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Agronomie

Effects of nitrogen applied after the last cut in autumn on a tall fescue sward. I. Analysis of morphogenesis during winter and subsequent growth in spring

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Summary — The effects of applying nitrogen to grass after the last cut in autumn on growth the following spring was investigated in a series trials at Lusignan, west central France. The grass used was tall fescue (*Festuca arundinacea*) cv. Clarine. 0 and 60 kg N · ha^{-1} were applied after a final cut in October in each of 5 years. In two of the trials, 0 and 60 kg N · ha^{-1} were applied also following a November cutting date. Growth the following spring was measured in all trials.

Autumn nitrogen resulted in greater grass yields the following spring, although it had no influence on the spring growth rate. This effect on the earliness of growth in the spring was greater when the nitrogen was applied in October rather than in November.

The leaf elongation rate revealed that, by the end of winter, the lamina length per tiller was the same on the plots that did not receive autumn nitrogen as on those that did. There were more tillers/m^2 in the nitrogen treated plot, however, and it was concluded that herbage yield in the spring was determined by the number of tillers.

tillering – leaf elongation – leaf senescence – earliness of growth

Résumé — Effets d'un apport d'azote après la dernière coupe d'automne sur une prairie de Fétuque elevée. I. Analyse de la morphogenèse durant l'hiver et de la croissance consécutive au printemps. *L'effet d'un apport d'azote, après la dernière coupe d'automne sur une prairie de fétuque élevée, a été étudié sur une série d'essais réalisés à Lusignan. Un apport de 60 kg N · ha^{-1} était réalisé après une coupe de fin d'octobre et comparé à l'absence d'apport pendant 5 années d'expérimentation. Durant 2 années les mêmes traitements ont été également réalisés après des coupes de fin novembre. La comparaison entre les traitements s'effectuait à travers les courbes de croissance de l'herbe au printemps suivant.*

L'apport d'azote d'automne se traduit par une production plus importante au printemps suivant. La vitesse de croissance de l'herbe n'est pas modifiée, seul le démarrage de la croissance est avancé. L'effet de l'apport d'azote est moins net s'il a lieu après une coupe tardive à l'automne.

La quantité de feuilles par talle en fin d'hiver n'est pas modifiée par l'apport d'azote d'automne. Par contre la densité de talle est très nettement augmentée.

La précocité de production de l'herbe au printemps apparaît intimement liée au nombre de talles qui ont été initiées pendant l'hiver.

tallage – allongement des feuilles – sénescence des feuilles – précocité de croissance

Introduction

In previous experiments, it has been shown that the earliness of growth of tall fescue in the spring was closely related to accumulated temperature from the date of the last cut in autumn (Lemaire and Salette, 1982; Lemaire *et al.*, 1982). The need to take into account the temperature during the entire winter indicates that, in the climatic conditions of west central France, growth does occur during winter and it can be concluded that this growth must be supported by adequate nitrogen nutrition.

Some workers have reported favorable effects of nitrogen application in autumn on the growth of grasses in early spring. Gillet *et al.* (1977) have

observed a positive effect on tall fescue. Baker (1960) has shown a positive but small effect on perennial ryegrass, while Thomson (1974) has obtained a very favorable effect on perennial ryegrass. Murphy (1977) reported that the effect of nitrogen applied in autumn was very variable and depended upon management of the sward. From a practical point of view, nitrogen applications in autumn are rarely recommended because of the risk of nitrogen loss by leaching or of increasing the susceptibility of tillers to frost (Hides, 1978; Azzaroli and Skjelvag, 1981). Under normal circumstances, an excess of growth during winter can cause a considerable increase in the proportion of dead material in the sward in spring (Beddows, 1973). For these reasons, autumn nitrogen application is not a common practice. Nevertheless, the available evidence suggests that autumn nitrogen can be used to give early growth in the spring. The objective of this paper is to define the conditions for applying nitrogen in autumn.

Materials and Methods

Experimental field set-up

Three experiments were carried out at Lusignan in west central France on tall fescue (*Festuca arundinacea*) cv. Clarine, to determine the effect of nitrogen applied following the final autumn cut on sward growth the following winter and spring. The experiments were carried out over several years. The experimental treatments are summarized in Table I.

The experiments were carried out on a loam top soil without excess water during winter. The pH of the top soil averaged 6.5. The initial rates of nutrient content in the top 0–20 cm of soil were 300 ppm P_2O_5 and 250 ppm K_2O. Every year adequate phosphorus and potassium fertilizers were applied to maintain a high level of fertility (100 kg · ha^{-1} P; 250 kg · ha^{-1} K).

In each experiment, the treatments were laid out in a randomized block design with 4 or 5 replications. Experiment 1 was carried out on the same sward during three successive years. This sward was sown two years before the beginning of the experiment. After the spring growth measurements, all plots were uniformly cut at the silage stage during the rest of growing season and received equal quantities of nitrogen fertilizer (30 kg · ha^{-1} after each cut). After the final cut in autumn, nitrogen treatments were administered on the same plots. We verified that no effect of nitrogen treatment in autumn persisted after the summer. Experiments 2 and 3 were carried out for only one year on different swards sown two years earlier.

