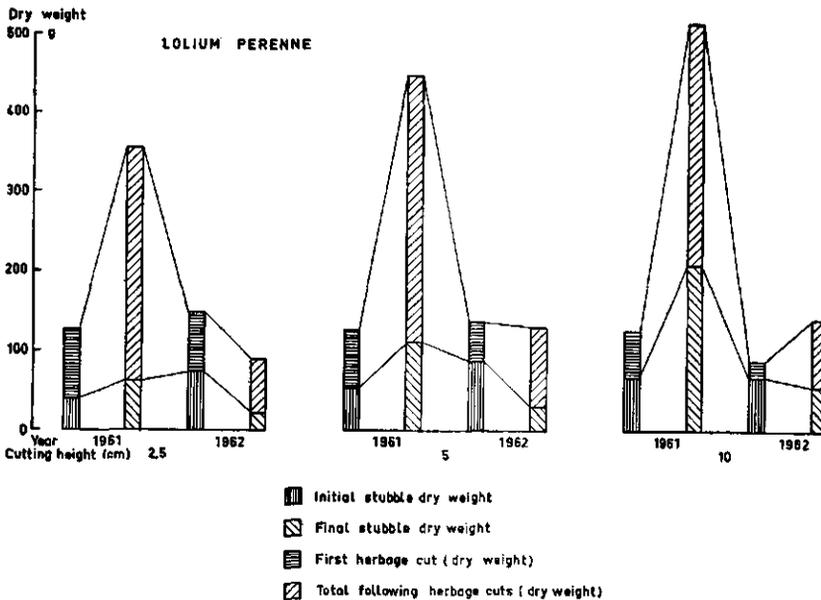

FIG. 7. Initial and final status of rows of perennial ryegrass in the experimental periods of 1961 and 1962. See text.

For *Lolium* (Fig. 5) the highest tiller number was found for the three-week interval, followed by 1 and 2 weeks respectively.

For *Dactylis* no significant differences were found between clipping frequencies, exactly as in 1961.

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From the 1961 final and 1962 initial stubble weights it is possible to study the effects of the winter period upon the grasses treated in different ways (see also Table 6).

Fig. 7 and Fig. 8 show the initial and final stubble weights per 1.5 m row together with the herbage production in both years divided into first cut and following cuts.

For *Lolium* the changes in stubble weight were caused by parallel changes in tiller number and tiller weight. For *Dactylis* matters are somewhat more complex. The increase in stubble weight during the winter in plants cut to 2½ cm and 5 cm resulted
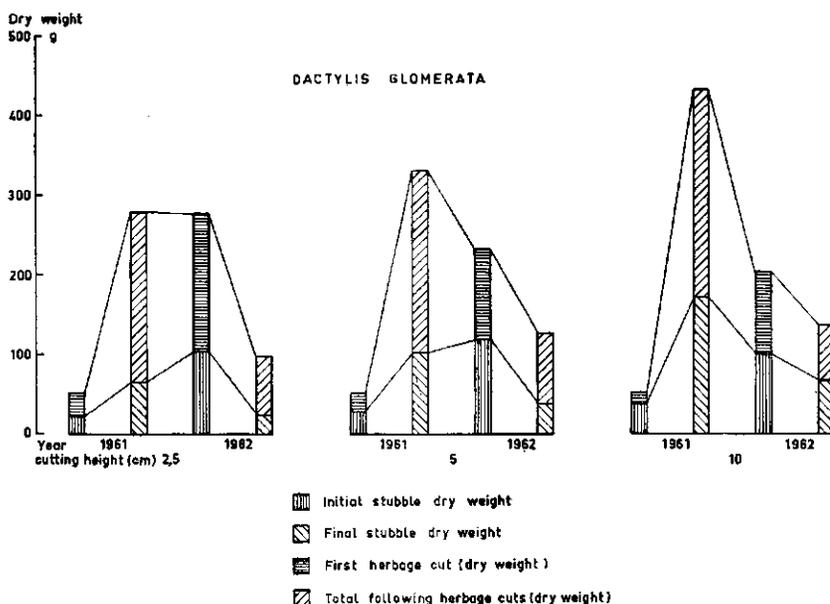

FIG. 8. Initial and final status of rows of cocksfoot in the experimental periods of 1961 and 1962. See text.

from a large increase in tiller weight, since the number of tillers decreased by about the same amount in all cases. For plants cut to 10 cm both the tiller number and tiller weight decreased during winter. Something similar can be seen for the intervals. A 10-day interval showed an increase in stubble weight resulting from an increase in tiller weight and a decrease in tiller number. For the 15-day interval the decrease in tiller number outweighed the increase in weight, so that there was a decrease in the total stubble weight per unit of row. For the 20-day interval both tiller number and tiller weight decreased during the winter.

A general result for both species seems to be the inverse relation between stubble weight at the end of 1961 and that at the beginning of 1962. The denser the stubble

mass (many and/or heavytillers) at the end of 1961 season, the greater were the losses during the winter period.

The result of this was that the great differences at the end of 1961 caused by different treatments disappeared largely during winter.

5.3 FIELD EXPERIMENT II. EFFECT OF DATE OF FIRST CUT ON PRODUCTION BY VERNALIZED AND UNVERNALIZED PLANTS

The aim was to study the effect of cutting on *Lolium perenne* and *Dactylis glomerata* in relation to both vernalized and vegetative plants and to the date on which defoliation treatments began.

For both species, the dry weight of the first cut (Table 7) was always higher for vernalized plants, except for *Lolium* at the latest initial date.

For ryegrass the herbage production at the second and following cuts was always higher for the unvernalized plants and the same was true of the total herbage production. For *Dactylis* no consistent results were obtained. However, it seems that there was a tendency for vernalized plants to produce more herbage in the two earlier cutting treatments.

As expected, the first cut was higher and formed a greater proportion of the total
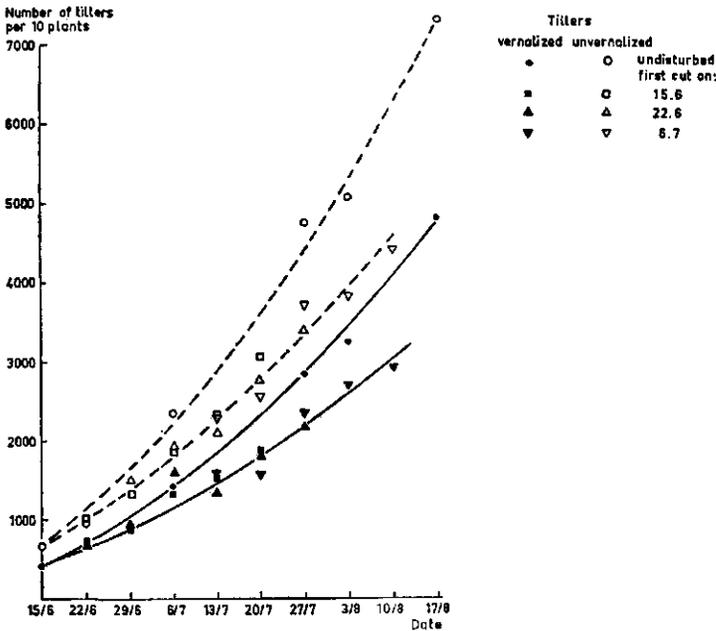

FIG. 9. Tillering in repeatedly cut plants of perennial ryegrass vernalized and unvernalized, in comparison with undisturbed ones. Cutting began on three different dates.

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TABLE 7. Effect of repeated cuts on *Lolium perenne* and *Dactylis glomerata*, vernalized and vegetative. Data calculated for 10 plants

| Treatment | Species[1] | Status | Initial date | 10 plants | | | | | | |
| | | | | herbage | | | stubble | | |
				first cut g	following cuts g	total g	initial g	final g	increase g
L 1a	Lp	vernalized	15.6	14.6	109.7	124.3	18.4	52.7	34.3
L 1b	Lp	,,	22.6	30.6	134.4	165.0	35.3	78.9	43.6
L 1c	Lp	,,	6.7	144.3	271.3	415.6	68.7	96.7	28.0
L 2a	Lp	vegetative	15.6	12.1	123.7	135.8	19.2	126.3	107.1
L 2b	Lp	,,	22.6	22.9	181.8	204.7	32.5	157.1	124.6
L 2c	Lp	,,	6.7	166.9	356.9	523.8	117.1	184.5	67.4
D 1a	Dg	vernalized	8.6	6.2	50.4	56.6	11.3	36.3	25.0
D 1b	Dg	,,	15.6	15.1	81.5	96.6	20.6	73.4	52.8
D 1c	Dg	,,	29.6	74.7	177.2	251.9	77.2	162.6	85.4
D 2a	Dg	vegetative	8.6	1.9	50.8	52.7	6.6	67.1	60.5
D 2b	Dg	,,	15.6	9.3	77.7	87.0	16.2	104.6	88.4
D 2c	Dg	,,	29.6	59.1	207.7	266.8	77.7	210.5	132.8

[1] Lp = *Lolium perenne*; Dg = *Dactylis glomerata*.

herbage production the later it was done. Herbage production at the following cuts also increased when the initial cut was made later. Both facts resulted in a consistent increase in total herbage production in the same direction.

In all cases the stubble increased its weight during the experiment and these increases were much more considerable for unvernalized plants.

In Figure 9 the number of tillers per 10 plants is plotted against time for *Lolium perenne*. Vegetative plants produced more tillers than vernalized ones. Clipping somewhat checked tillering, but with the same relative intensity for both kinds of plants. The date of the first clipping does not seem to have affected tillering.

For *Dactylis*, as found by other research workers (65, 66) and in other experiments reported in this paper, differential clipping treatment did not appear to have any effect on the rate of tiller production. During the first 35 days it would seem that vegetative plants produced more tillers than vernalized ones, but afterwards the results became completely confusing. However, it can be concluded that neither defoliation nor the date of the first cut had a detectable influence on tillering.

Table 8 shows the weight of the different plant parts expressed as g per 1000 tillers. In all cases vernalized tillers had the greatest amount of herbage.

5.3.1 *Effect of vernalization*

The growth of undisturbed vernalized and unvernalized plants is compared in Figs. 10 and 11.
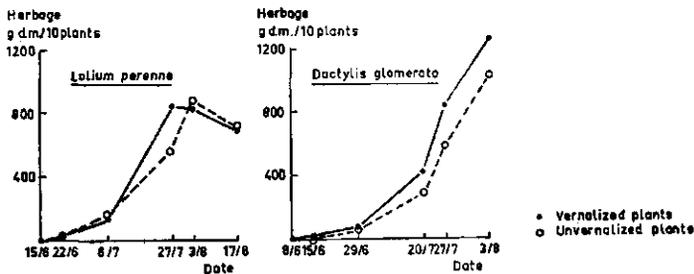
FIG. 10. Herbage production of vernalized and unvernalized plants of perennial ryegrass and cocksfoot growing undisturbed.
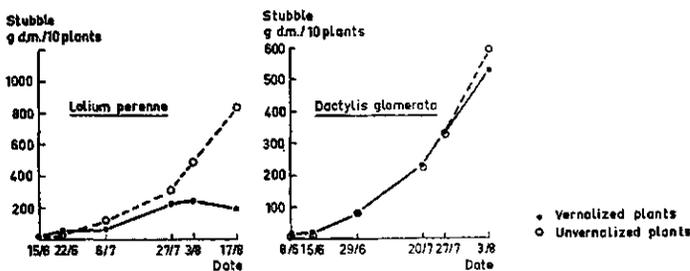

FIG. 11. Stubble dry weight in vernalized and unvernalized plants of perennial ryegrass and cocksfoot growing undisturbed.

