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Growth factors and management technique used in relation to the developmental rhythm and yield formation pattern of a pure grass stand

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Abstract. The investigation of meadow fescue as a forage crop was carried out at the University of Helsinki in Viikki in 1975—78. The main objective was to study the rhythm of the growth and yield formation pattern of a stand and the relationship between growth pattern and growth factors during different phases of the growing season. The management techniques studied were the number of cuttings, use of nitrogen, requirements of population density and the relationships of management factors to the changes in the quantity and quality of forage yield.

The most important growth factors in the seeding year spring and autumn development were the temperature sum and the total radiation available to the plant and nitrogen fertilization beyond the temperature sum range of Σ 500° C, respectively.

During the production years the most important variables in the spring growth were the growing time, the temperature sum and the total radiation. The midsummer and autumn growth were mostly influenced by the total precipitation, amount of nitrogen for the cut and the precipitation during the week before the prior cut.

For spring, summer and autumn growth one unit increase in LAI created a DM yield increase of 715, 500 and 315 ha^{-1} respectively.

Increasing the cutting frequency from two to four decreased the total DM yield 2 527 kg ha^{-1}. The protein content and DM cellulase digestibility increased 4.8 and 13.3 % units respectively. Increasing nitrogen from 130 to 260 kg N ha^{-1} raised DM and protein yields 1 110 and 485 kg ha^{-1}, the protein content and DM cellulase digestibility 4.2 and 1.4 % units. The seeding rate requirements for the maximum DM yield were 60 kg ha^{-1} in the seeding year, 15—30 kg ha^{-1} in the second year and 15 kg ha^{-1} in the third year.

The management system involving a seed rate of 30 kg ha^{-1}, 3—4 cuts and 260 kg N ha^{-1} is recommended.

1. Introduction

The growth and development of a forage crop follows a S-shaped growth pattern. The shape of the growth curve is defined by the growth factors, the management technique used and the utilization of the crop. A plant's growth and development are dependent on the environmental factors surrounding the crop. Of these factors, the most important are the growth medium's characteristics, the amount of light, temperature, the amount of available water and the availability of nutrients. The most effective utilization of the feeding material in order to meet economic constraints and forage feeding standard requirements is achieved through proper management techniques. It is important to know the quantity and quality changes connected to the plant's stage of development. These factors, combined with the intended use of the forage, determine its cutting schedule. Although many previous investigators (Huokuna 1964, Raininko 1968, Poutiainen and Rinne 1971, Syrjälä 1973—78, Salo et al. 1975, Rinne 1977, Hakkola 1978) have fundamentally described the relationships between growth stage and the cuttings schedule, the relationships between growth stage and growth factors demand more investigation. In addition, while energy prices continue to rise, the quantity of the nitrogen fertilizer and the time of its application during the growing season are becoming increasingly more important factors affecting the economic gains of forage production.

When establishing a stand without a companion crop, and the stand will be harvested in the year of seeding, the seeding rate needs to be taken into consideration, even more so than when using a companion crop. The observation is supported by the fact that since the studies during the 1940's and 1950's (Pohjakallio 1941, Salonen 1951, Paatela 1953, Laine 1955 and 1958) relatively few studies have been conducted in Finland dealing with seeding rates and crop establishment techniques related to the population density.

In this investigation the primary aim was to study the effects of cutting frequency, nitrogen fertilization and seed rates on the growth, development and yield formation of a forage stand. The investigation's second objective was to study the relationships between the crop's development and harvest rhythm and their relationships to the growth factors at different phases throughout the growing season. The growth analysis studies by the means of regression models has first used in Finland by Brummer (1961). The investigations were conducted in 1975—78.

2. Material and methods

Experimental design

The field trials were established on the Helsinki University farm in Viikki in 1975. The plots were organized in the following ways:

Experimental design: Split-plot

Main plot: Cutting treatments
1. 2-cut
2. 3-cut
3. 4-cut

Sub-plot: Nitrogen fertilization
1. 130 kg N ha^{-1}
2. 260 kg N ha^{-1}

Sub-sub-plot:	Seeding densities	
	1. 325 seeds m^{-2} (7.5 kg ha^{-1})	
	2. 650 seeds m^{-2} (15 kg ha^{-1})	
	3. 1 300 seeds m^{-2} (30 kg ha^{-1})	
	4. 2 600 seeds m^{-2} (60 kg ha^{-1})	
Reps	Three	

The plots were established on an eastward facing slope. The soil type was fine sand and the variety was Tammisto meadow fescue.

Fertilization and plant protection

In the spring of the seeding year the basic amount of commercial fertilizer mixture was 675 kg ha^{-1} NPK (15—25—15), which represents 100 kg N ha^{-1}.

After the first cut a higher nitrogen level was used. The 1975 nitrogen levels were:

100 N = 100 kg N ha^{-1}
200 N = 200 kg N ha^{-1}

In the spring of 1976 and 1977 the basic application of commercial fertilizer mixture was 1 000 kg PK ha^{-1} (2—15—15). The amount of nitrogen per cut was applied as follows (Nos = 27—0—0):

		130N	260N
2-cut system:		130N	260N
	In spring	200 kg Nos ha^{-1}	435 kg Nos ha^{-1}
	After 1st cut	200 kg Nos ha^{-1}	435 kg Nos ha^{-1}
3-cut system:		130N	260N
	In spring	100 kg Nos ha^{-1}	270 kg Nos ha^{-1}
	After 1st, 2nd cuts	150 kg Nos ha^{-1}	300 kg Nos ha^{-1}
4-cut system:		130N	260N
	In spring	100 kg Nos ha^{-1}	220 kg Nos ha^{-1}
	After 1st, 2nd, 3rd cuts	100 kg Nos ha^{-1}	220 kg Nos ha^{-1}

To study the management effects in 1978 all of the treatments received 500 kg ha^{-1} (15—15—15) which represented 75 kg N ha^{-1}. A herbicide (dinoseb, 1.6 kg ha^{-1}) was applied to control broadleaf weeds and a watering schedule of 4 × 30 mm was followed to ensure germination after seeding.

Cutting and yield procedure

During the seeding year the plots were cut twice:

First cut — 8 August
Second cut —29 September.

For the actual production years 1976—77 the cutting schedule was as follows:

		1976	1977
2-cut system:		1976	1977
	1st cut	2 July	27 June
	2nd cut	27 September	27 September
3-cut system:			
	1st cut	18 June	13 June
	2nd cut	27 July	28 July
	3rd cut	27 September	27 September
4-cut system:			
	1st cut	4 June	2 June
	2nd cut	8 July	6 July
	3rd cut	10 August	18 August
	4th cut	27 September	27 September

In order to investigate the management post effects the stand was harvested on 19 June 1978.

Two 200 g samples of chopped forage material were taken and dried for 24—36 h at 100° C. The raw protein and digestibility samples were taken and dried for 24—36 h at 70° C.

The raw protein content of the dried and ground samples was determined according to the Kjeldahl method. For determining the digestibility of DM, the one-stage chemical method of JONES and HAYWARD (1973) was employed (PULLI 1976).

Crop growth and yield analyses

The leaf area index (LAI) and the overall height of the crop were measured weekly during the seeding year throughout the growing season. In 1976—77 both the LAI and height of the crop were determined weekly in the spring and in the summer and fall cuttings.

Leaf area was measured with leaf planimeter, an optical instrument model K_1 designed and built by the Technical university of Helsinki.

During 1976 the raw protein content and the cellulase digestibility of dry matter were measured weekly throughout the spring, summer and autumn. In 1977 over the same time period also the development of the dry matter content was recorded in addition to the raw protein and digestibility factors.

3. Weather conditions

The average temperatures and amount of precipitation for 1975—77 and the long term average are presented in Table 1. The temperature sum in degree days ($\Sigma > 0°$ C) and the total amount of solar radiation (ΣWh cm^{-2}) from the seeding day in 1975 and from the beginning of the 1976—77 growing season to the last cutting day are shown in Fig. 1. The meteorological data was obtained from the Malmi airport station 1.5 km from the experimental fields. On the average, summer 1975 was warmer and drier than the long-term average. The mean temperature of June fell slightly below the long-term average and precipitation was exceptionally low from June to August.

Table 1. Average temperatures (°C) and precipitation (mm) May—Sept. in 1975—77 at Malmi airport.

Month	Temperature °C				Precipitation mm			
	1975	1976	1977	1931—60	1975	1976	1977	1931—60
May	11.7	10.7	9.4	8.4	38	27	22	41
June	13.7	13.0	14.4	14.1	12	42	36	47
July	18.0	15.9	14.7	17.2	26	52	122	68
Aug.	16.6	15.2	14.5	15.6	29	45	47	70
Sept.	13.3	8.1	8.3	10.5	53	48	73	66
Avg	14.7	12.6	12.3	13.2	Σ 158	214	300	292

In 1976, May was, on the average, warmer and less rainy. From June to the end of July the weather was cool and drier than the long-term average. The rains in August were concentrated in the beginning of the month. September was cool. The radiation energy conditions were comparable to those for 1975.

The 1977 growing season wound up being cooler than the long-term average. The greatest negative deviation from the average occurred in July, September was even cooler than in 1976. May, June and August were, under the conditions, somewhat drier, but July was very wet and September matched the long-term average. In 1977 the total radiation decidedly fell below the 1975—76 sum especially in July, which was exceptionally cloudy and rainy.