Each plot measured 2.5 x 5 m. Nitrogen fertilizer was applied as calcium ammonium nitrate (27% N) immediately after the final silage cut in autumn, according to the treatment (see Table I). At the end of winter (Feb./Mar.) nitrogen fertilizer was applied to all treatments at a rate equivalent to 60 N kg · ha^{-1} in experiments 1 and 2 and at a rate equivalent to 120 N kg · ha^{-1} in experiment 3.

Crop measurements

At 3-week intervals following the autumn fertilizer application, aerial biomass was determined on eight curves (each 0.375 m^2 selected at random from each

Table I. Summary of experimental treatments.

Experiment	*Year*	*Number of replications*	*Final autumn harvest*	*Nitrogen rate in autumn* N kg · ha^{-1}	*Nitrogen rate in spring* N kg · ha^{-1}
1	1979-80	5	28 Oct.	0	60
				60	60
	1980-81	5	25 Oct.	0	60
				60	60
	1981-82	5	24 Oct.	0	60
				60	60
2	1983-84	4	27 Oct.	0	60
				60	60
			18 Nov.	0	60
				60	60
3	1984-85	4	23 Oct.	0	120
				60	120
			19 Nov.	0	120
				60	120

plot. The biomass was separated into green lamina, green sheath and dead material. Tiller numbers were determined from the same samples.

In experiments 2 and 3, leaf elongation and leaf senescence rates were determined by twice-weekly measurement of total green and total chlorotic lamina length on each of 20 labeled tillers in each treatment. From late March the accumulation of herbage over a stubble height of 50 mm was measured by cutting with a reciprocating blade mower. The main plots were divided into subplots (2.5 x 0.6 m). One subplot was cut on each cutting date. Subplot regrowth was not measured.

Climatic conditions were recorde da ta meteorological station located close to the experimental site.

Results

Climatic conditions

Mean daily air temperature data for each experimental period is given in Table II. Pertinent features of the data are summarized in Table III.

Treatment effects on spring growth

In each year of experiment 1, the autumn treatments had no effect on the rate of herbage accumulation the following spring (Fig. 1). The yield differences between treatments in the spring were established during the the winter. The yield differences in the spring due to nitrogen application after a final cut in October ranged from 0.5 to 1.5 t · ha^{-1} (DM). The response to nitrogen was less when the final cut and nitrogen application were delayed to November in experiment 2 or when the winter was extremely cold, as in experiment 3 (Fig. 2). The effect of the autumn harvest date was also reduced after the cold winter of experiment 3 compared to experiment 2.

Growth of aerial biomass during winter

Nitrogen treatment effects on leaf lamina biomass were established by mid-December in all years in the case of the October final harvest treatments (Fig. 3). Lamina biomass tended to remain constant from December to February, although it increased in the mild winter of experiment 2 and decreased in the cold winter of experiment 3 (Fig. 4). When the lamina biomass began to accumulate after February, the differences in the biomass between nitrogen treatments increased except for the winter 1979-80. Sheath biomass data of experiment 1 showed broadly similar trends, although sheath biomass tended to decline during the December/February period (Fig. 3). The dead biomass was similar

Table II. Mean daily air temperature (°C) during the different winters of study.

Year	*November*			*December*			*January*			*February*			*March*		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1979-80	10.7	6.5	5.3	10.1	7.5	2.7	4.3	−1.5	5.0	9.1	6.3	5.3	5.5	5.9	8.3
1980-81	3.4	7.4	6.2	1.7	5.1	4.2	4.9	4.7	4.2	6.0	0.8	3.2	9.8	8.4	11.9
1981-82	7.5	7.0	7.1	5.8	5.7	5.7	7.8	6.9	5.5	8.4	6.4	2.7	6.8	6.9	7.2
1982-83	12.4	8.6	5.8	7.7	6.8	5.0	6.5	4.6	6.6	4.1	−0.3	7.4	6.6	8.8	7.1
1984-85	11.5	8.6	10.3	7.4	5.5	2.4	−3.6	−4.7	6.4	9.7	1.9	5.7	7.0	3.5	7.7

Each month is divided into three 10 day intervals.

Table III. Summary of temperature conditions in each experiment.