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TABLE 8. Effect of repeated cuts on *Lolium perenne* and *Dactylis glomerata*, vernalized and vegetative. Data reduced to 1000 tillers

Treatment	Species[1]	Status	Initial date	1000 tillers				
				herbage		total	stubble	
				first cut	following cuts		initial weight	final weight
				g	g	g	g	g
L 1a	Lp	vernalized	15.6	33.9	92.1	126.0	42.6	28.6
L 1b	Lp	,,	22.6	40.0	98.8	138.8	46.2	33.5
L 1c	Lp	,,	6.7	101.8	134.5	236.3	48.4	38.5
L 2a	Lp	vegetative	15.6	18.5	64.1	82.6	29.3	41.0
L 2b	Lp	,,	22.6	23.9	67.4	91.3	33.9	46.2
L 2c	Lp	,,	6.7	71.2	118.6	189.8	49.9	60.2
D 1a	Dg	vernalised	8.6	53.0	138.7	191.7	96.3	60.6
D 1b	Dg	,,	15.6	65.5	135.7	201.2	89.6	50.5
D 1c	Dg	,,	29.6	172.5	147.1	319.6	178.2	100.0
D 2a	Dg	vegetative	8.6	10.6	68.1	78.7	37.4	68.3
D 2b	Dg	,,	15.6	23.0	91.4	114.4	40.2	74.8
D 2c	Dg	,,	29.6	74.7	140.0	214.7	98.2	123.0

[1] Lp = *Lolium perenne*; Dg = *Dactylis glomerata*.

For *Lolium* the plant weight at the end of the experiment was considerably greater for the vegetative than for the vernalized plants. This difference was caused by a difference in stubble weight, since the herbage production was about the same in both cases. From the end of July onwards there was a slight decrease in both the stubble and herbage dry weight of the vernalized plants, apparently caused by the dying of the flowering tillers and the shedding of the seed. In this period the stubble weight of the unvernalized plants increased almost exponentially, probably due to the formation of new tillers. These tillers hardly reached the cutting level since the herbage weight of the unvernalized plants even decreased at the end of the experiment.

For *Dactylis* the total weight of both vegetative and vernalized plants did not differ much at the end of the experiment. The weight of both stubble and herbage increased almost exponentially, but the herbage of the vernalized plants at a somewhat higher rate than that of the unvernalized ones. At the end of the experiment the reverse was true for the stubble, but the decrease in weight observed in the vernalized *Lolium* plants could not be found in *Dactylis*.

6   RESULTS OF THE INDOOR EXPERIMENTS

6.1   EXPERIMENT G. EFFECT OF CUTTING HEIGHT AND TEMPERATURE ON REGROWTH

In the case of the regrowth of grasses cut to different heights more accurate information was aimed at than that obtained from field experiments. (See methods, experiments Gl and Gd.) Although the phytotron enabled this to be studied under different conditions, the temperature was the only climatic variable studied.
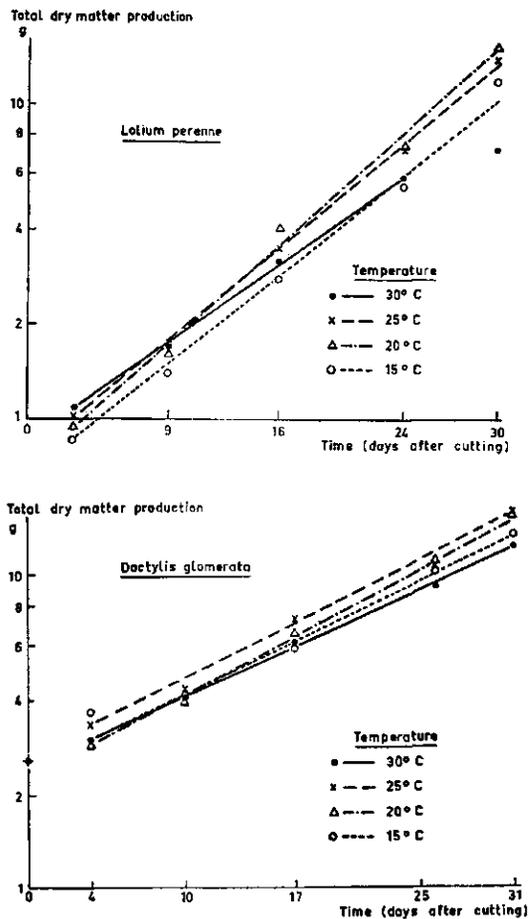

FIG. 12. Total dry matter production of *Lolium* and *Dactylis* growing under four different temperatures after cutting.

6.1.1 Temperature effect

The total plant production of grasses grown under phytotron conditions was found to be exponential (Figs. 12 and 15), at any rate during the period of the experiment which never exceeded 35 days after the initial cut. This exponential production did not start immediately after cutting but a few days later.

For the range of temperatures used the differences in rate of dry matter production were not very great. It is only in the case of perennial ryegrass at 30°C that the rate of growth differed somewhat from the rest. This was mainly due to the last sample. At this time plants were large and the transpiration needs were consequently greater. The water supply was inadequate during the last days and drought became a limiting factor for the normal growth of these plants. If in Fig. 12 we only consider the first four harvests the resulting line will differ much less from the other three.

For both species the optimal temperature was 20°, followed by 25° and then 15° and 30°. The *Dactylis* plants at 25° were always heavier than those at 20° owing to the initial weight, although the rate of dry matter production was somewhat higher at 20°C.

The differences in tillering between the two species were very conspicuous: with the *Lolium* the increase in tiller number was much greater and more or less exponential, whereas with *Dactylis* the number increased slowly and was approximately linear with time.

No distinct effect of the temperature on the rate of tillering of both species could be detected.
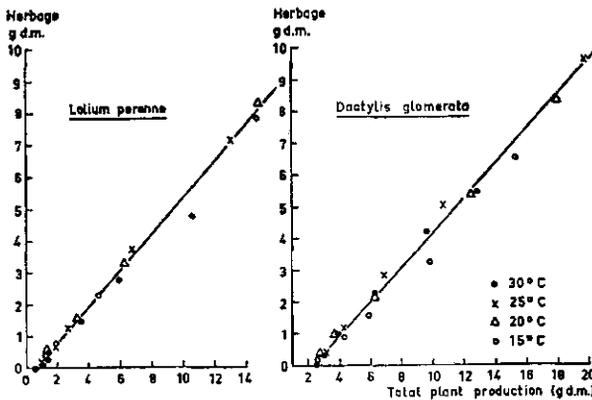
FIG. 13. Herbage/total plant dry matter distribution at four temperatures after cutting to 5 cm.

In Fig. 13 the herbage dry weight is plotted against total plant production. No apparent temperature effect could be detected, the only exception being the *Lolium* plants at 30° of which, as stated earlier, the last samples suffered from drought. It can therefore be concluded that temperature has no effect on the distribution of dry matter among herbage and the rest of the plant.

In Figure 14 the TSC content in stubble is plotted against time for plants cut initially to 5 cm and subjected to the four temperatures used. In all cases cutting was followed by a drop in TSC content. At all temperatures this drop was greater for *Lolium* than for *Dactylis*. Afterwards the TSC content increased with time. Both *Lolium* and *Dactylis* plants started with approximately the same reserves. After the initial drop *Lolium* recovered its reserves more rapidly and towards the end of the experiment it had a higher TSC content than *Dactylis*. The initial drop was also directly related to temperature for both species. Thereafter the temperature effects became less clear.
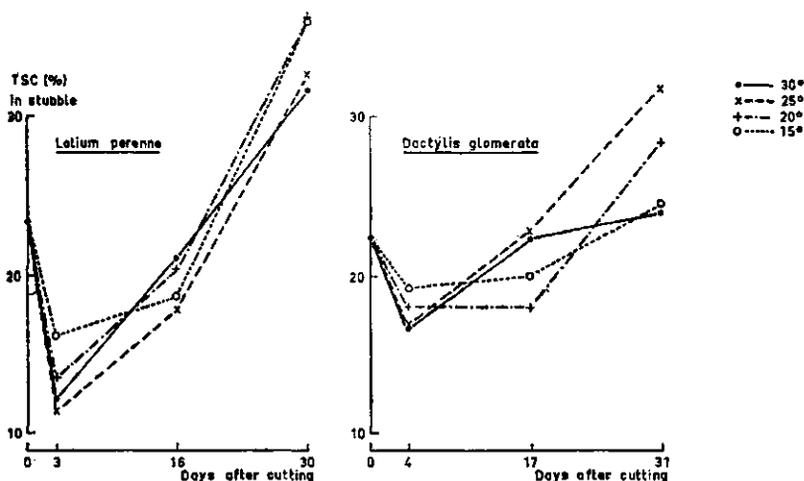

FIG. 14. Soluble carbohydrate content in the stubble of plants growing under four temperatures after cutting to 5 cm.

6.1.2 Cutting height

The relative rate of total plant production was not affected by the stubble height left after defoliation (Fig. 15). These curves were drawn as a mean of all temperatures, as it has already been seen that the effect of temperature on the rate of plant production was not so important for the range of temperatures used and the length of the experiment.

With *Lolium perenne* a clear effect could be observed of the cutting height on the rate of tillering. Fig. 16 shows that after four days the longer-cut plants had the highest number of tillers. It can be concluded that the higher a plant is cut the greater is the number of tillers it produces.

The rate of tillering was retarded immediately after cutting and increased again some days afterwards. There was a kind of time-lag, the length of which seemed to be inversely related to the height of cutting.

The same sort of lag is found in the tillering of *Dactylis* (Fig. 16), but in this case, as in the outdoor experiments, no effect of cutting height could be detected.

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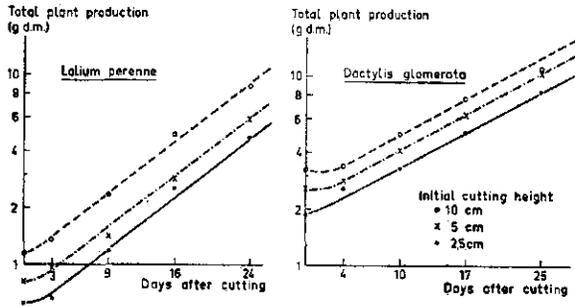
FIG. 15. Total dry matter production of plants cut initially to three different heights.
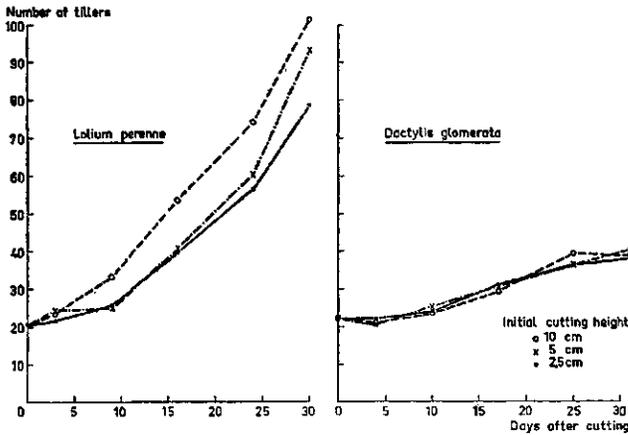
FIG. 16. Tillering in plants of *Lolium* and *Dactylis* cut initially to three different heights.
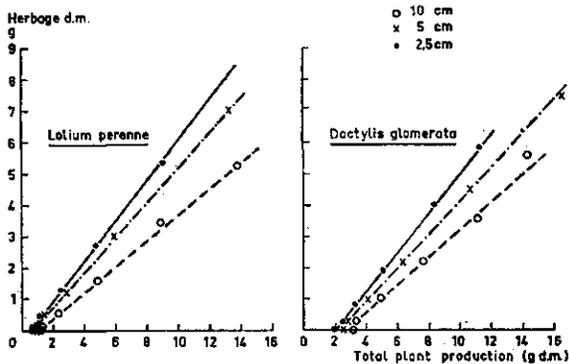
FIG. 17. Dry matter distribution over herbage and total plant after cutting to three different heights.

In Fig. 17 the herbage dry matter is plotted against the respective total dry matter. As we have already concluded that the temperatures used had no effect on the slope of these lines, the data have been averaged for all four temperatures. As was also seen

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above, for every treatment the points are on a straight line. As might be expected, the slope of such lines increases with decreasing cutting height. For a given cutting height the slope of the lines is about the same for both species indicating that the plant, at least under the constant conditions of the experiment, distributes its dry matter increment in a constant ratio above and below the initial cutting height.