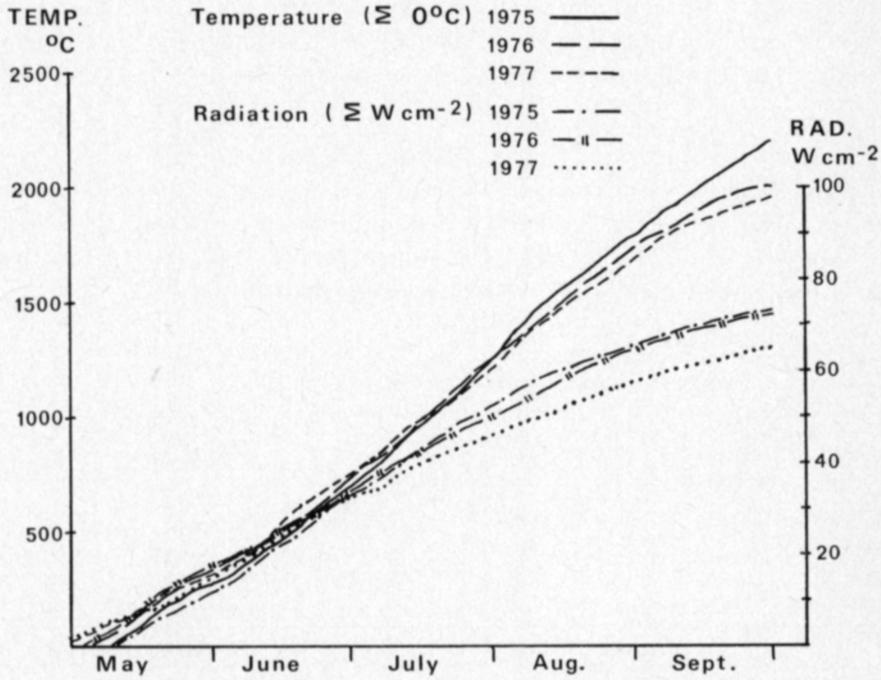

Fig. 1. Total amount of radiation (Σ Wh cm^{-2}) and temperature in degree days ($\Sigma > 0°$ C) in the experimental area during 1975—77.

4. Results and discussion

4. 1. Development and Growth of Seeding Year Stand

4. 1. 1. Population density

Numerous investigations have shown that an individual plant's development is not affected by the stand density as long as the plant's space requirements are met. As soon as the space limit is reached and exceeded, then the interplant competition, by reducing the rate of plant growth, brings about a smaller plant size. The reduction in growth rate occurs earlier and more strongly the denser the stand is (Donald 1951 and 1963, Baeumer 1964, Murtagh and Gross 1966). Increasing density reduces the amount of individual plants already in the germination stage (Braun-Blanquet 1964, Norrington-Davies and Harries 1977), but even more so as the stand develops under particularly dense conditions. In a well spaced stand changes in the number of plants are few. However, over time the number of individuals associated with different population densities turn out to be the same because a perennial forage crop has the tendency, under prevailing competition and constant growing conditions, to gradually reach an adjusted population density (DONALD 1951, HARPER and GAIJIC 1961). In addition to the intraspecific competition also, the management technique, crop's age and, especially under Finnish growing conditions, wintering affect the population density and the yield of the invidual plant. BAKER (1957) and BAKER and GARWOOD (1959) oberved in a stand that was cut frequently a considerably larger amount of individuals at the end of the growing season than in a nonmowed stand.

Results

The established stand emerged 12 days after seeding at all of the seeding densities. The first growing density measurements were taken three weeks after establishment (29 May) and the second set was taken on 3 July, eight weeks after establisment. The results are presented in Table 2.

Table 2. Stand density development in the seeding year in 1975.

Seeding rate			Density June 10		Density July 3	
Kg ha^{-1}	Seeds m^{-2}		Plants m^{-2}	%	Plants m^{-2}	%
7.5	325		109	33.5	202	62.2
15	650		207	31.9	239	37.8
30	1 300		405	31.2	414	31.9
60	2 600		959	36.9	386	14.9
		Avg.	420	33.4	310	36.7

Despite relatively good soil conditions emergence was only 33.4 %. At the time of emergence there were no significant differences in the percentages of emergence between densities. Severe competition factors developed in June and the stand with the greatest density experienced considerable thinning in July. The greatest plant density was achieved with the seeding rate of 30 kg ha^{-1} The final emergence percentage dropped very sharply with increasing seeding rate (Table 2).

4.1.2. Development of LAI and plant height

In a young forage stand the assimilated LAI is directly proportional to the population density. At the early stage of development the crop's growth is much more rapid under dense condititions than those of more space, resulting in the occurrence of an optimum LAI first in the dense stands (DAVIDSON and DONALD 1958, DONALD 1963).

Along with the seeding density the LAI is affected also by the number of shoots. According to HUOKUNA (1966) grass produces shoots more abundantly at low seeding rates rather than at high ones, but the differences in the number of shoots affecting yield level have major importance only during the three first months after seeding.

Under spaced conditions a crop in the early stages of development produces noticeably more leaves than under dense conditions (THOMAS 1974). SCARISBRICK and IVINS (1970) point out that frequent cutting significantly reduces both the number of shoots and the number of leaves per shoot in all cuttings.

As the growing density increases the net assimilation rate (NAR) tends to decrease. If the competition for light is severe, the decrease is relatively rapid (BLACKMAN 1968, KVET et al. 1971). NISHIMURA and NITTA (1974) observed the net assimilation rate and cross growth rate (CGR) to be higher in well spaced stands than in dense ones, irregardless of similar LAI values.

With nitrogen fertilization it is possble to obtain the proper LAI optimal for high production and to maintain it (DONALD and BLACK 1958).

The effect of nitrogen on the leaf area has good duration throughout the entire growing season (WATSON 1956). Phosphorus increses leaf area only in early stages of development and later, during ripening, it hastens the reduction of the LAI. Potassium, on the other hand, when applied in the later stages of growth is an effective agent for reducing the phosphorus influence (WATSON 1956).

The height increase of a forage crop follows a sigmoidal curve. In the early stages of development there are relatively little height growth and leaf size increases. During stem development height growth is the greatest. Maximum height is attained in the stage of flowering. Of the factors influencing height growth, temperature accounts for 75—96 % of the result (HARI and LEIKOLA 1974). According to MITCHELL (1956) the optimal temperature for leaf growth of a forage crop in cool areas is 18—21° C, resulting in daily increases of 1—5 cm for various grasses.

A reduction in the amount of light results in intense competition for light and height growth of the stand increases (HAN et al. 1977). Height growth will continue to increase until the light intensity reaches 50 % of full daylight. Any further reduction in light intensity causes a reduction in height growth because the shading becomes too great (KAMEL 1959). This has a significant influence, particularly on fall plant growth (POHJONEN and HARI 1973).

Results

For all seeding densities the initial increases in LAI and height growth were similar in the early stages of the seeding year. Only for the density of 325 seeds m^{-2} was the LAI constantly below the values by a slight amount (Fig. 2).

The early phase of the seeding year LAI and height growth were best described by the following regression equations (Fig. 3):

a) Growing days = X

LAI: $Y = -1.0429 + 0.116769X - 0.002755X^2 + 0.000024X^3$ ($R = .9923^{***}$)

cm: $Y = -5.57404 + 0.501106X - 0.00349X^2 + 0.000035X^3$ ($R = .9972^{***}$)

b) Temperature sum Σ °C = X

LAI: $Y = -0.444758 + 0.00325X - 0.0000037X^2 + 0.0000000028X^3$ ($R = .9923^{***}$)

cm: $Y = -6.51441 + 0.041844X - 0.000019X^2 + 0.0000000078X^3$ ($R = .9967^{***}$)

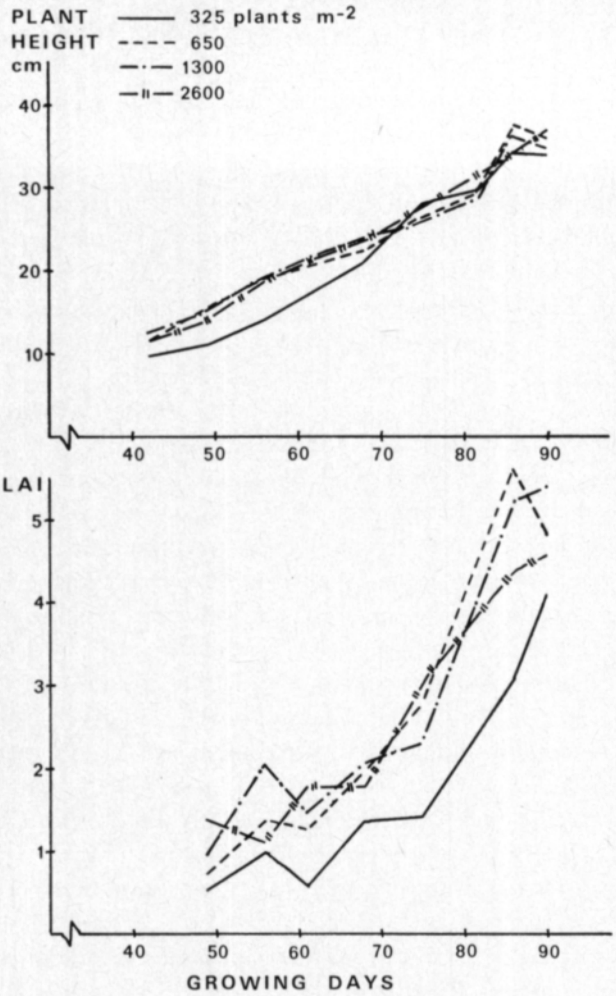

Fig. 2. Height and LAI development of the seeding year stand at four different population densities.

For the multiple regression analysis the variables of temperature sum in degree days (Σ° C) and the total radiation sum (ΣWhcm^{-2}) clearly proved to be the most important ones for early development of the seeding year's LAI and height growth. Other growth factors had statistically significant correlations as well (Table 3). The regression equation of $Y = 0.33481 + 0.01744X_1 - 0.35620X_2$ where $X_1 = \Sigma$ °C and $X_2 = \Sigma$Whcm^{-2} accounted for 99.1 %

Table 3. The correlation coefficients between growth factors and LAI and plant height in the seeding year development of the stand.