Experiment	*Year*	*Comment*
1	1979–80	mild autumn, frost mid-December and mid-January
	1980–81	cold autumn, frost mid-February, mild March
	1981–82	continuously mild
2	1982–83	mild except frost mid-February
3	1984–85	mild autumn–early winter, extreme cold subsequently

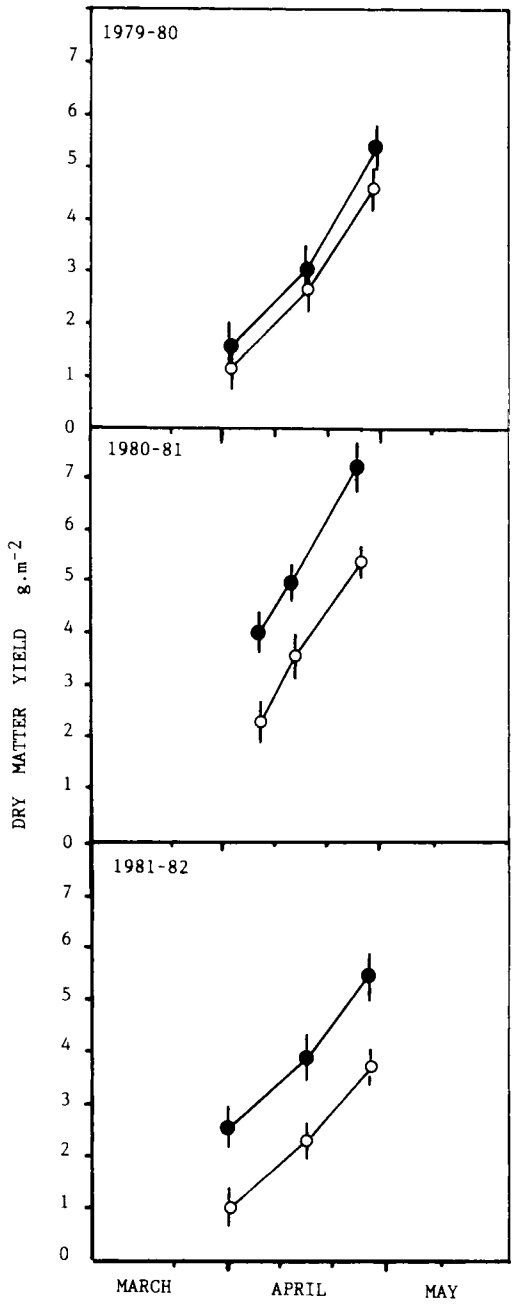

Fig. 1. Spring growth (net herbage accumulation) of tall fescue as affected by nitrogen application in autumn in Expt. 1. ○ : 0 kg N · ha^{-1}, in autumn; ● : 60 kg N · ha^{-1} in autumn. Vertical bars represent the confidence interval (f = 0.95).

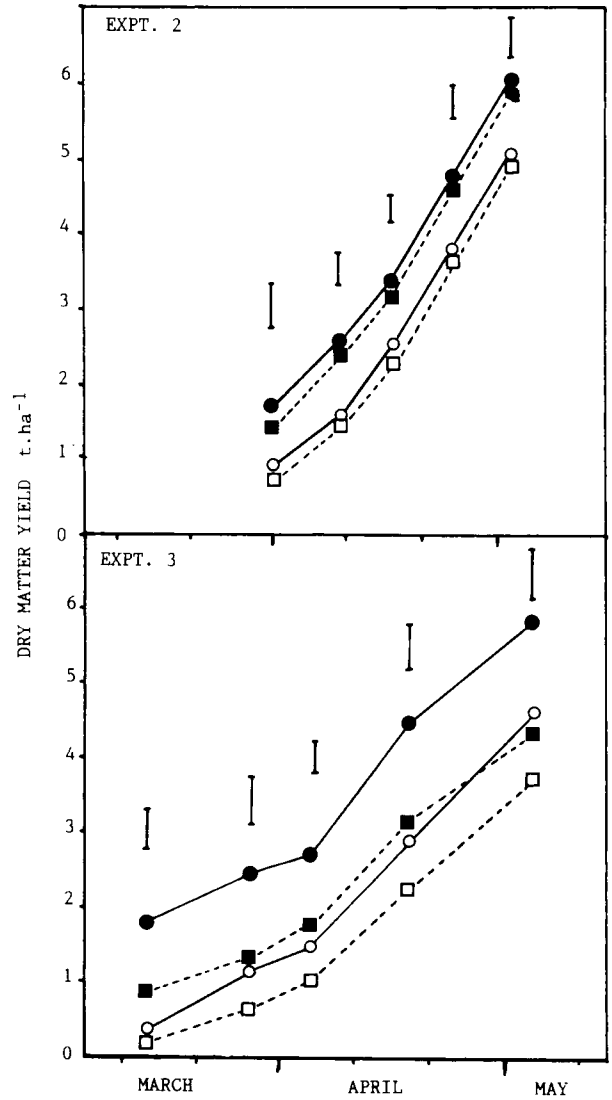

Fig. 2. Spring growth (net herbage accumulation) of tall fescue as affected by date of last cut and nitrogen fertilization in autumn (Exps. 2 and 3). Early cut (D1) : ○ : 0 kg N · ha^{-1}; ● : 60 kg N · ha^{-1}; Late cut (D2) : □ : 0 kg N · ha^{-1}; ■ : 60 kg N · ha^{-1}. Vertical bars represent L SD (P = 0.95).

for all treatments and remained constant (300-350 g · m^{-2}) through the winter. This indicates that the rate of decay of dead leaf material was equal to the rate of leaf senescence.