For perennial ryegrass, the herbage dry matter of the average tiller was the same for all three cutting heights, so that the number of tillers determined the total herbage production. Inversely for *Dactylis glomerata* the individual tiller is the main source of herbage production variation, since the number of tillers was found to be the same for all heights of cutting (Fig. 16).
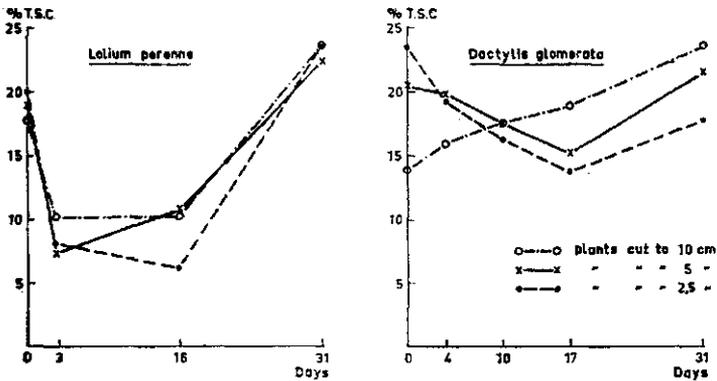

FIG. 18. Soluble carbohydrate content as percentage of the total plant dry matter in plants cut initially to three different heights and placed at 25°C.

In Figure 18, the TSC content as a percentage of the total plant dry weight is plotted against time for plants at 25°. A kind of U-shaped curve was obtained, in which, as might be expected, the initial TSC content was higher for the shorter stubble left after cutting. This shape of curve was far more distinct with *Lolium* than with *Dactylis*. The minimum point on these curves was lower for those belonging to the shorter cut plants. The increase in TSC content after cutting began earlier for the plants cut higher. However, it seems that after a given period there was a tendency for the reserve content to become about the same for all cutting heights, as was the case towards the end of the experiment with *Lolium perenne*.

6.2 EXPERIMENT R. THE RESERVE LEVEL AS AFFECTING REGROWTH AFTER CUTTING

The regrowth of plants cut at different reserve levels was studied. These differences in initial concentrations were created by differential environmental treatments immediately prior to clipping (see methods).

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For a study of the effect of reserves on growth the ideal situation would be to have plants differing only in TSC content. However, such a situation is very difficult if not impossible to obtain, since different external conditions will create differences not only in sugar content but also in such things as plant size, nitrogen content, etc. In this connection it is important to keep the pre-cutting treatment as short as possible. Consequently, the differences in reserve level were occasionally not very large, as for instance the difference between H- and L-plants with *Dactylis*. Nevertheless, in both species a real difference was obtained in the initial reserve level, although it was greater for ryegrass than for cocksfoot.
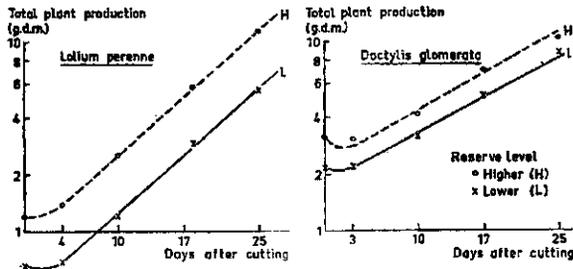

FIG. 19. Total dry matter production after cutting of plants with two different reserve levels.
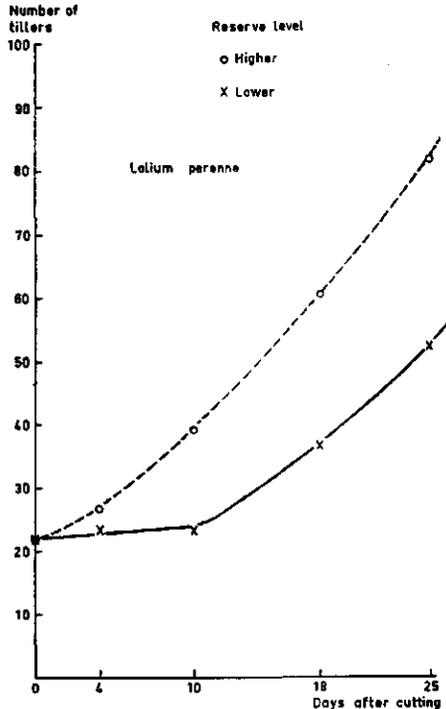

FIG. 20. Tillering after cutting in plants of *Lolium* with two reserve levels.

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In both groups of plants dry matter production was exponential, as before (Fig. 19). Since the curves for higher and lower sugar content run parallel for both species, this means that there was no difference in the relative rate of dry matter production.

The initial number of tillers was the same in both groups of plants. With *Lolium perenne* this number of tillers increased immediately after cutting when the reserve level was high. When the sugar content was low there was a time-lag of about 10 days in tiller formation. Afterwards tillering was renewed at approximately the same relative rate (Fig. 20).

In Figure 21 the number of tillers is plotted against temperature for H- and L-plants 10 and 25 days after the initial cut. For both species the rate of tillering of plants at 30° appeared to be distinctly lower than at the other temperatures. *Lolium* tillered more rapidly than *Dactylis* as was the case in the other experiments. A marked effect of reserve level on tillering was apparent in the case of perennial ryegrass, but in the case of cocksfoot this was only apparent at the higher temperatures.
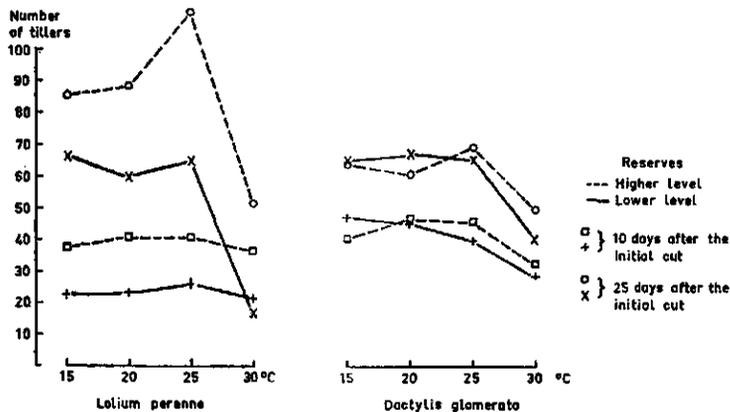
FIG. 21. Number of tillers in plants of *Lolium* and *Dactylis* with two different reserve levels, 10 and 25 days after cutting.

For *Lolium* the initial sugar content in the stubble was about three times as high in the H-plants as in the L-plants (Fig. 22). With the first group the concentration fell immediately after cutting. A temperature effect could also be easily demonstrated in these plants, the drop being steeper with increasing temperature. Between 5–10 days after cutting the TSC content increased again for all temperatures. With the low sugar content the initial drop was hardly visible at any of the temperatures and the TSC content remained approximately constant until a rise occurred at about the same time after cutting as with the higher sugar plants. At the end of the experiment there were still differences between the both groups, these becoming slightly larger with increasing temperature.

For *Dactylis* the general features were the same, but the trend in sugar concentrations

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TABLE 9. Variations in plants of *Lolium perenne* at two reserve levels placed at different temperatures a few days after cutting

Temp. °C	Reserve level	Herbage dry weight (g) 1st harv.	Stubble dry weight (g)			TSC in stubble (g)		
			initial	1st harv.	difference	initial	1st harv.	difference
30	H	0.23	0.91	0.73	—0.18	0.213	0.076	—0.137
	L	0.06	0.44	0.46	+0.02	0.034	0.030	—0.004
25	H	0.34	0.91	0.79	—0.12	0.213	0.098	—0.115
	L	0.13	0.44	0.50	+0.06	0.034	0.033	—0.001
20	H	0.26	0.91	0.77	—0.14	0.213	0.105	—0.108
	L	0.09	0.44	0.48	+0.04	0.034	0.036	+0.002
15	H	0.22	0.91	0.82	—0.09	0.213	0.136	—0.077
	L	0.06	0.44	0.41	—0.03	0.034	0.027	—0.007

TABLE 10. Variations in plants of *Dactylis glomerata* at two reserve levels placed at different temperatures a few days after cutting

Temp. °C	Reserve level	Herbage dry weight (g) 1st harv.	Stubble dry weight (g)			TSC in stubble (g)		
			initial	1st harv.	difference	initial	1st harv.	difference
30	H	0.22	2.58	2.00	—0.58	0.664	0.350	—0.314
	L	0.10	1.64	1.33	—0.31	0.211	0.138	—0.073
25	H	0.26	2.58	1.72	—0.86	0.664	0.263	—0.401
	L	0.13	1.64	1.64	0.00	0.211	0.158	—0.053
20	H	0.19	2.58	2.41	—0.17	0.664	0.530	—0.134
	L	0.10	1.64	1.50	—0.14	0.211	0.170	—0.041
15	H	0.14	2.58	2.57	—0.01	0.664	0.595	—0.069
	L	0.08	1.64	1.81	+0.17	0.211	0.204	—0.007

was far more irregular. The sugar content of the H-series at the time of cutting was slightly more than double that of the L-series and at the end of the experiment it was only at 30° that the TSC of the H-series was still above that of the L-series.

The initial post-cutting period did not yield much information. It might have been interesting to have some intermediate points between the time of cutting and that of the first sampling which occurred 4 days later for *Lolium* and 3 days for *Dactylis*. This could have enabled us to specify more accurately the starting point of exponential growth in the curves of Fig. 19. Unfortunately we were unable to do this on account of the lack of sampling material. But some statement of what happened can be made by studying the variation in the stubble dry weight, the amount of soluble carbohydrates in the stubble, and the leaf growth at the first sampling. These are shown in table 9 for *Lolium* and in table 10 for *Dactylis*.
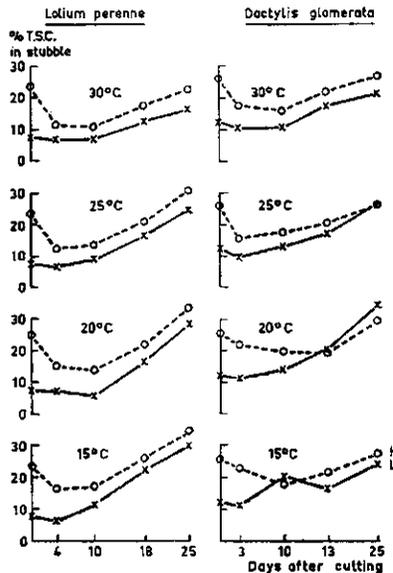
FIG. 22. Soluble carbohydrate content in stubble of plants with two different reserve levels.

For both species and in all cases the H-plants produced more herbage dry matter than the L-plants shortly after cutting. The stubble weight of the H-plants decreased relatively more than that of the L-plants. In the latter case there was even a slight increase with the *Lolium* plants. The differences in stubble weight ran parallel with differences in the amount of TSC in the stubble, but in general the losses in stubble dry weight were greater than those in TSC.

6.3   EXPERIMENT D. DRY MATTER DISTRIBUTION IN UNCUT AND CUT PLANTS

Cutting considerably reduces the amount of green tissue, so that it also decreases the

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rate of assimilation. The distribution of this small amount of assimilates over the various plant organs, particularly the leaves, may be of major importance for subsequent plant production. The purpose of Experiment D was to study if and to what extent dry matter distribution is affected by cutting.

Comparisons were made by dividing the sampled plants first into three portions, *viz.* roots, stubble (2½ or 10 cm long) and herbage (from 2½ or 10 cm upwards) and then subdividing these two top portions into leaf and stem (see Fig. 1).