Factors	LAI	Height
Growing time	.959***	.993***
$\Sigma > 0°$ C (temp.)	.965***	.993***
Σ Whcm^{-2} (rad.)	.934**	.982***
Σ mm (prec.)	.868*	.928**

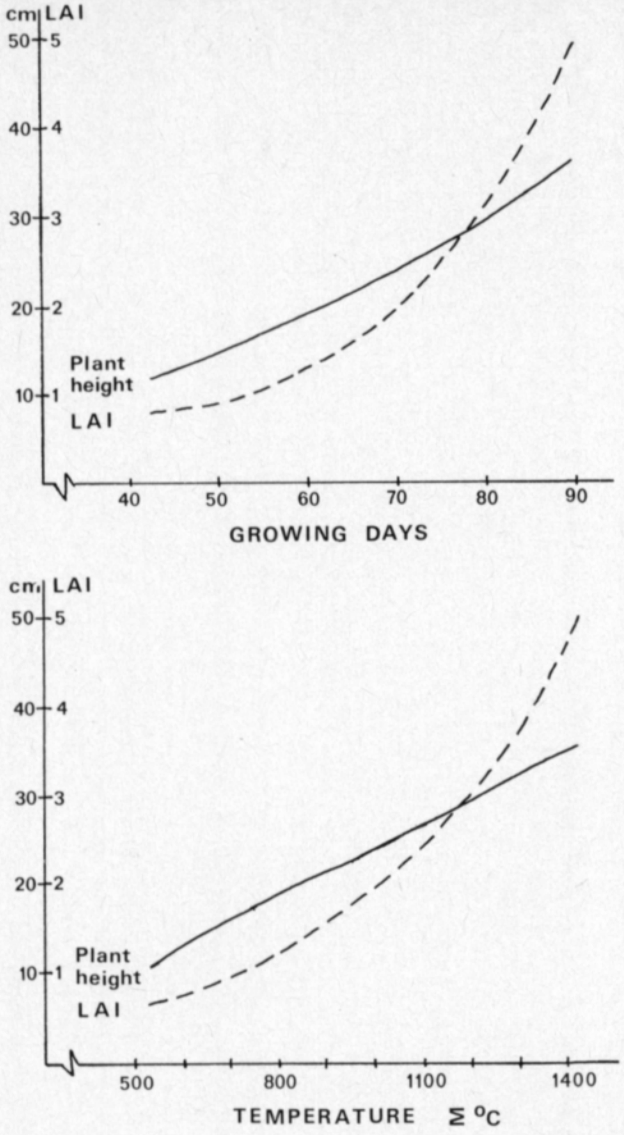

Fig 3. The relationship of plant height and LAI development to the growing time and to the temperature in degree days in the seeding year early growth.

(F-value = 224.8***) of the LAI increase. For height growth, temperature accounted for 98.5 % (F-value 338.5***), no other factors fit into the regression model. The seeding year's height growth regression equation was $Y = -0.40726 + 0.00281X$.

After the first cutting of the seeding year the autumn growth model changed noticeably. LAI correlated very weakly to growing days or temperature sum. In addition, nitrogen fertilizer influenced the height growth.

The dependence of crop height on growing time or temperature sum followed the following regression equations for 100 kg and 200 kg annual nitrogen levels (Fig. 4):

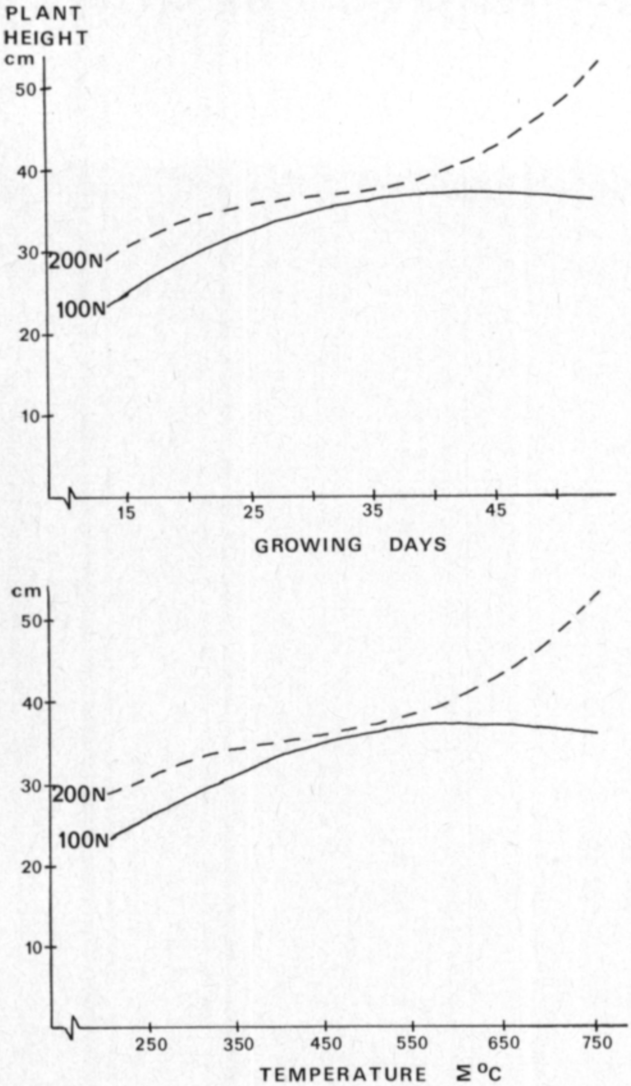

Fig. 4. The relationship of plant height development to the growing days and to the temperature conditions in degree days at two nitrogen levels in the fall growth after the first cut in the seeding year.

a) Growing days = X

100N : $Y = 5.08354 + 1.76477X - 0.030251X^2 + 0.00015X^3$ (R = .985***)

200N : $Y = 4.34552 + 2.92151X - 0.092640X^2 + 0.00103X^3$ (R = .982***)

b) Temperature sum (Σ °C) = X

100N : $Y = 5.03977 + 0.109555X - 0.000105X^2 + 0.000000019X^3$ (R = .985***)

200N : $Y = 4.41792 + 0.191482X - 0.000415X^2 + 0.000000327X^3$ (R = .978***)

From late summer height growth it can be observed that, nitrogen fertilizer begins to have an influence after the 500° C temperature sum has been reached. The crop with the lowest nitrogen level (nitrogen fertilization only in the spring) apparently stopped height growth after the depletion of the nitrogen in the soil (Fig. 4).

4.1.3. Seeding year yields

The seeding year yield at the beginning of the growing season is proportional to the seeding density and the maximum yields are achieved by using greater seeding rates (Donald 1951, Baeumer 1964, Baeumer and de Wit 1968). According to Huokuna (1966) the amount of the yield from a forage crop with no companion crop depends on the seeding rate, provided that the field is harvested 70—80 days after seeding or when it is in the pasture stage. In such a way then, a 10 kg increase in seed per hectare will provide an increase in dry matter yield of 60—430 kg ha^{-1}.

With the progression of growth the maximum yield can be achieved from a fluctuating density harvested at a later stage of development. Cutting in the middle of the growing phase provides a bigger yield the denser the crop is because the plant competition has not yet noticeably reduced plant growth (Donald 1951).

Competition for light while increasing the growing density also influences the quality of the forage (van Burg 1962). Those plant parts left in shadow begin to form mechanical tissue; in other words, plant tissue with more fibers and less proteins and the result is forage of lower quality.

Results

The greatest dry matter yield of the seeding year stand at either of the nitrogen levels in the first cutting and in the overall total of the year were achieved with a sowing density of 30 kg ha^{-1} (Table 4). In the second cutting the yield differences between seeding densities at both nitrogen levels were not significantly different despite the fact that for all seeding densities up to the greatest the yield mildly rose. The seeding density did not affect the dry matter content of the yield (Table 4). Nitrogen fertilizer had the greatest influence on the dry matter content. In the second cutting, the stand which received an additional 100 kg N ha^{-1} contained 3.2 % units less dry matter than the stand with 100 kg N ha^{-1} applied only in the springtime. Also the dry matter content of the total yield fertilized with 200 kg N ha^{-1} was significantly less than the one with 100 kg $ha.^{-1}$.

In the first harvest the raw protein content of the dry matter was highest among the two lowest seeding densities. However, the maximum protein yield was achieved with a seeding rate of 60 kg $ha\text{-}^{1}$ (Table 5). At both levels of nitrogen the highest raw protein content for the second cutting and for the total yield was obtained when the growing density was lowest. Still, the highest protein yield was obtained when the density was highest.

Table 4. Dry matter yields (DM kg ha^{-1}) and dry matter content (DM %) of seeding year stand at two levels of nitrogen cut twice in the seeding year.

Seeding rate kg ha^{-1}	Cut 1	Cut 2 100N	Cut 2 200N	Totals 100N	Totals 200N	Totals Avg.	
		DM kg ha^{-1}					
7.5	1 759a	1 387a	2 205a	3 054a	4 054a	3 554a	
15	2 297b	1 567a	2 353a	3 856ab	4 658ab	4 257b	
30	2 698bc	1 571a	2 580a	4 188bc	5 359bc	4 774c	
60	2 975c	1 654a	2 639a	4 678c	5 565c	5 123d	
Avg.	2 432	1 545A	2 444B	3 944A	4 909B	4 427	
	Cuts	N-Fert.	Density	CxN	CxD	NxD	CxNxD
F-value	NS	xx	xxx	NS	NS	NS	NS
LSD.05		168 kg	233 kg				
		DM %					
7.5	26.1a	27.3a	24.7a	26.7a	25.2a	26.0a	
15	26.1a	26.1a	27.8a	27.3a	24.7a	26.0a	
30	25.4a	27.7a	24.3a	26.5a	24.7a	25.6a	
60	25.6a	27.7a	24.4a	26.5a	24.8a	25.7a	
Avg.	25.8	27.2B	25.3A	26.8B	24.9A	25.9	
	Cuts	N-Fert.	Density	CxN	CxD	NxD	CxNxD
F-value	NS	xxx	NS	xx	NS	NS	NS
LSD.05		0.6 %		0.8 %			

Table 5. Protein content (% in DM) and protein yield (kg ha^{-1}) of seeding year stand at two levels of nitrogen and cut twice in the seeding year.