In the later autumn harvest treatments in experiments 2 and 3, the nitrogen effect on leaf lamina biomass did not become apparent until after January (Fig. 4). It can be noted that compared with results of experiment 2, the severe frost during the winter of experiment 3 had considerably reduced the effect of the date of the autumn cut, but had not substantially changed the effects of nitrogen.

Tillering rate during winter

Fig. 5 shows the changes in the number of tillers during the three years of experiment 1. At the end of autumn, there were generally between 3000 and 4000 tillers m^{-2}. During the winter of 1979-1980, tillering was low. Even with an application of 60 kg N, only 5500 tillers m^{-2} were counted at the end of winter compared with 12 000 m^{-2} in 1980–1981 and 9000 in 1981–1982.

The effect of nitrogen was important and persisted until mid-February. In contrast to dry mat-

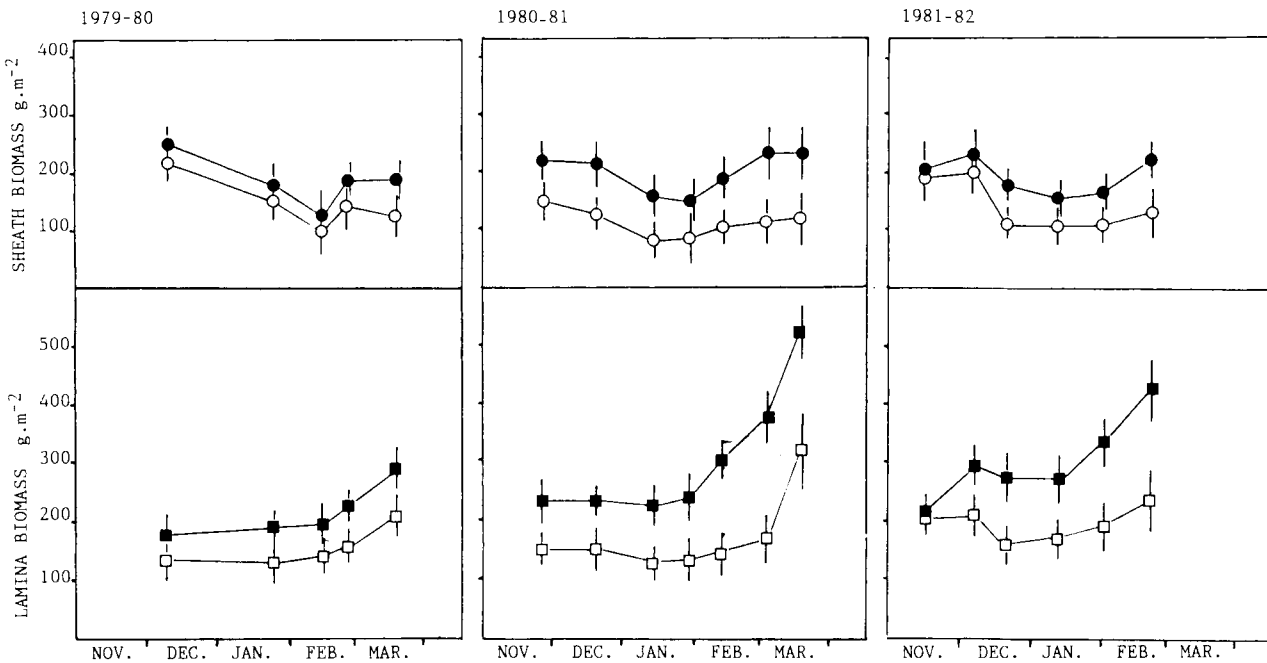

Fig. 3. Changes in sheath and lamina biomass during winter as affected by nitrogen application (Exp. 1). ○ □ : 0 kg N · ha^{-1}; ● ■ : 60 kg N · ha^{-1}. Vertical bars represent the confidence interval ($P = 0.95$).

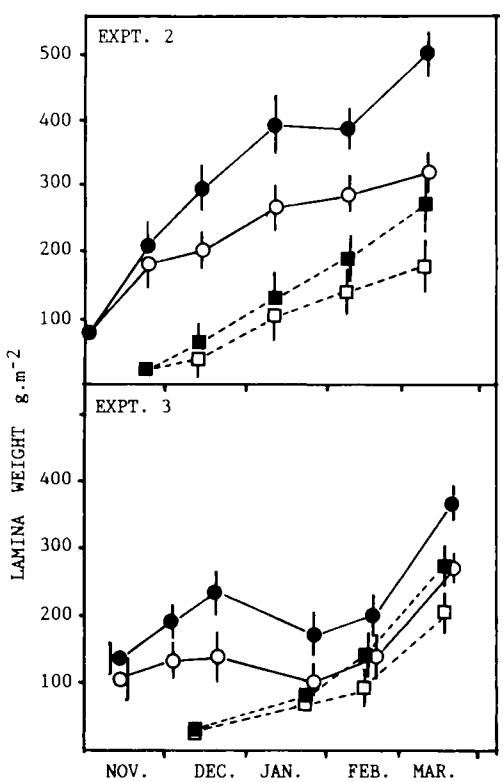

Fig. 4. Changes in lamina biomass during winter as affected by the date of last cut and the nitrogen application in autumn for Exps. 2 and 3. After an early cut (D1) : ○ : 0 kg N · ha^{-1}; ● : 60 kg N · ha^{-1}; After a late cut (D2) : □ : 0 kg N · ha^{-1}; ■ : 60 kg N · ha^{-1}. Vertical bars represent the confidence interval ($P = 0.95$).

ter accumulation which remained relatively constant during winter, tillering was continuous and the effect of nitrogen on tiller numbers increased with time.