6.3.1 Leaf production

The best way of studying changes in dry matter distribution over the various parts of the plant is to plot the weight of one part against another or against the total plant weight. A curve of this type we term a distribution curve (after VAN DE SANDE BAKHUYZEN (16) and WITTENROOD (129). In Fig. 2ç the leaf dry weight is plotted against total dry weight on a logarithmic scale. Since undisturbed plant production is exponential, a logarithmic representation gives each point on the curve about the same relative value. The distribution curve on a double logarithmic scale will be a straight line only if there is a constant distribution and if it meets the origin when plotted on
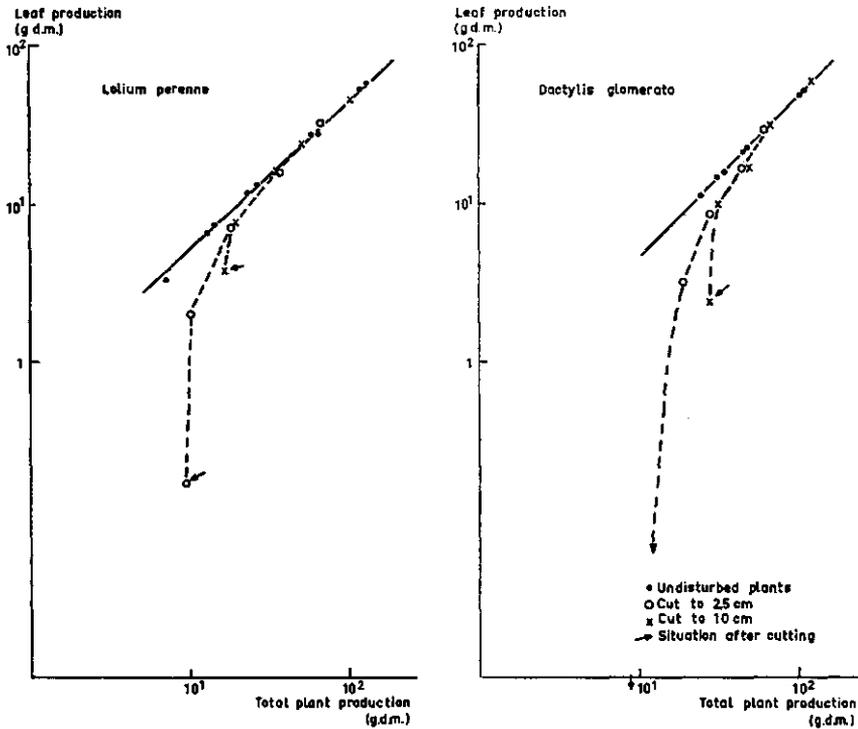

FIG. 23. Dry matter distribution over leaf and total plant in plants growing undisturbed compared with cut plants to two different heights.

a linear scale. In this case the resulting straight line will form an angle of 45° to the ordinates.

For *Lolium* the distribution line for undisturbed plant production forms such an 45° angle. When the plants are cut to 2½ cm or 10 cm the leaf weight is more reduced than the total plant weight. The arrow in the figure indicates the leaf/total ratio immediately after cutting. After this defoliation the leaves formed by the plants cut to 2½ cm were nearly all new; this changed gradually into the formation of other plant parts as well, until after 15 days the original pattern of dry matter distribution was again reached. With plants cut to 10 cm the reduction in leaf dry weight in relation to total plant weight was less. In this case it took only 10 days to reach the original ratio.

Similar results were obtained with *Dactylis*. Plants cut to 2½ cm recovered their initial leaf/total ratio 28 days after defoliation, and plants cut to 10 cm after only 18 days. *Dactylis* recovered much more slowly than *Lolium*, this probably being due to the fact that cocksfoot has more stem and less leaf in the stubble than ryegrass, as can be seen in table 11, in which the leaf and stem dry weights in the stubble of undisturbed plants of both species are given at different times of their growing periods.

TABLE 11. Leaf and stem weight in the stubble of undisturbed plants of perennial ryegrass and cocksfoot

Days after beginning exp.	Stubble height			
	2½ cm		5 cm	
	leaf	stem	leaf	stem
	g	g	g	g
Lolium perenne				
6	0.15	4.47	2.82	5.16
11	0.17	5.45	3.79	9.12
21	0.04	11.37	4.75	18.32
32	0.00	21.71	5.49	37.71
Dactylis glomerata				
0	0.00	9.16	2.29	11.77
6	0.00	10.79	2.56	16.03
12	0.00	14.44	2.38	21.18
26	0.00	33.97	6.83	49.35

Instead of plotting the weight of the leaf blades against the total plant weight, as in Figure 23, it is also possible to plot the plant dry weight above the level of cutting (herbage) against the total plant weight. This was done as it gives a better approximation of the grass yield in actual practice. Fig. 24 shows that in this case the original ratio was not restored. After an initial period in which the production of plant material above the level of cutting was provided to a relatively greater extent, a situation was soon reached in which the newly formed material was distributed above
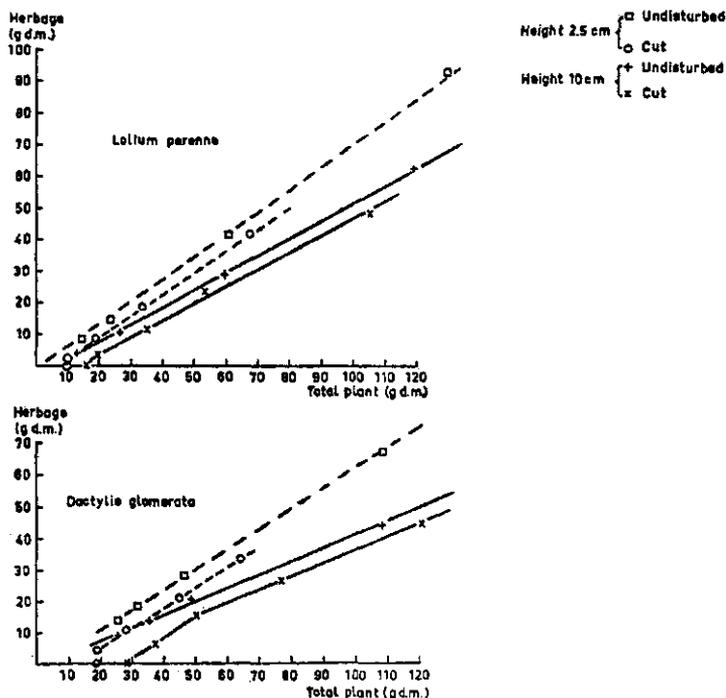
FIG. 24. Herbage/total plant dry matter distribution in cut and undisturbed plants at two different heights.

and below the cutting level in the same ratio as before cutting, but the original ratio is not reached again.

This is probably due to the fact that the stem portion in the herbage of cut plants decreased compared to that of undisturbed plants. Table 12 shows that on the one hand the herbage stem/stubble stem ratio was lower in cut plants than in undisturbed plants, and on the other hand that the leaf/stem ratio in herbage increased as a result of cutting. This means that after cutting the amount of leaf in herbage increased at a higher rate than the stem.

Cutting affects the rate of tiller formation of perennial ryegrass (table 13). Immediately after cutting the rate of tillering is reduced. But towards the end of the experiment, tillering seemed to increase, so that the differences between cut and uncut plants disappeared. No effect of the height of cutting could be distinguished. With cocksfoot no effect of cutting on tiller formation was found.

It should be noted that during the winter 1962–63 material could not be kept in the glasshouses without being vernalized. Thus when this experiment was started, *Lolium perenne* plants found suitable conditions for flowering. With *Dactylis* no flowering was observed since the experiment was carried out later in the season. Table 13 also shows the number of earbearing stalks at the end of the experiment. Clipping de-

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creased the number of ears in *Lolium* plants, in plants cut to 2½ cm it was reduced to less than half the number of the uncut plants.

In both species the rate of dry matter production of the roots decreased after cutting

TABLE 12. Leaf and stem weight in stubble and herbage at the end of the experiments in cut and uncut plants of perennial ryegrass and cocksfoot

Stubble height	Uncut plants		Cut plants	
	2½ cm g	10 cm g	2½ cm g	10 cm g
Lolium perenne				
Stem in the stubble	21.71	37.71	15.02	36.24
Stem in the herbage	35.29	15.31	10.10	10.69
Leaf in the stubble	0.00	5.49	0.00	7.36
Leaf in the herbage	37.01	46.87	31.22	37.34
Dactylis glomerata				
Stem in the stubble	33.97	49.35	23.02	57.06
Stem in the herbage	17.94	1.10	7.07	0.88
Leaf in the stubble	0.00	6.83	0.00	2.95
Leaf in the herbage	48.67	42.61	26.39	48.68

TABLE 13. Number of tillers at two clipping heights in comparison with unclipped plants

	Days after begin. exp.	Undisturbed (2 groups)		Cut to 2½ cm	Cut to 10 cm
	Lolium perenne				
	0	144	144		
	5	220	213		
	11	275	301	275	301
Day of cutting	15			285	338
	21	436	441	350	384
	26			429	426
	32	673	702	673	771
	Ears	55	44	20	35
	Dactylis glomerata				
	0	75	64		
	6	129	126		
	12	121	128	121	128
Day of cutting	19			138	158
	26	251	197	157	171
	33			199	173
	40			236	214
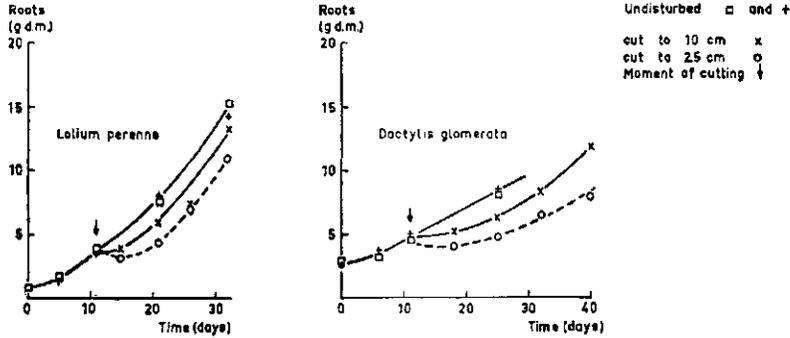
FIG. 25. Root dry matter production in plants growing undisturbed, compared with plants cut to two different heights.
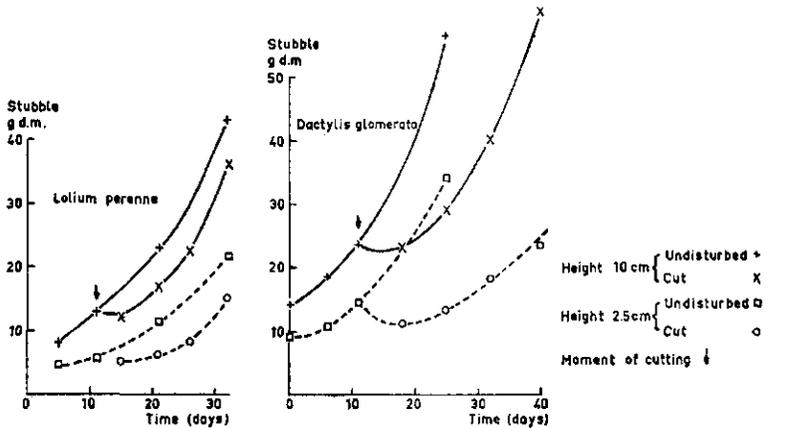
FIG. 26. Stubble dry matter production in cut and undisturbed plants at two different heights.

compared to the controls. There was even a temporary decrease in weight in both species after cutting to 2½ cm (Fig. 25). After about one week the rate gradually increased again, finally reaching about the same value as the controls.

A similar pattern is obtained when the stubble weight is plotted against time as in Fig. 26. Plants reduced their stubble growth when cut and in several cases they even lost some weight at the beginning. Plants cut short reduced their stubble growth more than those clipped more leniently.

Finally, table 14 shows the reduction in total herbage production caused by cutting. Clipped plants are presented with their herbage regrowth plus the initial herbage cut. At each moment after cutting it can be seen that clipped plants produced less than unclipped plants. Furthermore, the reductions are more than proportional to the material removed.

TABLE 14. Herbage production at subsequent harvests for plants cut to different heights in relation to unclipped ones

	Days after begin. exp.	Stubble height			
		2½ cm		10 cm	
		uncut g	cut g	uncut g	cut g
	Lolium perenne				
	6	8.20		3.72	
	11	14.41	14.41	10.13	10.13
	15		16.31		13.75
Day of cutting	21	41.43	22.68	28.75	22.63
	26		33.10		33.55
	32	92.30	55.73	62.18	58.16
	Dactylis glomerata				
	0	13.34		8.78	
	6	17.99		13.37	
	12	27.93	27.93	20.46	20.46
Day of cutting	19		31.86		26.71
	26	66.61	38.52	43.71	35.53
	33		48.57		47.18
	40		61.39		63.92

6.4 EXPERIMENT M. EFFECT OF REPEATING CUTTING AND TEMPERATURE REGIME

The effect of repeating cutting on herbage production was studied in both ryegrass and cocksfoot at different temperatures. The *Dactylis* tillers used for the experiment formed many ears; apparently this was the cause of the very irregular results obtained. Although there was some evidence that cocksfoot behaves in a similar way as ryegrass, no definite conclusions could be drawn from the data. Hence only the data for *Lolium* are given here.