Seeding rate kg ha^{-1}	Cut 1	Cut 2 100N	Cut 2 200N	Totals 100N	Totals 200N	Totals Avg.	
			Protein %				
7.5	17.6b	15.4c	20.8c	16.6c	19.3b	18.0c	
15	17.4b	13.8a	18.6a	15.9b	18.0a	17.0b	
30	16.4a	13.3a	19.8b	15.2a	18.0a	16.6a	
60	16.1a	14.8b	20.1b	15.6b	18.0a	16.8ab	
Avg.	16.9	14.3A	19.8B	15.8A	18.3B	17.1	
	Cuts	N-Fert.	Density	CxN	CxD	NxD	CxNxD
F-value	NS	xx	xxx	xxx	xxx	xxx	xxx
LSD.05		0.2 %	0.3 %	0.2 %	0.4 %	0.4 %	0.6 %
			Protein kg ha^{-1}				
7.5	310a	214a	446a	508a	771a	640a	
15	400b	216a	453a	614b	854b	734b	
30	443c	219a	511b	648b	967c	806b	
60	479d	245a	530b	732c	1 001c	867c	
Avg.	408	224A	485B	626A	899B	763	
	Cuts	N-Fert.	Density	CxN	CxD	NxD	CxNxD
F-value	NS	xxx	NS	xx	NS	NS	NS
LSD.05		0.6 %		0.8 %			

4.1.4. Discussion

Despite good growing conditions the overall average emergence percentage was 33.4. The growth density was directly related to the seeding density. Under dry conditions the competition became so severe, that almost from the beginning of July differences could be distinquished between different seeding densities. In addition, the final percentage of emergence followed, to a great extent, the model of NORRINGTON-DAVIES and HARRIES (1977).

Initial growth in a young stand is faster under dense than spaced conditions. At this time LAI is directly proportional to the growing density and a dense stand reaches the optimum LAI sooner (DAVIDSON and DONALD 1958, DONALD 1963). Also height growth is faster under dense than spaced conditions because competition for light stimulates leaf growth (ALBERDA 1965 a and b). The fact that in this investigation, during the early development stage, the lowest seeding density (7.5 kg ha^{-1} 325 seeds m^{-2}) produced the lowest LAI and height growth lends support to ALBERDA's statement. In contrast to this, at sowing densities of 15 kg ha^{-1} (650 seeds m^{-2}) there were no decisive differences between the different seeding rates LAI's and heights. In addition, the LAI for the lowest seeding density remained less than the others throughout the growing season and continued to grow when the LAI increase for the larger densities had already ceased. Differences in height growth of the seeding densities evened out before the first cutting. In this investigation it was observed, as in many other investigations (DONALD 1951, 1956, BAUMER and de WIT 1968), that during the seeding year it is possible to raise the dry matter yield through increased population density. The growing density influenced the quality of the seeding year yield only in that the raw protein content of DM in the first harvest was reduced. DONALD (1951) observed similar results in his investigation. On the basis of the results of this investigation the nitrogen treatment of 200 kg N ha^{-1} was detrimental during the seeding year and could cause poor wintering.

4.2. Development and Growth of Stand after Seeding Year

Developmental rhythm of forage stand

The dry matter yield of a hay crop increases as the stand becomes older (POIJÄRVI 1931, AGERBERG 1943, HUOKUNA 1960 b, KIVIMÄE 1965, HERNES 1972, SAU and VIIRALT 1974, PESTALOZZI and ØYEN 1977) and its growth follows a sigmoidal curve. In general the spring growth of a hay crop varies from 150 kg ha^{-1} to 300 kg ha^{-1} of dry matter a day (RINNE 1977). According to TEITTINEN (1959) and RAININKO (1968) the greatest possible total dry matter yield can be obtained by harvesting twice during the growing season and, putting off the second cutting for as long as possible because the differences in the regrowth are smaller than in the main yield. Protein production is strongest in the early development stages of the plant. Later the protein content decreases as protein production slackens, irregardless of the fact that the amount of dry matter is still increasing strongly. The fastest production of protein occurs in spring growth when the decrease in protein content is the greatest.

In later growth phases changes happen more slowly, and during autumn growth the protein yield remains lower than what it was in the early summer (Sau and Viiralt 1974).

Changes in quality as the stand ages are associated with the leave/stem relationship and development within the cells (Olofsson 1962). According to Terry and Tilley (1964) and Guequen and Faconneau (1960) the most decisive factor is stem development, because changes in the composition of different plant parts occur in a different way as the stand ages. It is significant that the chemical composition of a plant for a particular development stage is the same during different years under the same growing conditions (Poutiainen and Rinne 1971).

The dry matter content is lower in the spring yield than in later yields (Sullivan et al. 1956). Salo et al. (1975) observed a decrease in the dry matter content of timothy and meadow fescue during the spring until the leave/stem ratio fell to 1.0—0.8. The dry matter content was 15.4—16.8 %. After this low point, the dry matter content began to rise.

With favorable weather in the spring the reduction in protein content is rapid. In Finnish investigations the spring decrease in protein content has been 0.4—1.0 % units a day (Huokuna 1971 b, Poutiainen and Rinne 1971, Mela and Poutiainen 1975, Antila 1975, Rinne 1977). In the regrowth the decrease in protein content slows down the closer the end of the growing season approaches (Sau and Viiralt 1974). In the autumn the protein content usually surpasses those of the spring and summer yields (Sullivan et al. 1956, Winkler et al. 1961, Rinne 1976).

The stems of young forage are more digestible than the leaves up until flowering (Movat et al. 1965). After this point the digestibility reduces faster in the stems than in the leaves. On the whole, the digestibliity of forage drops sharply with the advent of flowering (Terry and Tilley 1964). An earlier investigation (Poutiainen and Rinne 1971) showed that the in vitro digestibility of organic matter of a timothy-fescue mixture at 20 % flowering decreased by 0.47 % units a day. Following this flowering percentage the digestibility dropped by 1.0 unit a day. The lignin content, which increases in the later development stages, reduces forage digestibility relatively linearly even though the fiber content does not increase anymore (Agerberg 1956, Salo et al. 1975).

Nitrogen and yielding ability of a forage stand

In studies on the affect of nitrogen fertilization on silage stands (Laine 1966, Giöbel and Steen 1960 and 1965) it has been observed that, the dry matter yield of forage increases linearly up to a fertilization level of 40 kg N ha^{-1} per cutting. Beyond this level nitrogen provides a still smaller increase in the yield. Beyond a level of 300 kg N ha^{-1} per season a stand does not produce any further significant increase in the growth of dry matter (Laine 1954, Jäntti and Köylijärvi 1964, Steen 1968, Rinne 1971, Huokuna 1973, Hunt et al. 1975, Baerung 1977 a). According to Giöbel and Steen (1965) protein production is linear up to a level of 60 kg N ha^{-1} per cutting. Beyond this level the protein yield increase begins slowly to become smaller.

Hiivola et al. (1974) suggest that the largest practical amount of nitrogen for protein yield is also 300 kg N ha^{-1} per season. In late summer and with aging crops the fertilizer optimum becomes less and less. Nitrogen fertilizer reduces the forage's dry matter content in all growth stages (Anttinen 1961, Steen 1968, Huokuna 1973, Baerung 1977 b). Steen (1968) found with pasture studies that the dry matter content dropped with nitrogen fertilizer applications of up to 375 kg N ha^{-1}. Applications above this amount encouraged the dry matter content to rise again.

Giöbel and Steen (1965) showed forage protein content to rise almost linearly up to a nitrogen level of 240 kg N ha^{-1}. Hiivola et al. (1974) and Rinne et al. (1976) found with silage forage cut three times during the summer that in the spring growth the protein content rose linearly at nitrogen levels up to 200 kg N ha^{-1}. For the second and third cuttings the increase in protein content became slower at the highest levels of nitrogen. The greatest rise in protein content, 4.2 % units, was obtained by applying from 50 to 100 kg N ha^{-1} per cut (Rinne et al. 1976).

The minimum allowable protein content for cattle feed, 16—18 % of the dry matter, can be achieved by cutting the crop three times and applying nitrogen 250—300 kg N ha^{-1} (Huokuna 1970, 1971 b, 1973, 1976).

The decrease in hay digestibility because of stand ageing cannot be compensated for by applying more nitrogen fertilizer (Steen 1968, Willman 1975). Poutiainen and Rinne (1976) showed that of silage forage components, only protein digestibility improved from nitrogen application. The effect of nitrogen on the digestibility of the other components was not statistically significant.

Population density in relation to the growth and development of the stand

Wilson (1960) stressed that stand height depends on the competition within the stand for light. Regarding the utilization of light, it is important that the crop's assimilated surface be evenly distributed along the vertical axis. In this manner each part of the stand receives a balanced amount of light and even with a small LAI a great amount of growth can be obtained. According to Kelly (1958) the stand's height and stem formation greatly affect the spring growth because the greatest amount of the shoots are generative. In midsummer a plant usually forms new shoots, which means that the stand height alone does not determine the yield. In the autumn neither of the aforementioned factors prevail, they both influnce the yield. The use of light related to the effective height growth in late stages of development is rather limited because of the decrease in the assimilation rate. Such factors related to the decrease are canopy formation, cessation of shooting and the influence of increasing shadow on the acceleration of old leaf withering (Michell and Calder 1958).