Fig. 6 shows the effect of the date of the cut and nitrogen application in autumn on tillering. In experiment 2, during the regrowth from the early autumn cut, tillering in the nitrogen treated plots increased until the middle of January and then it stabilized after this. For the later autumn cut, there was no effect of nitrogen during the early part of the winter and it appeared, with a reduced effect, in February and March.

In experiment 3, during the regrowth after the early cut, the increase in the number of tillers caused by nitrogen application was stopped by the severe frost period at the end of December and it started again when the weather conditions improved. By 20 March, there were 5200 tillers m^{-2} in the plot without N and 6500 m^{-2} in those receiving 60 kg N ha $^{-1}$. After the late cut, the effect of nitrogen was only evident at the end of winter and there were 4300 tillers m^{-2} in the plots without N and 5600 tillers m^{-2} in the N plots. The gain in tillers (1300) was similar to that achieved by nitrogen application after the early cut. Despite the severe frost, no tiller mortality was observed, and this was confirmed on labeled tillers. The leaf appearance interval showed a small reduction only as a result of nitrogen application : 265 degree days for N30 and 240 degree

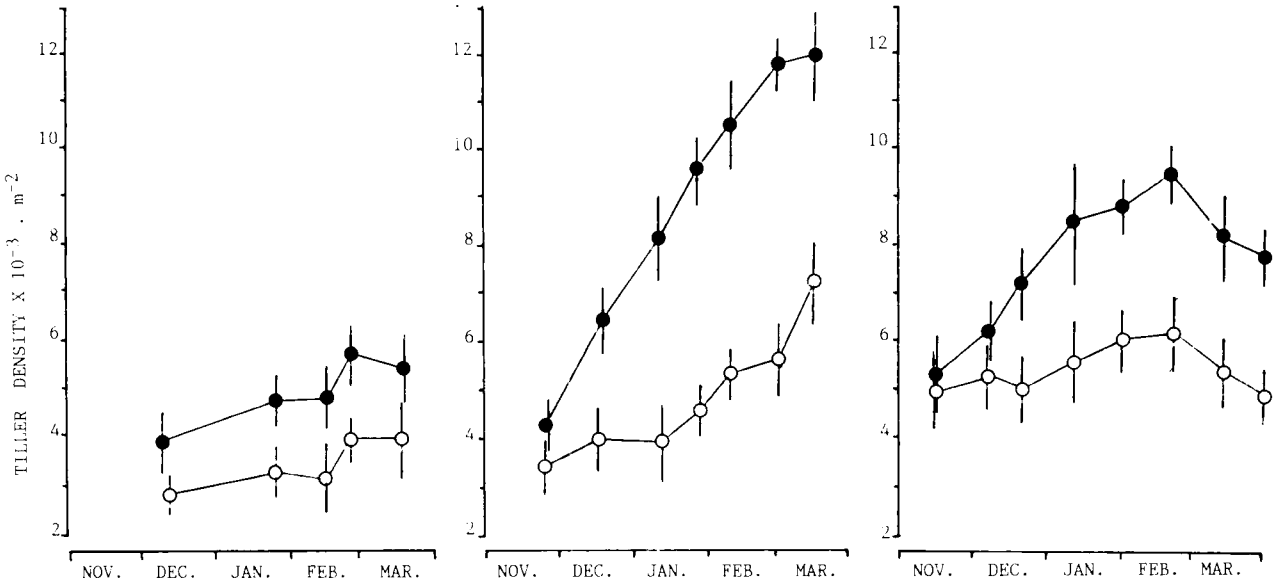

Fig. 5. Pattern of tillering during winter as affected by nitrogen application in autumn (Exp. 1). ○ : 0 kg N; ● : 60 kg N. **a.** 1979–1980; **b.** 1980–1981; **c.** 1981–1982. Vertical bars represent the confidence interval ($P = 0.95$).