Starting with Fig. 27, it can be seen that the highest herbage production was not always found at the same temperature or temperature combination. The temperature of 30° or the combination 30/25° gave the poorest growth in all cuts. Considering first the constant temperatures, the 25° temperature gave the highest dry matter production at the first harvest. At the second harvest, however, this took second place to the plants at 20°, whereas at the following harvests the lowest temperature gave the highest yields. The same pattern was found with a night temperature 5° lower than the day temperature, the 25/20° plant coming first for the first two harvests, the 20/15° for the third harvest and the 15/10° for the other harvests (with the exception of the last). The 5° drop in the night temperature resulted in a somewhat higher dry matter production, although the combination 15/10° did not differ significantly from that at
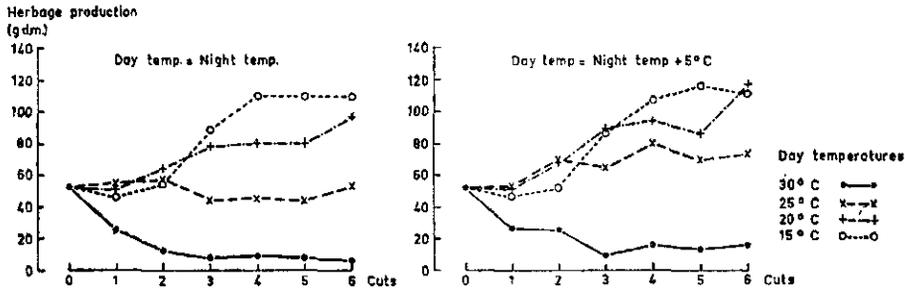
FIG. 27. Herbage production at the successive cuts of perennial ryegrass under different temperature regimes.
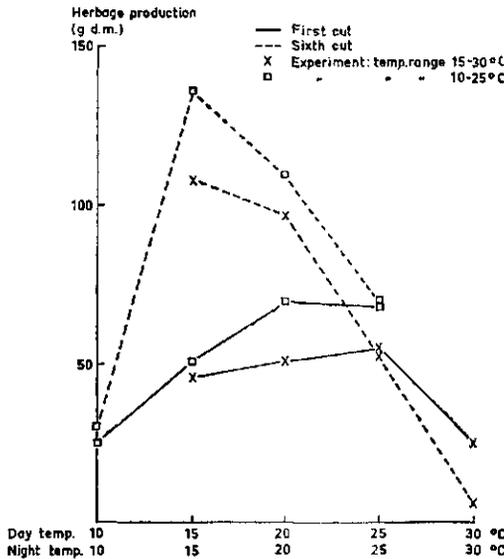
FIG. 28. Comparison between herbage production of two experiments with overlapping temperature ranges. See text.

a constant temperature of 15°. In all cases there was a tendency to reach a constant herbage production after a certain number of cuts.

From a similar experiment with temperatures ranging from 10° to 25° we plotted the herbage dry matter at the first and the sixth cut against temperature in comparison with the results of the present experiment for the same cuts (Fig. 28). Although the weights were not equal, a similar trend was found, viz. an optimal herbage production at the first cut between 20–25°C and at the sixth at 15°. In this case the most interesting feature is that both at the first and sixth cuts plants at 10° produced less herbage than those at 15°.

The rate of tillering was also distinctly affected by temperature (Fig. 29). At 30/30° the number of tillers gradually decreased with successive cuts, especially after the

third. At 30/25° the number remained more orless constant, and for the other temper-
atures the number increased with decreasing temperatures or temperature combi-
nations.

A further shifting effect of the temperature may be observed in the growth in length.
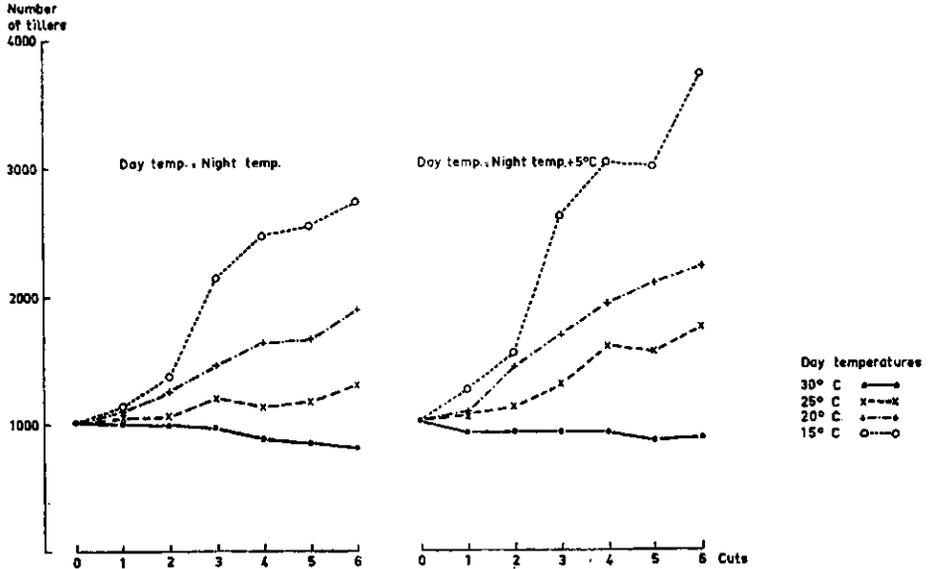
FIG. 29. Tillering in *Lolium* under repeated cutting and different temperature regimes.
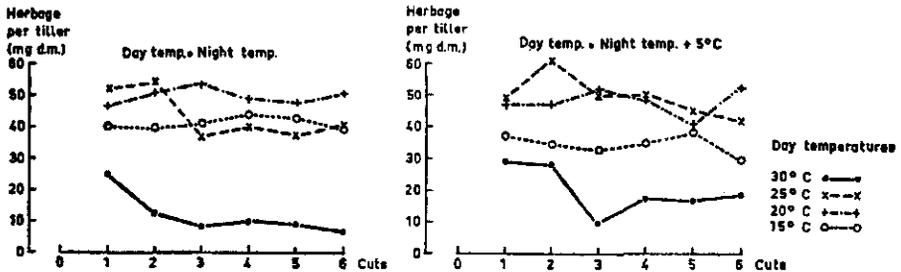
FIG. 30. Average herbage production per tiller at every harvest in *Lolium* under different temperature
regimes.

At all harvests the maximum length was found around day temperatures of 20° and
25°, the length slightly decreasing towards 30° and considerably at 15°. At 10° the
plants remained very short. The night temperature did not seem to have an appreci-
able effect on the growth in length.

Owing to these effects the herbage weight per tiller (Fig. 30) was very low at 30/30°,
forming fairly long shoots at this temperature, followed by 30/25° with about the same

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TABLE 15. Plants weights at the end of experiment M

Temperature[1] °C	Root g	Stubble g	Herbage g	Total g	Tiller weight g
15/10	16.4	8.2	20.5	45.1	0.069
15/15	15.5	6.6	15.8	37.9	0.082
20/15	15.5	6.3	19.2	41.0	0.108
20/20	19.2	5.5	15.7	40.4	0.126
25/20	10.0	4.6	12.8	27.4	0.095
25/25	14.3	3.2	8.5	26.0	0.136
30/25	4.4	2.1	2.7	9.2	0.070
30/30	2.3	1.6	0.9	4.8	0.034

[1] Temperature treatments are given as day temp./night temp.

appearance, and then by 15/10° at which the tiller weight is low on account of its high number and the small length.

Moreover it is a remarkable fact that herbage production per tiller appeared to be practically constant at all temperatures. At constant temperatures the maximum herbage production per tiller was found with the 20° plants. For the plants with a lower night temperature those at 20/15° and 25/20° produced about the same amount of herbage per tiller and the highest of the four treatments. From this it may be concluded that there is an optimal temperature lying between 20° and 25° for herbage production per tiller. The greater the difference between a certain temperature and the optimal, the smaller will be the weight of individual tiller grown under these conditions (Fig. 31).
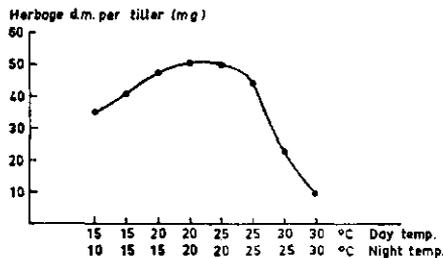
FIG. 31. Average herbage production per tiller in *Lolium* under different temperature regimes.

Table 15 shows the dry weights of the various plant parts sampled at the last harvest. With a few exceptions, the total plant material and the herbage weight per pot increased with decreasing temperatures. The average dry weight per tiller increased with temperature, but fell sharply when the temperature exceeded 25°.

7 DISCUSSION

The dry matter production of a grass sward during early growth was found to be exponential. At this time the number of leaves and tillers is on the increase thereby reducing the area of bare ground. When the vegetation covers the soil surface in such a way that the light is completely intercepted, dry matter production becomes linear with time (BROUGHAM, 22) until other factors interfere (see below).

DE WIT, DIJKSHOORN and NOGGLE (128) have clearly stated the effect of a closed crop condition on differences in growth rate. If for some reason the early growth of a certain crop is delayed compared to another crop of the same species, relative differences in dry matter production will increase during the period of exponential growth. There will probably be total light interception of both plants when they reach the same size. Consequently both crops will grow at the same rate of dry matter production when the crop with the slowest growth rate has reached the stage of complete light interception. The differences in dry weight which then exist will there-after remain constant and the relative difference in dry weight will decrease with time. DE WIT et al. therefore suggested that the effect of a factor on plant production should be studied during the time of exponential growth.

For a grass sward such a difference will even tend to decrease in an absolute sense since it has been shown that the relative rate of dry matter production does not proceed linearly with time for a very long period (BROUGHAM, 21; ALBERDA and DE WIT, 9; ALBERDA and SIBMA, 10). Apparently chiefly owing to an increasing rate of respiration, the relative rate of dry matter production may even fall to zero after prolonged periods of undisturbed growth.

These considerations may explain BAKER's results (15) who found that the difference in weight between uncut and cut plants in a sward decreased with time. This also explains why in short time experiments with single plants, the undisturbed plants give the highest yield, whereas under sward conditions cutting improves dry matter pro-duction during the whole season as compared with undisturbed growth.

When evaluating the results of cutting experiments one should therefore always take into consideration the kind and duration of the experimental period. With single grass plants an exponential growth rate can be expected for a prolonged period (6–10 weeks). For field experiments it is important to know whether the duration of the experiment includes periods with an exponential growth rate, a linear growth rate or even a decreasing growth rate.

This is very likely the reason for many of the confusing results of experiments on grass production under differential cutting management.

All our indoor experiments were carried out with single plants growing exponentially. But the material of some of the field experiments consisted of grass sown in rows.

Since there was some overlapping between the plants of the separate rows growth may be expected to be linear with time at the end of some of the regrowth periods.

For all these reasons it is necessary to define exactly the growing conditions during the experiment, as has been done in our indoor experiments. This facilitates comparisons with practical field experiments.

7.1 EFFECT OF CUTTING

7.1.1 The morphology of the plant

The stubble left after cutting consists of the true stem, the leaf sheaths (or a part of them), and a small amount of leaf blade. In fully vegetative plants the stem is very short and is not touched by the clipping operations. On this stem are inserted the buds in the axis of the leaves which develop to secondary tillers. The number of developing buds of a given tiller is a measure of its tillering possibilities. In vegetative plants this tillering potential is not reduced by cutting, but since most of the material required to develop these buds into new tillers has to be supplied by the assimilation of the mother tiller, and since this is greatly reduced by cutting, tillering is usually checked after defoliation (Fig. 16 and 20).

The formation of visible tillers depends on external conditions, as will be discussed below. Some time after cutting tillers become visible at an increasing rate and there is often no difference in tiller number between cut and uncut plants at the end of the experiment (table 13). This would indicate that it is rather bud development that is checked after cutting than the formation of new buds by the meristems.

7.1.2 The dry matter production

Since the leaf blade surface has been severely reduced by cutting the assimilation rate is also reduced.

The plant has not even enough sugars left for its respiration and has to use some of the reserves accumulated previously; this often causes a decrease in plant weight immediately after cutting (Figs. 25 and 26).

At the same time the formation of new leaves continues and the assimilation increases gradually. It goes so far as to reach the same relative production rate as it had before being cut (Figs. 25 and 26).