According to Brown and Blazer (1968) the maximum crop yield can be achieved by maintaining the optimal LAI which is related to the desired growth rate as compared to a momentarily high one. However, during the growing season there may be various optimum LAI's. The lowest LAI's promote shooting. On the other hand, the biggest LAI values may be needed for production of dry hay or pasturing frequently. The maximum seeding year yields are obtained by making good use of LAI in connection with a large population density. Over successive growing seasons, however, the stand conforms to its environment. In regard to competition, the crop becomes dense or thins to achieve a balanced state (DONALD 1956). As the stand ages there are accompanying changes in the population density such that the less dense stands produce greater yields (LAINE 1958, NISHIMURA and NITTA 1974). The effect of applying fertilizer is that for each level of nitrogen a characteristic maximum yield is obtained with increasing population densities (DONALD 1951, NORRINGTON-DAVIES and GROWLEY 1969).

Population density increases competition for light which in turn encourages lengthwise growth in the leaves. This has the effect of influencing a color change in the leaves to light green and etiolating the internodes (ALBERDA 1965 b). An increase in population density lowers the plant's nitrogen content (DONALD 1951) and the plant parts left in the shade begin to produce mechanical tissue which reduces the quality of the forage.

4. 2. 1. Spring growth and development

In the actual production years 1976—77, the spring growth comprised the first cut of the 2-, 3 and 4-cut systems. The spring growth had the characteristic that each of the influencing growth and development factors individually increased LAI, dry matter content and yield while at the same time reduced

Table 6. The correlation coefficients between growth factors and some parameters describing the development of spring growth of the stand.

	LAI	DM %	DM yield	Prot. %	Cell. dig. %
Crowing days	.625*	.730**	.994***	—.740**	—.967***
$\Sigma > 0°$ C (temp.)	.354	.893***	.945***	—.841***	—.953***
Σ Whcm^{-2} (rad.)	.247	.909***	.895***	—.869***	—.930***
Σ mm (prec.)	.651*	.725**	.977***	—.658*	—.909***
kg N ha^{-1}	.300	.602*	.552	—.187	—.379*

the protein content and cellulase digestibility of dry matter. Of the influencing factors on spring growth, the one with the smallest correlation to the yield was nitrogen fertilization (Table 6). The LAI for spring growth had the highest correlation with the precipitation of the growing period. Nevertheless, the highest determination coefficient for spring growth LAI, 81,6 % (F-value = 19.945***), was given by the regression model : $Y = -3.1572 + 0.3971 X_1 - 0.0218 X_2$

where X_1 = growing days
X_2 = temperature sum in degree days ($\Sigma > 0°$ C)

Spring growth's dry matter content correlated best with the spring radiation energy sum. In the selective regression analysis the dry matter content

depended so heavily on the radiation energy sum that no other factors within the given limits (P = .90) fit into the model
$Y = 13.248 + 0.457\ X$ (R^2 = 82.6 %, F-value = 47.4***)

The spring growth dry matter yield had the best correlation with growing days (R = .994***). The regression model for dry matter yield was $Y = 3198.031 + 115.3085\ X_1 - 6.1056\ X_2 + 1.8524\ X_3 + 16.0215\ X_4$ (R^2 = 99.9 %, F-value = 1245.13***)

where X_1 = growing days
X_2 = nitrogen fertilization for the cut (kg N ha^{-1})
X_3 = temperature sum in degree days ($\Sigma > 0$ °C)
X_4 = precipitation (Σmm)

The spring growth's protein content correlated strongest with the growing period's radiation energy sum (R = −.869***). The highest determination coefficient 93.0 % (F-value = 59.757***), for protein content was provided by the regression model $Y = 26.2261 - 0.6595\ X, + 0.061\ X_2$

where X_1 = total radiation (ΣWh cm^{-2})
X_2 = nitrogen fertilization for the cut (kg N ha^{-1})

The DM cellulase digestibility of the spring growth correlated best with the growing days (R = −.967***). The regression model was
$Y = 136.9089 - 1.3114\ X_1 - 0.6540\ X_2 - 8.7564\ X_3 + 0.456\ X_4$
(R^2 = 99.1 %, F-value = 188.703***)

where X_1 = growing days
X_2 = precipitation (Σmm)
X_3 = total radiation (ΣWh cm^{-2})
X_4 = temperature sum in degree days ($\Sigma > 0$° C)

4. 2. 2. Summer growth and development

Midsummer temperature and radiation intensities are high and most often there is a prevailing scarcity of water. Summer growth comprised the second cut in the 3- and 4-cut systems as well as the third cut in the 4-cut system.

The midsummer changes in crop growth were noticeably more irregular than during the spring. Only five statistically significant correlations were observed between the factors describing the yield and the growth factors (Table 7).

Table 7. The correlation coefficients between growth factors and some parameters describing the development of the summer growth of the stand.

	LAI	DM %	DM yield	Prot. %	Cell. dig %
Growing days	.220	−.670*	.345	−.160	−.397
$\Sigma > 0$ °C (temp.)	.186	−.559	.120	0	−.104
Σ $Whcm^{-2}$ (rad.)	−.081	−.156	.055	.048	−.775**
Σ mm (prec.)	.340	−.589*	.341	.120	−.297
Σ mm [1]) (prec.)	.198	−.448	.360	−.331	.324
kg ha^{-1} [2])	−.011	−.199	−.021	.045	−.530
kg N ha^{-1}	.635*	−.380	.199	.716**	−.120

[1]) Precipitation mm during one week before previous cut
[2]) yield kg ha^{-1} in the earlier cut.

In the selective regression model only nitrogen fertilization had statistically significant influence on LAI development. The model was
$Y = 1.5133 + 0.0364\ X$ ($R^2 = 40.4\ \%$, F-value 6.773*)

The dry matter content had a strong correlation ($R = -.670$*) to the midsummer growing days. The regression model which gave the best determination coefficient (80.8 %, F-value = 7.358*) was
$Y = 44.0798 - 0.5364\ X_1 + 0.0024\ X_2 - 0.0497\ X_3 - 0.0405\ X_4$

where X_1 = growing days
X_2 = previous cut's yield (kg ha^{-1})
X_3 = nitrogen fertilization for the cut (kg N ha^{-1})
X_4 = precipitation (Σmm)

All of the growth influencing factors investigated poorly described the development of the dry matter yield. In the selective regression analysis all variables remained below the given limits ($P = .90$).

Nitrogen fertilizer was the factor affecting the protein content development the most ($R = .716$**). The following regression model gave the highest coefficient of determination (85.6 %, F-value = 10.389**)
$Y = 22.39065 + 0.1416\ X_1 - 1.1480\ X_2 + 0.0448\ X_3 + 0.0392\ X_4$

where X_1 = nitrogen fertilization for the cut (kg N ha^{-1})
Z_2 = growing days
X_3 = temperature sum in degree days ($\Sigma > 0$°C)
X_4 = precipitation (Σmm)

Concerning the DM cellulase digestibility of the summer growth, the following regression model gave the highest coefficient of determination (97.8 %, F-value = 79.308***)
$Y = 83.0525 + 0.2060\ X_1 + 0.1308\ X_2 - 2.7610\ X_3 + 0.0262\ X_4$

where X_1 = precipitation during the week before the previous cut (Σ mm)
X_2 = temperature sum in degree days ($\Sigma > 0$° C)
X_3 = growing days
X_4 = nitrogen fertilization for the cut (kg N ha^{-1})

4. 2. 3. Fall growth and development

In late summer the day length shortens, daytime and especially nighttime temperatures drop and the radiation intensity in particular decreases. On the other hand, rainfall is abundant and this abundance is not a limiting growth factor at this time as it was in midsummer. Also the autumn growth changes are more irregular than those of the spring but are not as irregular as the summer ones. All of the final cuts of the various cutting systems are categorized under fall cuttings.

Growth factor influence on fall growth LAI was not determined because the autumn LAI was recoredd only for 1976.

The highest coefficient of determination for fall growth's dry matter content (95.1 %, F-value = 33.837***) was obtained with the following regression model $Y = 22.531 + 0.50428\ X_1 - 0.05237\ X_2 - 0.00101\ X_3 - 0.11299\ X_4$

where X_1 = total radiation (ΣWh cm^{-2})
X_2 = nitrogen fertilization for the cut (kg N ha^{-1})
X_3 = previous cut's yield (DM kg ha^{-1})
X_4 = precipitation during the week before the previous cut (Σ mm)

Table 8. The correlation coefficients between growth factors and some parameters describing the development of the fall growth of the stand.

	DM %	DM yield	Prot. %	Cell. dig. %
Growing days	.550	.760**	−.504	−.788**
$\Sigma > 0$°C (temp.)	.605*	.716**	−.487	−.737**
Σ $Whcm^{-2}$ (rad.)	.663*	.631*	−.443	−.637*
Σ mm (prec.)	.277	.828***	−.508	−.862***
mm[1]) (prec.)	−.331	.215	−.205	−.285
kg ha^{-1} [2])	.248	.638*	−.321	−.670*
kg N ma^{-1}	−.037	.782**	.294	−.319

[1]) Precipitation mm during one week before previous cut.
[2]) yield kg ha^{-1} in the earlier cut.