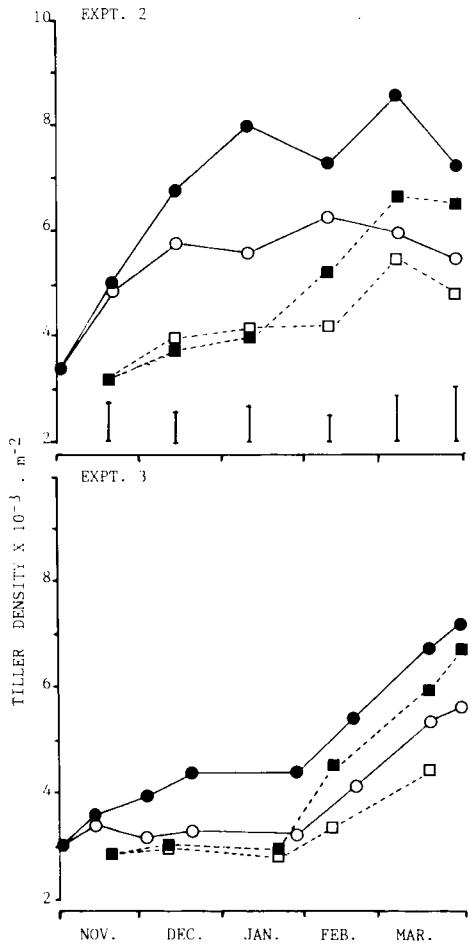

Fig. 6. Pattern of tillering during winter as affected by the date of the last cut and nitrogen application in winter for Exps. 2 and 3. Early cut (D1) ○ : 0 kg N · ha^{-1}; ● : 60 kg N · ha^{-1}; Late cut (D2) □ : 0 kg N · ha^{-1}; ■ : 60 kg N · ha^{-1}. Vertical bars represent 1 SD ($P = 0.95$).

days for N90 during the winter of 1982-83. So the main effect of N on tillering rate was obtained by a higher proportion of sites to be taken up.

Elongation and senescence of leaves

The curves in Fig. 7 represent the changes in the length of the green lamina on tillers which were labeled at the time of the autumn cut in 1982-1983 and again in 1984-1985.

After the early autumn cut, a period of rapid elongation was observed and a maximum leaf length of 30 cm tiller^{-1} was obtained on 29 December in 1982-1983 and 24 cm tiller^{-1} on 17 December in 1984-1985. This difference cannot be related to temperature. Afterwards, for both years, the length of the green lamina per tiller decreased steadily. This decrease was the result of the senescence of the first leaf per tiller that appeared after the autumn cut. The senescence of the first leaf began only when the third leaf appeared. By mid to late December, each tiller had an average of three leaves (two adult leaves and one young elongating leaf). Due to the turnover of leaves, this number of 3 leaves per tiller remained constant throughout the winter (Lemaire, 1985).

In both years, the advantage of the rapid growth after the early autumn cut was totally lost by the end of winter: long leaves were replaced by new shorter leaves growing at a lower temperature. Similarly, the effect of nitrogen after the early cut was at a maximum at the end of December and it decreased during the winter, and in 1984-1985 it disappeared completely. At

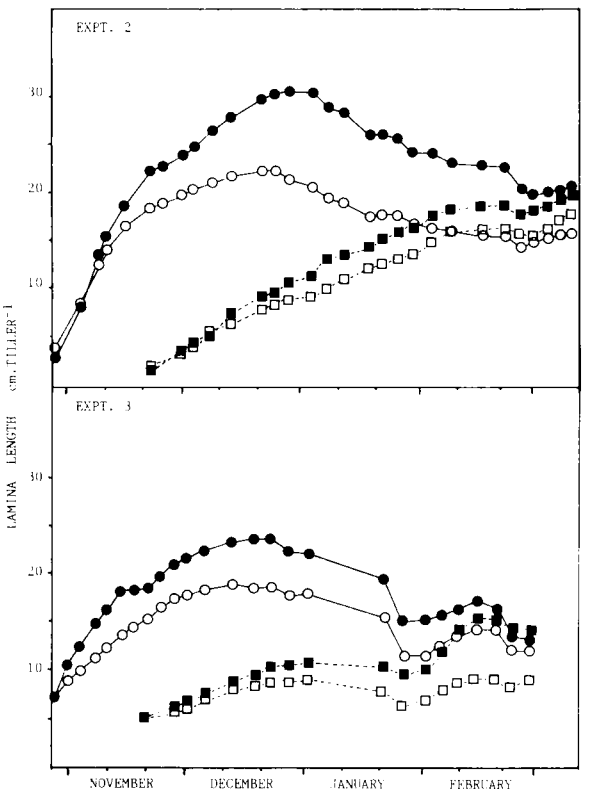

Fig. 7. Changes over time in the length of green leaves on labeled tillers during winter as affected by the date of the last cut and nitrogen application in autumn for Exps. 2 and 3. Early cut (D1) : ○ : 0 kg N · ha^{-1}; ● : 60 kg N · ha^{-1}. Late cut (D2) : □ : 0 kg N · ha^{-1}; ■ : 60 kg N · ha^{-1}.

the end of February, the total leaf length per tiller ceases to decrease and begins to rise. This corresponds to an increase of the leaf elongation rate which occurs simultaneously with the change of apices from the vegetative to the reproductive stage (Parsons and Robson, 1980; Lemaire, 1985).

Discussion

The data in Figs. 1 and 2 show that, although autumn nitrogen application affects the yield of herbage in spring, it has no effect on the rate of herbage accumulation in spring. These results were observed consistently during the 5 years of the experiments.