A comparison between the dry matter production of a cut plant and that of undisturbed growth shows that:

1. the relative rate of dry matter production is not affected by cutting (except for a short period immediately after cutting),
2. the amount of dry matter produced is reduced by cutting; the time lag immediately after cutting actually means a delay in the re-establishment of exponential production. This increases the subsequent differences in plant dry weight between cut and uncut plants (table 13).

7.1.3 Plant reserves

After the plants have been cut the soluble carbohydrate content in stubble and roots decreases rapidly to fairly low levels. The concentration is far less in the roots than in the stubble, so that the drop in sugar content is less conspicuous here. The lowest concentration is usually reached around 5 to 7 days after cutting. Afterwards there is a steady rise in all plant parts. This is a well-known fact which has been found by many workers in this field.

The concentration of soluble sugars never falls to zero, indicating that a part is necessary for maintaining the normal life processes. This is supported by the fact that after cutting under very adverse conditions a number of tillers die, suggesting that part of their contents is used for the regrowth of the remaining ones. In this case also the soluble sugar content never falls below a certain level. Above this level the sugar content fluctuates between far greater limits than the other organic plant constituents, suggesting its reserve status in this range of concentrations. Moreover, the carbohydrate content of high sugar plants drops more steeply after cutting than in low sugar plants (Fig. 22), showing that in the second case the sugar content was much closer to the necessary minimum and only a small amount was available as reserves for use after cutting.

There has been some discussion lately as to whether the soluble carbohydrates in the grasses of temperate regions would actually be of any importance for regrowth, and according to MAY (73) and MAY and DAVIDSON (74) they can only be called reserves if this question is answered in the affirmative. Contrary to this, I would state that when the greater part of certain structural plant constituents are used after cutting, or during otherwise changing growing conditions, and restored when the conditions return to "normal", these constituents may be called reserves. This is irrespective of the question whether growth is affected by the level of these reserves or whether the reserves are used for building new structural material or as a source of energy.

7.1.4 Dry matter distribution

The fact that the distribution of dry matter over the different plant parts, roots, stems, leaves, fruits, etc., remained constant for a certain period was clearly stated by VAN DE SANDE BAKHUYZEN (16) and later by WITTENROOD (129). They plotted the weight of a part of the plant against total plant weight and were thus able to demonstrate that such a dry matter distribution diagram, as they called it, shows abrupt changes, coinciding with the entry of the plant into a new phase, e.g. from the vegetative into the reproductive stage.

With the fully vegetative plants of our indoor experiments no such change of phase is to be expected, and it can actually be seen that the dry matter distribution over the leaves and the rest of the plant remains constant for the undisturbed plants during the whole experimental period (Fig. 23). This constancy has been explained by a kind of mutual relation between the different parts of the plant (see SINNOTT, 94). Thus,

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assimilation mainly occurs in the leaves; the sugars formed are first used for new leaf growth and what is left can be used elsewhere, e.g. for root formation. On the other hand, the roots take up the ions from the medium and can use them first; what is left is passed to the other plant parts, e.g. the leaves.

The more the dry matter is used up for the formation of leaves, the greater will be the growth rate of the plant. Since, however, part of the dry matter formed has to be used for the formation of new roots it will be an advantage to use not more than is strictly necessary for leaf growth. BROUWER (27, 28) has shown that removal of part of the roots does in fact cause a change in the distribution of dry matter; relatively more roots are formed until the original ratio is restored.

Figure 23 shows that the same applies when shoots are cut. When we distinguish between leaf (blades) and the rest of the plant, leaf growth is promoted after cutting until the original ratio is reached again. If, however, we consider the distribution of dry matter between herbage and the rest of the plant it seems that the newly-formed material is distributed over herbage and the rest of the plant in the same ratio as before cutting. This is true of both *Dactylis* and *Lolium*. This difference is not easy to explain. It shows at any rate that the herbage becomes leafier after cutting.

7.2 EFFECT OF CUTTING TO DIFFERENT HEIGHTS

Figure 15 shows that once exponential production has been restored the height of cutting has no effect on the relative rate of dry matter production. This was to be expected, since this was already the case with uncut and cut plants.

Figure 15 also shows that there is no difference in the length of the time lag. From the first sampling date onward the rate of dry matter production was already exponential. If there is any difference in time lag this must occur in the first few days after cutting. Some indications that this lag period is longer when plants are cut lower are found in experiment D, Fig. 25 and 26. When plants are cut to 2½ cm root and stubble production is resumed later than when they are cut to 10 cm. Moreover, it appears from table 14 that there is an effect of cutting which is greater at a cutting height of 2½ cm than of 10 cm. That this is not only due to the herbage initially removed can be seen from the fact that the ratio of the reduction to the removed portion is smaller for plants cut higher.

It is thus suggested that the length of the time lag is to some extent related to the time in which the plant is able to recover its characteristic leaf/total ratio. After cutting, this ratio drops more steeply with decreasing cutting height. Thereafter, these plants need more time to revert to the previous ratio (Fig. 23).

The cutting height therefore has a double effect in the plant dry matter production. The higher cut plants have a greater plant weight after defoliation, and these plants also possibly show a shorter time lag until exponential production is restored. For

these two reasons these plants increase more in dry weight than plants cut at a lower level (Fig. 15).

But when we consider the production of herbage, it can be seen from Figure 17 that the ratio of increase in herbage dry weight/increase in total plant dry weight remains constant for each cutting height, but that its value increases with decreasing cutting height.

Hence this ratio changes in a direction opposite to the plant production, following variations in cutting height. For every species it should therefore be possible to find an optimal cutting height for herbage production.

In the indoor experiments G the highest herbage production was in fact found at the end of the experiment at the intermediate cutting height for both *Lolium* and *Dactylis*, the data being:

Cutting height in cm	*Lolium*	*Dactylis*
2½	5.37	5.82
5	6.99	7.49
10	5.28	5.63

For the field experiments the same was found for both species for the first regrowth period (table 4, harvested on 13.7). However, the pattern changed with successive cuts.

7.3 EFFECT OF REPEATED CUTS

It has already been shown that after cutting, a recovery period soon begins in which the plant weight, tiller number and the soluble carbohydrate content increase rapidly. It can be reasonably assumed that the cutting can be repeated for an indefinite number of times provided the total plant weight and the reserves have reached at least the same level as they had before the previous cutting.

It can in fact be shown (Fig. 27) that with repeated cutting and good growing conditions, the herbage dry weight harvested per pot increased with successive cuts. However, under more adverse circumstances it may decrease apparently because the interval is then too short to ensure complete recovery.

Thus if the interval is long enough the weight of the roots and stubble will increase with successive cuts, and more so when plants are cut higher since we have seen that with increasing cutting height dry matter production after cutting increases and a relatively greater proportion of it goes to the stubble and the roots.

Consequently, the difference in total dry matter production in favour of the plants cut higher will increase relatively at each successive cut. This difference may therefore eventually outweigh the difference in the ratio herbage increase/total increase, and there will then be a shift in optimal cutting height to a higher level. This, of course,

only holds good as long as the individual plants do not influence each other to any considerable extent.

Many of the above observations were borne out by field experiment I. The relative increase in stubble weight appeared to be higher at the highest cutting level (tables 3 and 5). Consequently, taking the apparent dry matter production over the whole experimental period it appeared that plants cut higher produced more (table 3). The shift in optimal cutting height from low to high can be seen very clearly in table 4. For *Lolium*, 10 cm gives a better herbage production at the last regrowth interval (harvested on 27.8), whereas for *Dactylis* the same phenomenon occurs as early as the second interval (harvested on 28.7). Thus, when we consider the total herbage production throughout the experiment (table 3), 5 cm appears to be the optimal cutting height for *Lolium*, whereas 10 cm appears to be better for *Dactylis*.

However, inspection of the 1962 results shows that the optimal cutting height for *Lolium* was again 5 cm and this was also true for *Dactylis* (table 5). During this year overwintering caused much damage in rows cut to 10 cm in the previous season, and herbage production from cutting to this height was very scanty, particularly at the first cuts.

It can be seen from experiment M (Fig. 27) that after a certain number of cuts the herbage production per pot remained constant during subsequent intervals. In this experiment, which was fairly protracted, several bunches of tillers were planted in a pot filled with gravel. Apparently these plants affected each other, as could be seen from the fact that the plants in the centre were usually smaller than those on the periphery. It may be assumed that a kind of sward condition occurred in which there was a linear rate of dry matter production for at least a part of the regrowth period. But in cases where the growth remains entirely exponential, herbage production will increase at every harvest, provided conditions (environmental, height and frequency of cutting) are kept constant and the regrowth period is sufficiently long.

7.4 Effect of the length of the interval between cuts

Provided these intervals do not become too long and there is only exponential production between two successive cuts, then the longer the interval the greater is the total dry matter production during the season, since, as stated above, cutting means a reduction in plant production.

The herbage production will also increase with the length of the interval because the ratio of herbage production to total production is constant (tables 3 and 5).

This is equally true even if the interval is so long as to allow total light interception and linear dry matter production to occur.

In our field experiments both the highest apparent dry matter production and herbage yield were found in the rows cut less frequently. Since there were no intervals longer than three weeks, most probably the plants were always growing exponentially.

But, as stated before, when the plants are allowed to grow undisturbed for a long period, production becomes linear. Eventually increases in respiration and other losses will result in a still further decrease in the rate of production. In our field experiment with separate *Lolium* plants (Fig. 10) we even found a decrease in production after a long period of undisturbed growth. This will be a limitation to the length of the interval. This question has not yet been specially studied in our investigation.

7.5 EFFECT OF CUTTING TREATMENTS ON RESERVES

Finally, the height of cutting also affects the concentration of soluble sugars in the plant (Fig. 18). The TSC content in the plant immediately after cutting was lower in plants cut to a higher level. With *Dactylis* these differences were far greater than with *Lolium*, suggesting that the sugar concentration increased far more from the top of the tiller to the base than with *Lolium*.

In both species the steepest drop after cutting was found in the plants cut to $2\frac{1}{2}$ cm. With *Dactylis* the drop was less steep than with *Lolium*; with plants cut to 10 cm a drop was not even found.

According to Figure 18 it would seem, at least in the case of *Lolium*, that all plants cut to different heights tend to reach the same TSC content after a certain time.

In the field experiments (Fig. 4) the initial reserve level of *Dactylis* was extremely low, probably owing to the fact, mentioned above, that cutting treatments began too early for cocksfoot and the plants were then too small.

Moreover, throughout the experimental period the higher sugar content was found in the stubble of the plants cut higher. Since the intervals used were not longer than 20 days it is possible that when cutting was repeated plants were at the stage of initial rapid TSC recovery. One indication of this is that the length of the interval between cuts was also found to have a considerable effect on the sugar content in the sense of higher concentrations as the interval is longer (Fig. 6). However, it does not mean that when the intervals are still longer either they or the cutting height can have no distinct effect on the carbohydrate content.

7.6 EFFECT OF TEMPERATURE

The herbage/total ratio was found to be independent of temperature (Fig. 13), so that changes in total plant production due to temperature will also give proportional changes in the herbage production.

The total plant production is made up of two factors, *viz.* the average tiller weight and the number of tillers. The average tiller weight was found to be constant for a temperature at every successive cut of a cutting treatment in which cutting height and interval between defoliations were always the same (Fig. 30). The tiller weight is therefore determined by the temperature regime. It increases with temperature up to

a maximum value; in our experiments this value for *Lolium perenne* was found at a temperature between 20 and 25°C (Fig. 31). The tiller weight decreases rapidly at temperatures higher than this optimal value.

The second factor affecting plant production is the number of tillers. This was not constant at the successive cuts. The rate of tillering was found to increase with decreasing temperatures (Fig. 29). Thus at every cut differences in number of tillers will be larger in favour of the plants at the lower temperatures.

When grasses are subjected to different temperatures at the first cuts, the differences in number of tillers will be not great enough to outweigh the differences in tiller weight. Hence at this first harvest the higher plant production will be found at the temperature at which tiller weight is maximal. But as cutting is repeated differences in number of tillers between the temperatures become greater, so that this factor will determine to a greater extent the total plant production. Thus at every subsequent cut the maximal production will be obtained at a lower temperature.