Whereas the dry matter yield of the summer growth did not correlate with any of the growth factors, the yield from the fall growth was found to correlate with the precipitation measured during the week before the previous cut (Table 8). The best regression model for the dry matter yield was ($R^2 = 93.9$ %, F-value = 40.720***)

$$Y = -1249.79 + 13.7815\ X_1 + 19.6328\ X_2 + 53.190\ X_3$$

where X_1 = precipitation (Σ mm)
X_2 = nitrogen fertilization for the cut (kg N ha^{-1})
X_3 = precipitation during the week before the previous cut (Σ mm)

The dependence of the fall growth's protein content on one separate growth factor turned out to be low. The protein content development was best described by the following regression model ($R^2 = 93.1$ %, F-value = 36.253***)

$$Y = 18.4625 - 0.0195\ X_1 + 0.1029\ X_2 - 0.1470\ X_3$$

where X_1 = precipitation (Σ mm)
X_2 = nitrogen fertilization for the cut (kg N ha^{-1})
X_3 = growing days

For depicting the cellulase digestibility of the fall growth the following regression model was used $Y = 70.4166 - 0.1010\ X_1 - 0.2720\ X_2$

where X_1 = precipitation (Σ mm)
X_2 = precipitation during the week before the previous cut (Σ mm)

The coefficient of determination for changes in the DM cellulase digestibility was 86.8 % (F-value = 29.496***).

4. 2. 4. Growing time and temperature relations to growth and development characters of a forage stand

The growing days and the temperature sum in degree days are the most important factors upon which the descriptive factors of spring, summer and fall growth depend. These two factors are basic growing conditions for forage crops in Finland.

Spring growth

In general, all of the investigated characters related to the yield of spring growth showed relatively strong changes. All regression equations were of the third degree which had very high statistical significance. The independent variables in the regression equations were either growing time (a) or temperature sum in degree days (b). The regression equations were as follows (Fig. 5).

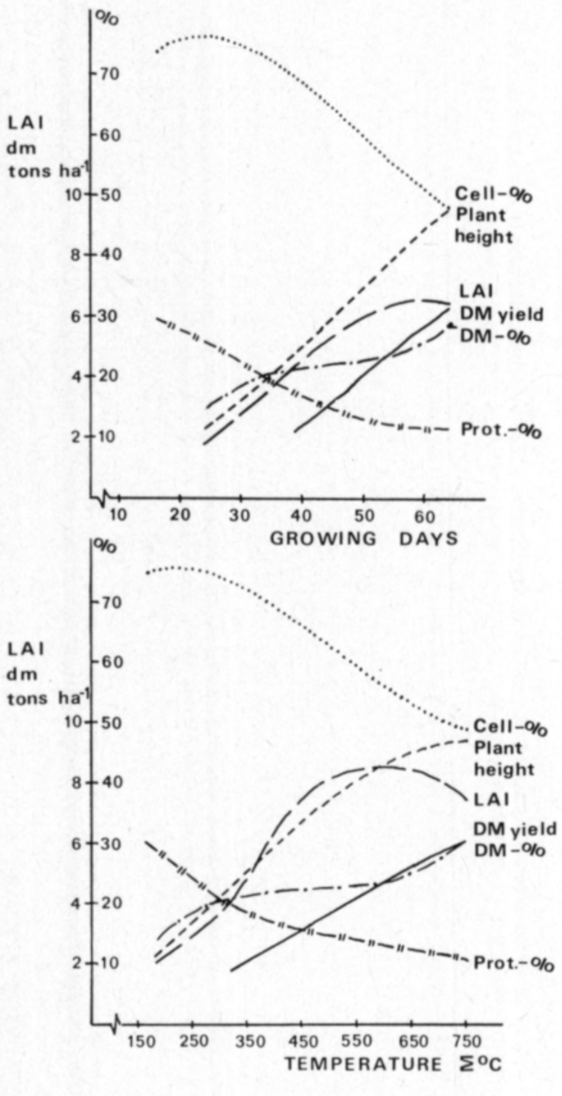

Fig. 5. Spring development and growth of the fesque stand after seeding year in relation to the growing days and to the temperature conditions in degree days.

1. LAI

a) $Y = 0.009661 - 0.054069\,X + 0.007144\,X^2 - 0.000074\,X^3$ (R = .876***)

b) $Y = 0.043788 + 0.006107\,X + 0.000033\,X^2 - 0.00000004\,X^3$ (R = .836***)

2. Stand height

a) $Y = 0.532344 + 0.255315\,X + 0.033959\,X^2 - 0.000230\,X^3$ (R = .988***)

b) $Y = 0.759275 + 0.077105\,X + 0.000295\,X^2 - 0.00000031\,X^3$ (R = .995***)

3. Dry matter content

a) $Y = -36.474 + 3.74591\,X - 0.08198\,X^2 + 0.000615\,X^3$ (R = .868***)

b) $Y = -12.4056 + 0.21366\,X - 0.044399\,X^2 + 0.000031\,X^3$ (R = .973***)

4. Dry matter yield

a) $Y = 0.792528 - 65.7417\,X + 4.21189\,X^2 - 0.026107\,X^3$ (R = .998***)

b) $Y = 5.75349 - 1.65495\,X + 0.027957\,X^2 - 0.00007\,X^3$ (R = .977***)

5. Protein content

a) $Y = 33.6065 - 0.013368\,X - 0.018151\,X^2 + 0.000204\,X^3$ (R = .917***)

b) $Y = 52.1947 - 0.167158\,X + 0.000254\,X^2 - 0.00000014\,X^3$ (R = .952***)

6. Cellulase content

a) $Y = 51.0319 + 2.36978\,X - 0.06537\,X^2 + 0.000431\,X^3$ (R = .955***)

b) $Y = 60.1753 + 0.150145\,X - 0.000428\,X^2 + 0.00000028\,X^3$ (R = .966***)

Summer growth

The correlation of midsummer growth to growing days and temperature sum in degree days was less and noticeably less, respectively, than for spring

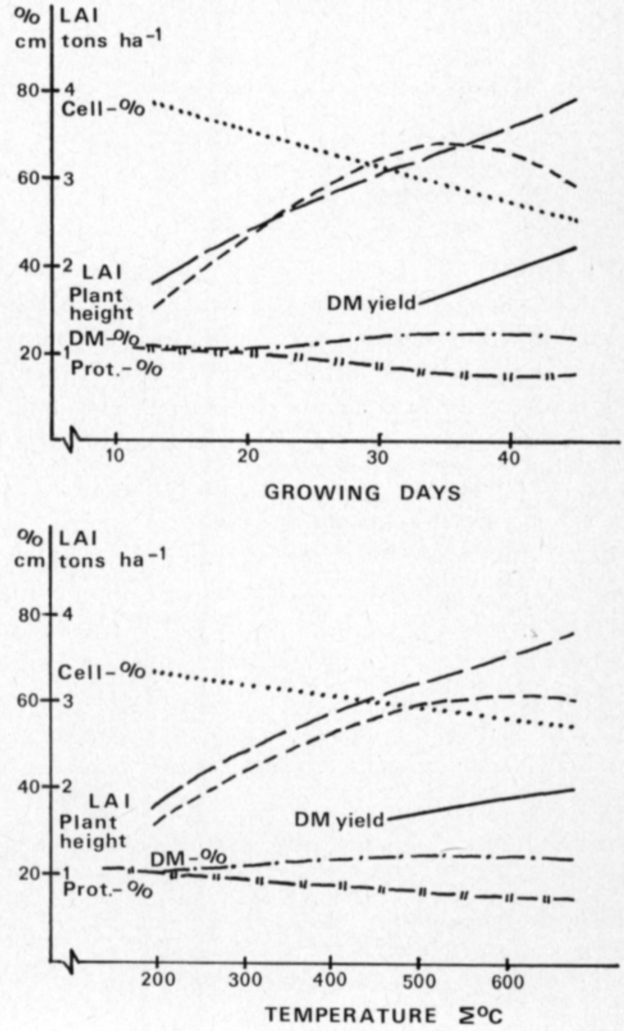

Fig. 6. Summer development and growth of the fesque stand after seeding year in relation to the growing days and to the temperature conditions in degree days.

growth. In particular, midsummer growth had especially slow changes in the dry matter and protein contents. Also, the cellulase digestibility of dry matter dropped relatively slowly and linearly. The independent variables for midsummer growth were either growing time (a) or temperature sum in degree days (b). The regression equations were as follows (Fig. 6):

1. LAI

a) $Y = -0.025061 + 0.183391\,X + 0.00389\,X^2 - 0.000039\,X^3$ (R = .853***)

b) $Y = -0.029375 + 0.012003\,X - 0.0000155\,X^2 + 0.000000009\,X^3$ (R = .850***)

2. Stand height

a) $Y = 5.14303 + 1.28261\,X + 0.073425\,X^2 - 0.0016839\,X^3$ (R = .992***)

b) $Y = 4.98153 + 0.146748\,X - 0.0000223\,X^2 - 0.00000011\,X^3$ (R = .988***)

3. Dry matter content

a) $Y = 24.5757 - 0.624244\,X + 0.03392\,X^2 - 0.0004598\,X^3$ (R = .486**)

b) $Y = 18.1263 + 0.009892\,X + 0.000026\,X^2 - 0.00000004\,X^3$ (R = .505**)

4. Dry matter yield

a) $Y = 4.591 + 42.442\,X + 0.15536\,X^2$ (R = .822***)

b) $Y = 20.4374 + 4.79395\,X - 0.27944\,X^2$ (R = .791***)

5. Protein content

a) $Y = 16.3465 + 0.89533\,X - 0.04697\,X^2 + 0.00059\,X^3$ (R = .626***)

b) $Y = 23.6649 - 0.018688\,X + 0.0000091\,X^2 - 0.000000001\,X^3$ (R = .598***)

6. Cellulase digestibility — %

a) $Y = 89.0095 - 0.945977\,X + 0.002175\,X^2$ (R = .702**)

b) $Y = 70.6825 - 0.02441\,X$ (r = .381 NS)