Such consistency is particularly significant against the background of the wide year to year variation in over-wintering temperature patterns. It is also important to note that the same result was obtained in the case of both October and November final harvests.

The labeled tiller data of experiments 2 and 3 (Fig. 7) indicate that the treatment differences in biomass yield in spring is mainly the result of treatment effects on tiller numbers. Differences in lamina yield per tiller due to autumn management were small.

The absence of any effect of autumn management on the rate of herbage accumulation in the spring suggests that the model of Lemaire and Salette (1982) may be used to estimate temporal changes in herbage yield in the spring, as a function of cumulative temperature from the beginning of spring growth without taking autumn management into account. However, in the spring, it is not only important to be able to estimate the rate of herbage accumulation but it is also important to be able to estimate the yield present from day to day. The model requires a value for the constant representing the cumulative temperature from the date of the last harvest in autumn to the beginning of spring growth (a_0 and a_N in Fig. 8). This coefficient has only a mathematical significance because at the beginning the growth curve is not linear. That is the reason why we prefer to determine the "earliness of growth" in the spring as the cumulative degree days required from the autumn harvest to achieve a yield of 1.5 t · ha^{-1} (a'_0 and a'_N in Fig. 8). The data of this study show that the value of a' is influenced by autumn nitrogen application and the final harvest date through their effect on tiller numbers. The Lemaire–Salette model has been applied to the spring yield data of experiments 1–3. The estimated values of a' were closely related to the tiller numbers present at the end of the winter (Fig. 9). A given yield was reached earlier when the number of tillers developed during winter was high.

The practical application of the model would be enhanced if it included the capacity to estimate tiller numbers at the end of winter. The over-wintering trends in the lamina biomass and tiller number show that, after the October harvest, both lamina biomass and tiller number increased. The rate of lamina biomass increase, due in part to lamina increase per tiller and in part to the tiller number increase, declined to zero as the individual tillers achieved the equilibrium leaf number, 3. Subseqently the biomass remained constant. The loss of lamina biomass per tiller (Fig. 7) was offset by the continued increase in tiller numbers (Fig. 6).Tiller numbers continued to increase through the winter, although at a progressively declining rate due to a lower site filling. The site filling is largely determined by the radiation flux density at the base of the sward (Davies *et al.*, 1983). Radiation flux density at the base of the sward is determined by radiation flux density incident at the sward surface and canopy density. This latter is determined by tiller number and by leafiness per tiller. Brere-