This explains the results of our experiment G in which the best herbage production after a single cut was obtained at 20°C, which is quite close to the temperature of maximal tiller weight (Fig. 12). In experiment M also we found a shifting in optimal temperature from 25° at the first cut to 15° at the last (Fig. 27). Similar results were reported by WENT in peas (124) and tomatoes (122, 124).

But, as stated above, after a certain number of cuts the herbage production per pot remains constant at the subsequent harvests. This shifting in optimal temperature will not go further since as there will be no further increase in the differences in number of tillers. The optimal temperature at that moment will remain the same. In our experiments it is not to be expected that the production at 10° will ever exceed that obtained at 15° (Fig. 28). 15° will remain the optimal temperature at all subsequent cuts.

Night temperature does not seem to affect the growth in length of the tillers so much as it does the tiller weight and rate of tillering (Figs. 31 and 29).

A colder night causes the formation of lighter tillers and increases the rate of tillering. In all cases a higher herbage production was obtained from grasses at a 5° lower night temperature than at a constant day and night temperature (Fig. 27).

Similar results have been obtained in work on tomatoes (WENT, 122) and on peas (WENT and MONSELISE, 125). However, this fact has been criticised by WELLENSIEK (126), who, quoting FORTANIER's results on groundnuts, suggests that this is not a general phenomenon, although it has been found to occur more often than not.

This phenomenon may be due to a decrease in the plant respiration at night when there is no assimilation. This lower temperature would save some sugar which could be used for dry matter production.

7.7 EFFECT OF THE RESERVE LEVEL

It was impossible to have plants with different reserve levels and the same dry weight.

In our experiments the different reserve level was obtained by a short pretreatment immediately before cutting (see 4.2.3). In this way we were able to obtain this difference in sugar concentration in plants having about the same leaf area. However, the high sugar plants appeared to be much heavier than the low sugar ones, especially the stubble and roots, in which most of the reserves are located.

After cutting the reserves of the H-plants dropped more steeply than those of the L-plants. But the minimum reached by the former was never as low as the minimum of the latter (Fig. 22).

If there was actually a minimum TSC content for the living organism (see 7.1.3) then L-plants would be closer to it than the H-plants. A fall in the TSC content in L-plants would therefore be more limited.

This drop in sugar concentration means that the reserves were being utilized by the plant in regrowth after cutting. The H-plants used more reserves and the leaves appeared sooner than in the L-plants (tables 9 and 10). This means that the H-plants could recover their characteristic leaf/total ratio earlier than the L-plants. Consequently, the time lag after cutting before exponential dry matter production was reached was shorter in the case of plants with a higher reserve level.

In *Lolium perenne* this difference in length of the time lag caused by the reserve level is well reflected by tillering (Fig. 20). Plants with a higher reserve level began producing tillers at a more or less exponential rate shortly after cutting, whereas plants with a lower reserve level needed a certain time (in our experiments about 10 days) to reach the same relative rate of tillering as the former.

Once exponential dry matter production has been reached, it will continue at the same relative rate irrespective of the reserve level at cutting (Fig. 19). In this respect, therefore, the effect of reserve level is similar to that of cutting height (*cf.* Fig. 15).

A. G. DAVIES (40), studying the regrowth of three clones of perennial ryegrass with different reserve levels, also concluded that the reserve level had no influence on the relative rate of dry matter production. But a lowering of the reserve level can delay growth and tiller production.

In conclusion, a plant with a higher reserve level will be capable of a better dry matter production after cutting not because it has any effect on the relative rate of dry matter production, but because the stubble and roots will be heavier and probably also because exponential plant production will be reached earlier.

This is in agreement with the statement made by WARD and BLASER (114) that reserves are important in the growth of grasses immediately after cutting.

7.8 OVERWINTERING

It has very often been stated that plants with a high level of reserves at the beginning of the cold period are in the best condition at the following spring (GRABER, *et. al.*, 44).

However, in our experiments it was found that plants which also had a longer and

denser stubble mass were the most damaged during the winter (Figs. 7 and 8, table 6).

Cutting height and interval between cuts have a positive effect on the density of the stubble and also on the reserve level (see 7.4 and 7.5). Thus the results obtained in our experiments are in disagreement with the above assessment.

SONNEVELD (personal communication) in a collection of clones of perennial ryegrass, also managed to obtain different reserve levels in this way and found the highest sugar concentrations in plants with a greater size. These plants also suffered most during the winter.

The general opinion on the relation between reserve status and overwintering is mainly based on research with lucerne and tussock-forming grasses.

Our results indicate that this rule does not always apply to pasture grasses, so that further investigation is required in order to ascertain the importance of the reserves on overwintering of grass species capable of forming a dense turf. The microclimate in a dense sward is possibly less favourable to overwintering.

7.9 EFFECT OF VERNALIZATION

Vernalized perennial grasses shoot and flower under suitable conditions of temperature and photoperiodism; this occurs in the spring or summer.

When heading occurs a greater part of the dry matter produced is transported into the upper parts. Consequently the herbage of vernalized grasses is then heavier than that of unvernalized ones. This can be seen from table 7 in which the herbage weight of the first cut is always higher for vernalized than for vegetative plants, except for *Lolium* harvested on 6 July.

As stated earlier the unvernalized plants keep a constant ratio between the herbage and the stubble production. In the vernalized plants this ratio changes in favour of the herbage. Thus from the point of view of obtaining a heavy hay cut vernalized tillers are preferable.

However, the stubble mass depends on the number of tillers and stubble weight per tiller. In our experiments a higher rate of tillering was recorded for vegetative plants than for vernalized ones (Fig. 9). A decrease in tiller number in spring and early summer was even reported by LANGER (68, 69) and SONNEVELD (95) in flowering grasses. At this time plants need the greater part of their assimilated material for flowering and they stop tillering or at least decrease the rate of tillering. Moreover, axillary buds, which under vegetative condition will develop to tillers, will produce spikelets during head formation in vernalized tillers (COOPER and SAEED, 36).

Moreover when a cut is taken after head elongation has begun, a part of the stem apices will be removed. After this cut only the young apices of the side tillers remain, and these will develop into new heads if conditions are suitable.

For all these three reasons, in the following cuts the unvernalized plants have a denser stubble mass and are in a better position to produce a large amount of herbage than vernalized ones (table 7 and 8).

In a small experiment, not reported here in detail, vernalized tillers of a clone of perennial ryegrass and others of cocksfoot were planted separately in the spring. Towards the end of the experiment each tiller was the origin of a plant whose flowering stalks and vegetative tillers were counted. There appeared to be a good correlation between the number of flowering stalks and the number of vegetative tillers, although they were higher for *Lolium* than for *Dactylis*. We were therefore able to conclude that the ratio between them is constant.

Relating this with what has been said above, strains with a high proportion of reproductive tillers will be preferable for a heavy hay cut, whereas those with a low proportion will give a more abundant after-growth. Similar results were obtained by STAPLEDON and BEDDOWS (102). In a trial with different strains of cocksfoot, he found the heavier hay cut with varieties having a high "stemmy/leafy shoots" ratio, whereas with a low ratio the aftermath cut was better.

7.10 GRASS SPECIES DIFFERENCES

Some differences found between the species used were so important as to deserve particular mention.

It was our intention to study the dry matter production of both perennial ryegrass and cocksfoot under a wide range of temperatures in order to ascertain the optimal temperature for each species. A higher optimal temperature was expected in the case of cocksfoot as it is usually found in the field. But such a feature was not clearly obtained. In both cases the optimal temperature was situated between 20 and 25°C (Fig. 12), although there were some slight indications that for perennial ryegrass this optimum is closer to 20°, whereas for cocksfoot it is nearer to 25°.

Tillering in *Lolium perenne* was a variable depending not only upon climatic and soil conditions but also on clipping treatments (Figs. 3 and 5).

After the plants were cut tillering stopped for a certain time (ALBERDA, 4). The length of this period varies in relation to the reserve status of the cut plants, and this in turn depends on previous growth and the defoliation itself. Thus it was found that increasing reserve status (Fig. 20), cutting height (Figs. 3 and 16), and interval between cuts (Fig. 5) decreased this time lag and increased the number of tillers.

On the other hand none of the factors listed above had any effect on tillering of cocksfoot (Figs. 3, 5, 16 and 21); it seems to be a constant for a given environment. The same surprising results were found by KNIGHT (65, 66).

It seems, then, that the production of *Lolium perenne* depends more on tillering and sward density, whereas in *Dactylis glomerata* it depends on the production of the individual tiller. MITCHELL (79, 82) also concluded that the rate of increase in tiller number in ryegrass is of major importance in the field. KNIGHT (66) reported that no significant relation could be found between tillering and dry matter production in different varieties of cocksfoot.

After cutting, cocksfoot keeps relatively less leaf in the stubble than ryegrass (table 10). In *Lolium* a significant number of leaves can be found at the base of the tillers, whereas in cocksfoot leaves can be found mainly in the upper parts. This may be the reason why it has been suggested (12) that after being cut cocksfoot is more dependent on reserves than ryegrass, which actually recovers more rapidly the original leaf/total ratio after cutting.

In our experiments, however, differences in dry matter production between H- and L-plants were greater for *Lolium* than *Dactylis*. This apparent contradiction is only due to the fact that the difference in sugar content between H- and L-plants was much greater in the case of ryegrass than in the case of cocksfoot (Fig. 22).
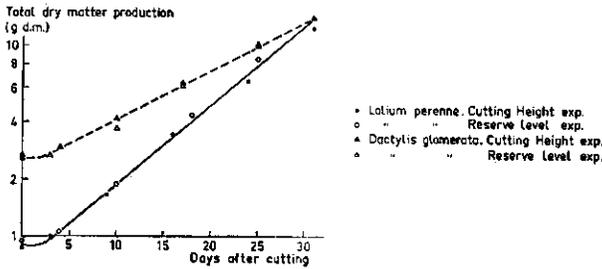
FIG. 32. Average dry matter production curves for *Lolium perenne* and *Dactylis glomerata*.

Finally, it was found that the rate of plant production was higher for ryegrass used in our experiments than for cocksfoot (as shown in Figure 32 in which the average plant weight in experiments G and R is plotted against time for both grass species). The soluble carbohydrates were usually lower for cocksfoot (Figs. 6, 14, 18 and 22). It is remarkable, however, that in both species the assimilated material was more or less distributed in the same pattern over the different parts of the plant (Figs. 23 and 24).

SUMMARY

1. The effect of cutting treatments on grass production was studied both in the field and in experiments under controlled conditions.
2. In general the investigations were carried out with plants growing at an exponential rate of dry matter production.
3. Cutting vegetative tillers does not remove any of the buds inserted on the stem, so that after a certain time the same number of tillers was found in cut and uncut plants (table 13). Cutting only temporarily reduced the rate of appearance of new tillers (Fig. 16 and 20).
4. Cutting reduced the increase of total dry matter for a certain time (Fig. 25 and 26); after this "lag period" the production of plant dry weight continued at the same relative rate as in undisturbed plants.
5. Immediately after cutting the TSC content fell to fairly low levels. Thereafter a recovery took place which was so extensive as to reach or even exceed the initial level, provided enough time and suitable growing conditions were provided (Figs. 14 and 18).
6. The distribution of the increase in dry matter over the different plant parts was studied. The ratio *leaf blade dry weight/total dry weight* was constant for vegetatively growing grasses (Fig. 23). When this ratio was reduced by cutting, the rate of leaf dry matter production was increased in comparison with the other plant parts, until the former ratio was recovered.
7. The plant material removed by cutting to a certain height was called herbage (Fig. 1). The ratio between the increase of herbage dry weight and total plant dry weight was also constant in undisturbed plants. Immediately after cutting herbage production also increased relatively to the rest, but the former ratio was not again reached. In this case the distribution of the increases over herbage and the rest of the plant was the same before and some time after cutting (Fig. 24).
8. When the effect of cutting (see 4) was studied for different levels ($2\frac{1}{2}$, 5 and 10 cm), this had also no effect on the relative rate of dry matter production (Fig. 15). Nevertheless, heavier plants were found when they had been cut higher; this was due to a larger plant residue after cutting and possibly also to a shorter lag period.
9. It took more time to recover the original leaf/total ratio when plants were cut shorter (Fig. 23).
10. For both species an intermediate cutting height (5 cm) was the optimal for herbage production after a single cut (see table on page 54).
11. When plants were cut repeatedly a larger plant production was found when grasses were defoliated at the 10 cm level. The optimal cutting height for herbage production shifted from low to high at successive cuts (table 4).