Fall growth

The changes in dry matter and protein contents occurred relatively slowly also during late summer, LAI did not reach its maximum in the autumn despite a growing period of 90 days in the 2-cut system. The regression equations for late summer growth with the independent variables of either growing period (a) or temperature sum in degree days (b) were as follows (Fig. 7):

1. LAI

a) $Y = -0.104588 + 0.109084\,X - 0.000270\,X^2$ (R = .853**)

b) $Y = -0.129214 + 0.908704\,X - 0.0247926\,X^2$ (R = .853**)

2. Dry matter content

a) $Y = 22.1133 - 0.251295\,X + 0.005943\,X^2 - 0.0000258\,X^3$ (R = .638***)

b) $Y = 16.2234 + 0.020281\,X - 0.000035\,X^2 + 0.00000002\,X^3$ (R = .566***)

3. Dry matter yield

a) $Y = -8.71256 - 10.0924\,X + 1.15345\,X^2 - 0.006842\,X^3$ (R = .877***)

b) $Y = 13.8027 - 0.988314\,X + 0.0083108\,X^2 - 0.0000044\,X^3$ (R = .863***)

4. Protein content

a) $Y = 23.0423 + 0.06078\,X - 0.006185\,X^2 + 0.000046\,X^3$ (R = .808***)

b) $Y = 24.6414 - 0.006555\,X - 0.000012\,X^2 + 0.000000008\,X^3$ (R = .746***)

5. Cellulase digestibility — %

a) $Y = 75.4445 - 0.36397\,X + 0.000866\,X^2$ (R = .806**)

b) $Y = 73.084 - 0.027699\,X + 0.0000077\,X^2$ (R = .743**)

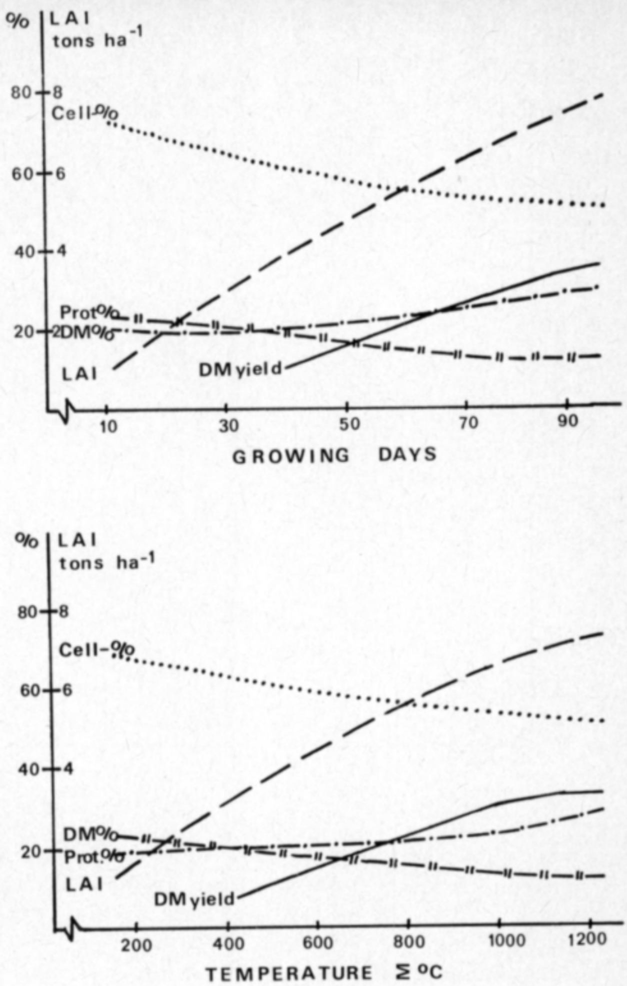

Fig. 7. Autumn development and growth of the fesque stand after seeding year in relation to the growing days and to the temperature conditions in degree days.

For the 1976—77 cuttings also the relationships between LAI and dry matter yield were determined (Fig. 8). During spring growth the dry matter yield increased rather sharply as LAI increased. However, as LAI increased over the growing period the resulting increase in yield slowly decreased, but at the same time significance of the liner regression line improved.

4. 2. 5. Discussion

The growing conditions under which forage yield development is the most effective in Finland, occur in early summer. Because of long days there is abundant light, the radiant intensity is high, temperatures are relatively high and the amount of water for plant utilization in the soil is sufficient. However, a scarcity of water can limit the benefits of the other aforementioned conditions. In the autumn there is abundant water for plants, but light and temperature become the limiting factors. In addition, growth slows down anyway in the autumn because the plant gradually starts to prepare for wintering (Rappe 1948).

The regression models describing the yield show that the yield forming characteristics of spring growth experienced faster changes than the yield

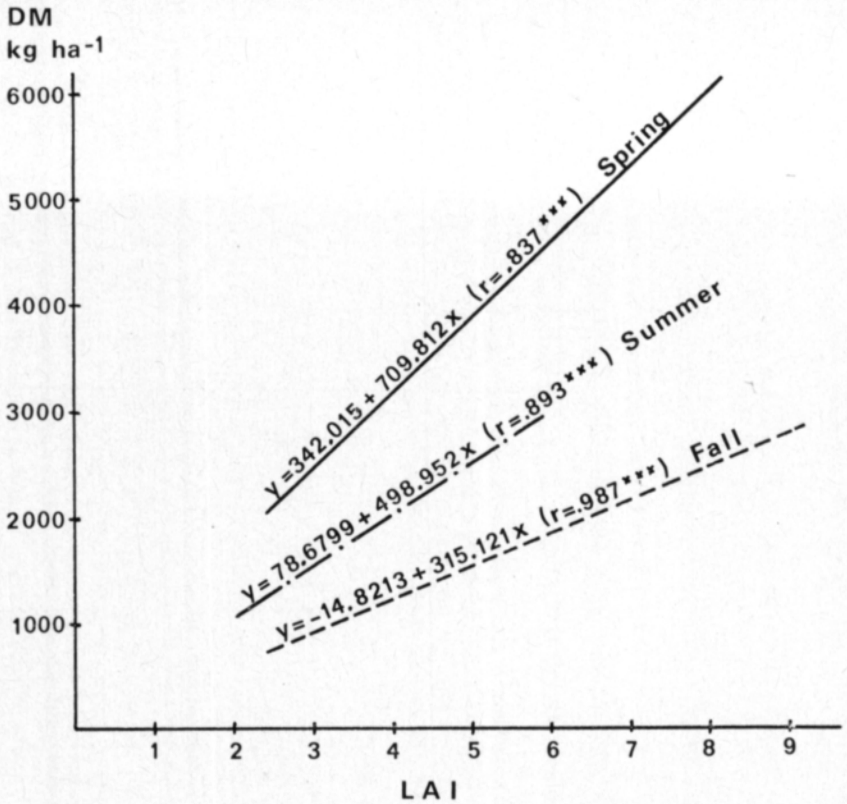

Fig. 8. The relationship between the dry matter yield (DM kg ha^{-1}) and leaf area index (LAI) in spring, summer and autumn growth.

quality characters of mid and late summer growth. These results agreed with those of many previous investigations (HUOKUNA 1964 and 1973, POUTIAINEN and RINNE 1971, SYRJÄLÄ 1973 and 1974, HIIVOLA et al. 1974, SALO et al. 1975, RINNE 1977). The growth factors which best described the spring growth DM yield were growing days, temperature sum in degree days and total radiation.

Midsummer growth is most often limited by a shortage of water. By applying nitrogen fertilizer it is possible, in part, to overcome the effect of drought (MELA 1974), and therefore the fertilizer displays a more noticeable influence on midsummer growth than spring growth. An important factor to ensure establishment of a sufficient assimilative surface is enough water immediatly after cutting. In the midsummer regression model the most important variables affecting the yield were the amount of nitrogen applied precipitation, and the precipitation during the week before the prior cutting. What is particularly worth considering is the low coefficient of determination in the selective regression model, while in the descriptive parabola for the dry matter yield both the growing time and the temperature sum in degree days were statistically highly significant.

Not including the dry matter content, in the regression model for fall growth the factor which best described crop growth was the late summer precipitation. The regression model for the fall DM yield surprisingly set the precipitation, the amount of nitrogen applied and the precipitation during the week before the prior cutting as the most determining factors; presumably due to the dominant weather conditions. During the investigation years, August remained noticeably below the long-term average and, the abundant September rains could not counteract the stop in growth which occurred in August because the other growth factors decreased at the same time. According to the regression model, precipitation reduces the protein content and cellulase digestibility of the DM yield. Olofsson (1962) and Salo et al. (1975) suggest that in grasses ample moisture easily increases the amount of mechanical tissue at the expense of digestible material.

LAI and dry matter yield had extremely statistically significant correlations with spring, summer and fall growth. The significance was lowest in the spring when stem formation was strongest and the highest for the leafy autumn yield.

During spring growth an increase in LAI of one LAI-unit increased the yield by 710 kg ha^{-1}. The maximum LAI of 8.5 was reached 50—60 days after the initiation of growth in the spring, at which time it began to decrease but the stand's height still increased. The maximum LAI for spring growth was achieved with a temperature sum of 550° C ($\Sigma > 0°$ C).

The reduction in LAI at the end of the spring growth shows that a crop left growing longer would have gone beyond the optimum cutting time as determined with the aid of LAI (Brown and Blaser 1968) even though the height was still increasing. The LAI's determined in this investigation corresponded with those of previous studies (Brougham 1958, Evans 1964, Raininko 1968).

The protein content dropped sharply in the temperature range of 150—350° C, where a rise in cumulative temperature sum of 10° C induced a 0.17 % units decrease in protein content. At the same time, every 10° C increase caused a 0.4 % units increase in dry matter content. The second intensive increase in dry matter content begins during the growth stage where LAI reaches its maximum. The digestibility of dry matter improves in the spring and then begins to decrease a little bit later than the protein content does. Cellulase digestibility of dry matter declines in the temperature range of 250—650° C, where a 10° C rise reduces digestibility by abount 0.6 % units.