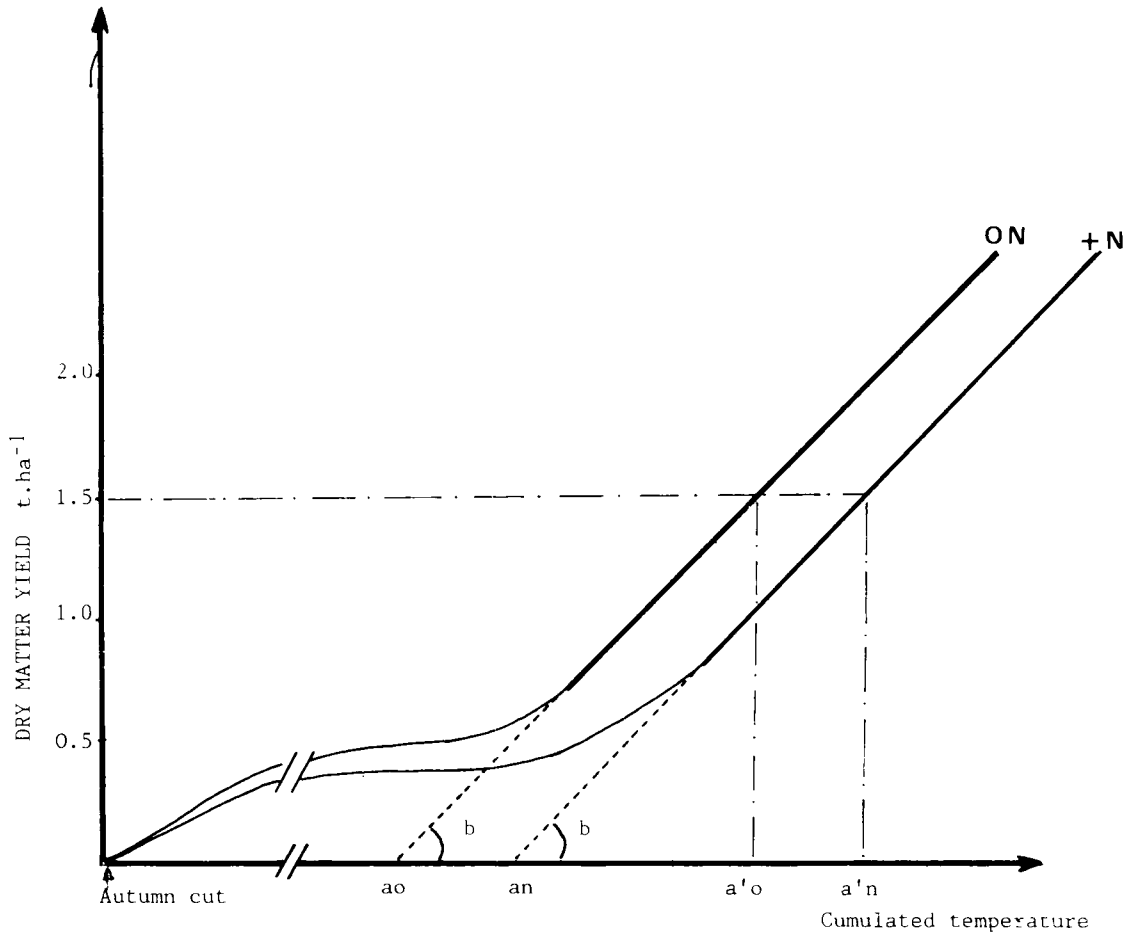

Fig. 8. Effect of nitrogen application in autumn on the parameters of the model of grass growth in the spring according to (Lemaire and Salette, 1982); DM yield = b ($\Sigma\theta$ $-a$) where b = growth rate; a = apparent starting of growth; a' = "earliness of growth": cumulative degree days required from the autumn harvest to achieve a yield of 1.5 t · ha^{-1}.

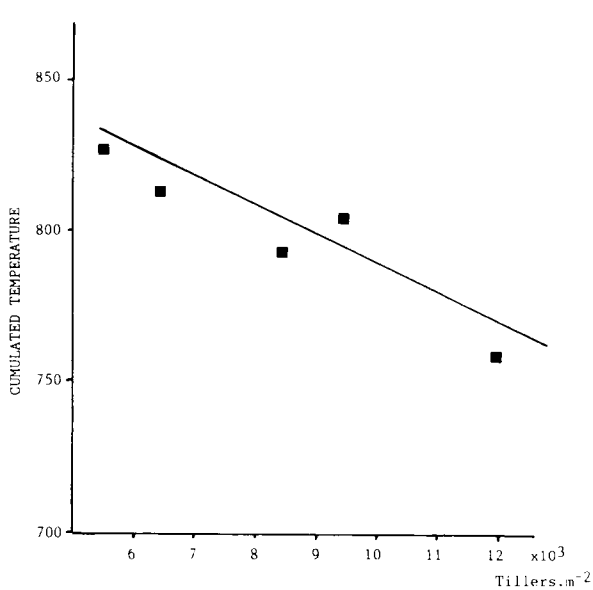

Fig. 9. Effect of the number of tillers at the end of winter on the earliness of growth in the spring expressed by ($\Sigma\theta$) 1.5 = temperature cumulated from autumn out necessary to obtain a given yield of 1.5 t · ha^{-1} DM (Lemaire *et al.*, 1982).

ton *et al.* (1985) have shown that, in an Atlantic climate area of Europe at 52° latitude, tillering and leaf expansion rates are restricted by radiation and temperature, respectively, in perennial ryegrass during the winter. Simon and Lemaire (1987) have shown that tillering ceased when the *L.A.I.* of the sward reached a value of 3, which corresponds to the extinction of radiation flux density at the base of the sward. The existence of such a limit of *L.A.I.* for tillering can help to explain some contradictory effects of temperature. Too low a temperature reduces tillering by a lack of site (low leaf appearance rate), on the other hand, too high a temperature accelerates leaf elongation and the *L.A.I.* of 3 is reached earlier. This phenomenom can lead to a lower tiller density compared to that obtained at a medium temperature.

The extension of the Lemaire–Salette model to incorporate the capacity to estimate initial yield in the spring will require the examination of the quantitative relationships between leaf area expansion, tiller number, temperature and radiation.

Conclusions

Nitrogen application after the last cut in autumn has an important effect on growth in the following spring, even under cold conditions like the winter of 1984-1985. This effect is on the date of initiation of growth, but does not modify the subsequent growth rate. These results have been obtained with a species characterized by a low tiller density. The effect of nitrogen application in autumn would be less important with species having high tiller density, such as perennial ryegrass.

The nitrogen nutrition of tall fescue acts mainly by increasing the tiller numbers and this effect lasts through most of the winter. The effect of nitrogen on leaf elongation in the first part of the winter is largely counterbalanced by an increase in leaf senescence in the second part.

We can therefore hypothesize that the effect of nitrogen in autumn would be greater when conditions are more favorable to tillering. If the temperature after the last cut in autumn is too high, leaf elongation rates on existing tillers will be very high. This can have the effect of self-shading which would cause tillering to cease.

In the same way, management with frequent cuts in autumn would stimulate tillering and would therefore encourage a greater effect of nitrogen application in autumn (Murphy, 1977).

An analysis of nitrogen uptake by the sward during the winter is necessary for a fuller understanding of the effects observed on dry matter accumulation. This aspect will be treated in another paper (Lemaire and Culleton, 1989).

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