12. When the plants are growing at an exponential rate of dry matter production, the longer interval between cuts gave the highest dry weight both for the total plant and the herbage (table 3).

13. Under a certain cutting system (fixed cutting height and interval between cuts), the tiller weight appeared to be influenced by temperature (Fig. 30). The heaviest tillers were found at about 20°C (Fig. 31). The rate of tillering increased with decreasing temperature (Fig. 29). Since the number of tillers gradually became more important, a shifting in optimal temperature from high to low took place at the successive cuts (Fig. 27).

14. At a colder night temperature tiller weight was lower (Fig. 31) but the rate of tillering higher (Fig. 29). This resulted in a larger herbage production in comparison to plants at a constant temperature (Fig. 27).

15. The reserve level had no effect on the relative rate of dry matter production (Fig. 19) (as in the case of differences in cutting height (see 8)). There was some evidence that the length of the lag period increased with decreasing reserve level. In the case of *Lolium* this was shown by the longer delay in tillering for low sugar plants (Fig. 20).

16. The more leniently plants were treated in 1961, the more damage they suffered during the winter, despite the fact that they had the higher reserve level (table 6, Figs. 7 and 8).

17. Vernalized tillers produced more herbage than vegetative ones (table 8, Fig. 10). However, vegetative plants produced more tillers than vernalized ones (Fig. 9). Vernalized plants therefore gave more herbage dry matter at the first cut and vegetative ones at the subsequent cuts (table 7).

18. With *Lolium* tillering stopped for a certain period after cutting. The length of this period decreased with increasing reserve level (Fig. 20) or cutting height (Fig. 16). On the other hand, none of these factors had any effect on tillering of *Dactylis* (Fig. 16 and 21).

SAMENVATTING

1. De invloed van afsnijden op de droge-stofproduktie is bestudeerd zowel in veld-proeven als onder constante omstandigheden aan twee grassoorten namelijk Engels raaigras (*Lolium perenne*) en kropaar (*Dactylis glomerata*).

2. Bij het merendeel der proeven verliep de droge-stofproduktie exponentieel.

3. Wanneer vegetatieve spruiten werden afgesneden bleef het groeipunt tezamen met de aanwezige okselknoppen intact. Als gevolg hiervan werd het te voorschijn komen van nieuwe spruiten na afsnijden wel vertraagd doch uiteindelijk werd weer hetzelfde aantal bereikt als in niet afgeknipte planten (tabel 13, figuren 16 en 20).

4. Door afsnijden werd de droge-stofproduktie gedurende een zekere tijd verminderd (fig. 25 en 26); na deze ,,onderbrekingsperiode'' werd de relatieve droge-stofver-meerdering weer dezelfde als vóór het afsnijden.

5. Het suikergehalte daalde direct na het afsnijden tot een vrij lage waarde. Daarna begon het weer op te lopen en onder gunstige omstandigheden kon daarbij het aanvankelijke niveau weer worden bereikt of zelfs overschreden (fig. 14 en 18).

6. De verdeling van de droge stof over de verschillende delen van de plant was voor beide grassoorten constant gedurende de vegetatieve groeiperiode (fig. 23). Wan-neer de verhouding *drooggewicht blad/totaal drooggewicht* door afsnijden drastisch werd verkleind trad een herstel van de oorspronkelijke verhouding op doordat tijdelijk naar verhouding meer blad werd geproduceerd.

7. De verdeling van de gevormde droge stof over wortel, stoppel en geoogst gras bleef echter voor de nieuw gevormde droge stof na afsnijden onveranderd ge-handhaafd (fig. 24).

8. Het afsnijden op verschillende hoogte (2½, 5 en 10 cm) had geen invloed op de relatieve snelheid van droge-stofproduktie (fig. 15). Dat planten die het hoogst waren afgesneden toch het hoogste gewicht bereikten kwam door een groter ge-wicht na afsnijden en waarschijnlijk ook door een kortere ,,onderbrekings-periode''.

9. Wanneer planten korter werden afgesneden duurde het langer voordat de oor-spronkelijke verhouding blad drooggewicht/totaal drooggewicht weer was hersteld (fig. 23).

10. Voor de aangroei na afsnijden was knippen op een hoogte van 5 cm optimaal (zie tabel blz. 54).

11. Wanneer de aangroei na herhaald afsnijden werd bepaald bleek de optimale snijhoogte van 5 naar 10 cm te verschuiven (tabel 4).

12. Bij een exponentieel verloop van de droge-stofproduktie bleek een langere periode

tussen het afsnijden het hoogste gewicht te geven. Dit gold zowel de gehele plant als ook het afgesneden gras (tabel 3).

13. Onder constante omstandigheden ook wat betreft hoogte van afsnijden en duur van de aangroeiperiode, bleek het spruitgewicht van de temperatuur afhankelijk te zijn (fig. 30). Het optimum lag bij $\pm$ 20°C (fig. 31). De uitstoeling bleek duidelijk met stijgende temperatuur af te nemen (fig. 29). Doordat bij herhaald afsnijden het verschil in het aantal spruiten bij iedere volgende snede toenam verschoof het temperatuuroptimum geleidelijk naar lagere temperatuur (fig. 27).

14. Een nachttemperatuur van 5° beneden de dagtemperatuur bleek een gunstige invloed op de uitstoeling te hebben (fig. 31). Vergeleken met de constante temperatuur was de grasproduktie hoger doch het spruitgewicht lager (fig. 27).

15. De koolhydraatreserve had geen invloed op de relatieve snelheid van droge-stofproduktie (fig. 19). Evenals dit bij verschillende hoogten van afsnijden het geval was lag de hoogste produktie bij het hoogste reserveniveau veroorzaakt door een hoger aanvangsgewicht en waarschijnlijk ook door een kortere „onderbrekingsperiode". Dit laatste bleek bij *Lolium* duidelijk uit het aantal spruiten (fig. 20).

16. De planten die in de buitenproeven als gevolg van verschillen in behandeling het hoogste gewicht hadden en ook de hoogste koolhydraatreserve bleken het meest van de winter te lijden te hebben (tabel 6, fig. 7 en 8).

17. Gevernaliseerde spruiten hadden aanvankelijk een grotere grasproduktie dan nietgevernaliseerde (tabel 8, fig. 10), doch de laatste stoelden beter uit (fig. 9). Als gevolg daarvan werd bij volgende sneden bij de vegetatieve planten een hogere grasproduktie gevonden (tabel 7).

18. Bij *Lolium* bleek het aantal spruiten veel meer door de uitwendige omstandigheden te worden beïnvloed dan het spruitgewicht; bij *Dactylis* was dit net andersom. Dit blijkt o.a. uit de invloed van afsnijden op het aantal spruiten: *Lolium*, fig. 16 en 20; *Dactylis* fig. 16 en 21.

RESUMEN

1. El efecto de distintos sistemas de corte sobre la producción de dos gramíneas (*Lolium perenne* y *Dactylis glomerata*) ha sido objeto de estudio en experiencias de campo así como bajo condiciones controladas.

2. En general las investigaciones se han llevado a cabo con plantas produciendo materia seca a ritmo exponencial.

3. Al cortar plantas en estado vegetativo no se dañan las yemas situadas en la base del tallo; por ello después de un cierto tiempo plantas que habían sido cortadas produjeron el mismo número de tallos que las que no lo habían sido (cuadro 13). El cortar solamente redujo temporalmente la velocidad de aparición de nuevos tallos (fig. 16 y 20).

4. Cortar redujo la producción de materia total seca durante cierto tiempo (fig. 25 y 26); después de este periodo crítico la producción de materia seca continuó a la misma velocidad que en las plantas no cortadas.

5. Inmediatemente después de cortar el contenido en hidratos de carbono soluble descendió sensiblemente. Más tarde las plantas recuperaron dicho contenido hasta alcanzar el mismo nivel que al principio e incluso sobrepasarlo, siempre que se les permitió crecer bajo condiciones de medio adecuadas durante suficiente tiempo (fig. 14 y 18).

6. La distribución de los aumentos en materia seca entre las diferentes partes de la planta fueron estudiadas. La relación *hoja (materia seca)/materia seca total* apareció ser constante para gramíneas en estado vegetativo (fig. 23). Cuando esta razón se redujo por corte, la velocidad de producción de hoja (cantidad de materia seca) fué aumentada en comparación con las otras partes de la planta, hasta que la antigua relación fué recuperada.

7. La parte de la planta retirada al cortarse se llamó "herbage" (fig. 1). La relación entre el aumento de materia seca de "herbage" y de toda la planta apareció ser también constante para plantas que crecían sin ser cortadas. Inmediatemente después de la siega la producción de "herbage" fue también incrementada relativamente al resto de la planta pero la antigua relación no fué alcanzada de nuevo. En este caso la distribución de los aumentos en materia seca entre "herbage" y el resto de la planta fué siempre la misma antes y después de cortar (fig. 24).

8. Cuando el efecto de cortar (ver 4) fué estudiado a diferentes alturas (2½, 5 y 10 cm), se encontró que esta altura de corte no tenía influencia sobre la velocidad relativa de producción de materia seca (fig. 15). A pesar de ello, plantas más pesadas se encontraron cuando previamente eran cortadas más altas; esto fué debido a un mayor residuo después del corte y posiblemente también a un más corto "periodo crítico".

9. Tardó más en recuperarse la original proporción de hoja/planta total cuando las plantas fueron cortadas más bajas (fig. 23).

10. Para ambas especies una altura de corte intermedia (5 cm) resulto ser óptima en cuanto a producción de "herbage" después de un solo corte (ver cuadro en página 54).

11. Cuando las plantas fueron cortadas repetidas veces una mayor producción de materia seca se registró cuanto más altas fueron cortadas las plantas. La altura de corte óptima para producción de "herbage" se desplazó desde niveles bajos hacia altos a medida que el número de cortes aumentaba.

12. Mientras que las plantas crecían con velocidad exponencial de producción de materia seca, el más largo intervalo entre cortes dió la mayor cantidad de materia seca tanto para toda la planta como para la porción "herbage" (cuadro 3).

13. Bajo un cierto sistema de corte (fijados la altura de corte y el intervalo entre cortes), el peso por tallo apareció ser influenciado por la temperatura (fig. 30). Los tallos más pesados fueron producidos a temperaturas alrededor de los 20°C (fig. 31). La velocidad de producción de tallos era mayor cuando la temperatura era menor (fig. 29). Puesto que el número de tallos se hacía cada vez más importante como determinante de la producción total, la temperatura óptima descendió según aumentaba el número de cortes (fig. 27).

14. Cuando la temperatura durante la noche fué más baja el peso por tallo fué tambien menor (fig. 31) pero la velocidad de producción de tallos fué más alta (fig. 29). Esto tuvo como consecuencia una mayor producción de "herbage" en comparación con plantas sometidas a la misma temperatura día y noche (fig. 27).

15. El nivel de reservas no tuvo influencia en la velocidad relativa de producción de materia seca (fig. 19); exactamente lo mismo que ocurrió con la altura de corte (ver 8). También se encontró alguna evidencia de que la longitud del "periodo crítico" aumentó al disminuir el nivel de reservas. Esto se hizo aparente en el caso de *Lolium* por medio de un más tardío comienzo en el aumento del número de tallos para plantas con una menor concentración de azúcares (fig. 20).

16. Las plantas que menos duramente fueron tratadas en 1961, sufrieron los mayores daños durante el invierno, aunque presentaban los mayores niveles de reservas (cuadro 6, fig. 7 y 8).

17. Tallos vernalizados produjeron más "herbage" que los vegetativos (cuadro 8, fig. 10). Sin embargo, plantas en estado totalmente vegetativo produjeron mayor número de tallos que los vernalizados (fig. 9). Por ello, plantas vernalizadas dieron una mayor cantidad de "herbage" al primer corte y las en estado totalmente vegetativo en los cortes subsiguientes (cuadro 7).

18. Con *Lolium* la producción de tallos paró después del corte durante un cierto tiempo. La duración de este periodo disminuyó cuando aumentaron el nivel de reservas (fig. 20) o la altura de corte (fig. 16). Por el contrario, ninguno de estos factores influyó en la producción de tallos de *Dactylis* (fig. 16 y 21).

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