In 45 growing days the midsumer LAI reached a value of 4, and an one LAI-unit rise corresponded to an increase in dry matter yield of 500 kg/ha. In contrast to the spring LAI, the midsummer LAI had not reached its maximum whereas in the span of 35 days and with the temperature sum = 600° C, the crop reached its maximum height. Both the protein content and DM cellulase digestibility reductions were steady during summer growth.

In the temperature range of 200—400° C every 10° C increase in cumulative temperature sum brought about a 0.1 % unit and 0.4 % units reduction in the protein content and cellulase digestibility respectively. At the same time each 10° C rise increased the dry matter content by 0.1 %.

The autumn LAI was initially almost as vigorous as the midsummer LAI in regard to growing period or temperature sum in degree days. In the 92 day growing period the autumn LAI approached a value of 8. Usually in the autumn the LAI remains less than the early and late summer ones (ANSLOW 1965 a and b). For fall growth an increase of LAI unit increased the dry matter yield by 315 kg ha^{-1}.

4. 3. Forage Yields and Quality

4. 3. 1. Dry matter content

The total DM yield's dry matter content was, on the average, significantly higher during the production years for the 2-cut system than for the 3- and 4-cut systems (Table 9, Fig. 9). There were no significant differences between individual cuttings in regard to the dry matter contents for any of the cutting systems over the two year average (Fig. 10). Nitrogen fertilization decreased the DM yield's dry matter contents, even though a statistically significant difference was recorded actually for only the first production year. By checking each cutting system it was found that nitrogen reduced the dry matter content by a statistically significant amount only in the 4-cut system (Fig. 9). Nitrogen also had an effect on the individual cuttings' dry matter content only in the 4-cut system which had the most significant differences in its late summer cuttings (Fig. 10).

Seeding rate was significant at a low nitrogen level in the 2-cut system during the first actual production year in such a way than an increase in the seeding rate significantly increased the dry matter content (Table 9). The reason for this was the overdelayed cutting time resulting in overmaturity and a decrease in quality. The dry matter content proved to significantly decrease also when using the 4-cut system at a low level of nitrogen combined with the highest seeding rate (Fig. 10).

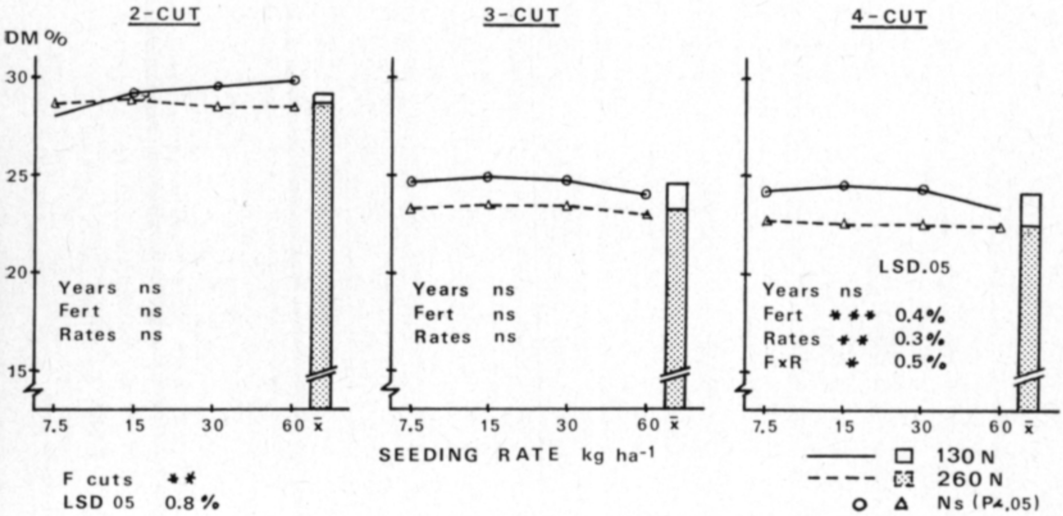

Fig. 9. Average dry matter content (% DM) of three cutting systems at four population densities and two levels of nitrogen.

Table 9. Dry matter content (%) of the stand in 1976 and 1977.

Seeding rate kg ha^{-1}	2-cut 130N	2-cut 260N	2-cut Avg.	3-cut 130N	3-cut 260N	3-cut Avg.	4-cut 130N	4-cut 260N	4-cut Avg.	Cuts avg. 130N	Cuts avg. 260N	Cuts avg. Avg.
1976												
7.5	29.2a	30.4a	29.8a	25.6a	25.2a	25.4a	25.3b	24.5a	24.9a	26.7a	26.7a	26.7a
15	30.9ab	30.7a	30.8a	26.0a	25.7a	25.9a	25.9b	24.1a	25.0a	27.5a	26.7a	27.1a
30	31.3bc	30.2a	30.8a	25.9a	25.1a	25.5a	25.7b	24.1a	24.9a	27.6a	26.5a	27.1a
60	32.1c	29.4a	30.8a	24.9a	24.7a	24.8a	24.2a	23.9a	24.1a	27.1a	26.0a	26.6a
Avg.	30.9a	30.2a	30.6B	25.6a	25.2a	25.4A	25.3b	24.2a	24.8a	27.2b	26.5a	26.9
1977												
7.5	26.8a	27.4a	27.1a	23.5a	21.5a	22.5a	23.0a	20.9a	22.0a	24.4a	23.3a	23.9a
15	27.4a	27.1a	27.3a	23.7a	21.1a	22.4a	23.0a	20.9a	22.0a	24.7a	23.0a	23.9a
30	27.7a	26.8a	27.3a	23.5a	21.6a	22.5a	22.9a	21.0a	22.0a	24.7a	23.1a	23.9a
60	27.2a	27.5a	27.4a	23.0a	21.0a	22.0a	22.3a	20.9a	21.6a	24.2a	23.1a	23.7a
Avg.	27.3a	27.2a	27.3B	23.4a	21.3a	22.4A	22.9a	20.9a	21.8A	24.5a	23.1a	23 8

		Cuts	N-fert.	Density	CxN	CxD	NxD	CxNxD
1976	F-value	xxx	x	NS	NS	NS	NS	NS
	$LSD_{.05}$	1.1 %	0.6 %					
1977	F-value	xxx	x	NS	NS	NS	NS	NS
	$LSD_{.05}$	1.5 %	1.3 %					
	F-years	xxx, $LSD_{.05}$ 0.8 %						

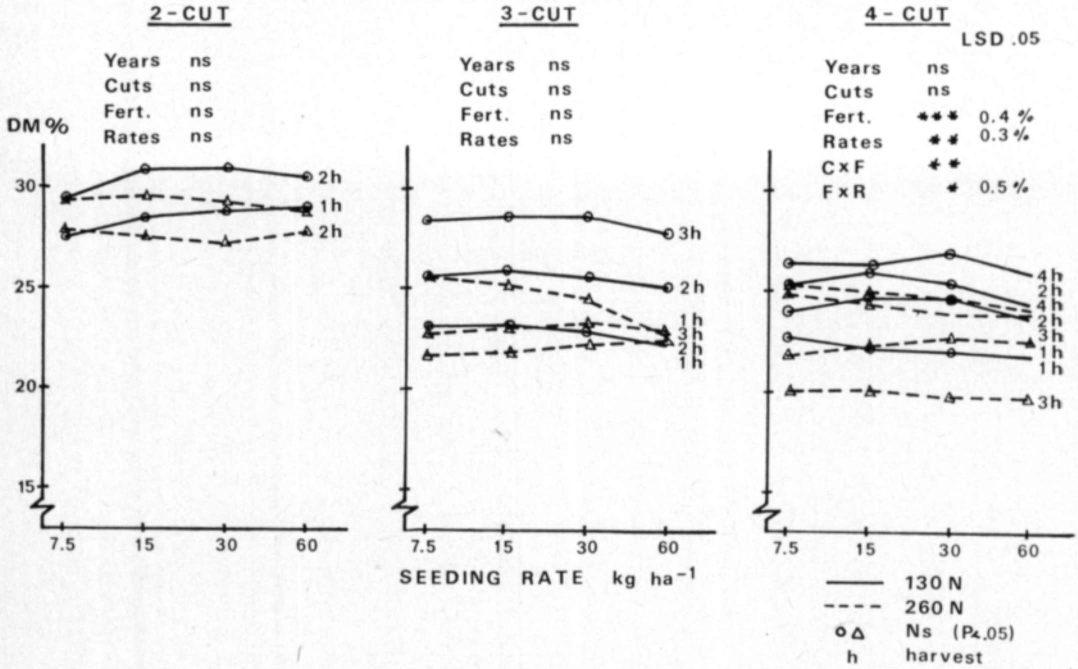

Fig. 10. Average dry matter content (% DM) of individual cuts in three cutting systems seeded at four population densities and ferilized at two levels of nitrogen.

4. 3. 2. Dry matter yields

The dry matter yields for the seeding year average 4.4 tons ha^{-1}, and for the two following production years 6.7 and 9.2 tons ha^{-1} respectively. The greatest dry matter yield was obtained by cutting twice and the smallest by cutting four times (Table 10). The differences between cutting systems were statistically significant for 1976 and 1977 (Table 10) and on the average for 1976—77 (Fig. 11). In the grand total yield for 1976—77 (Fig. 13) the yield level of the 4-cut system was significantly lower than yield level of the other cutting systems.

During the first cut of the 2-cut system two-thirds of the total yield for the growing period were obtained (Table 11). The 3-cut system produced the largest yields in the first cut and the smallest in the second in midsummer (Fig. 12). In the 4-cut system the smallest yield was obtained in the last cut (Table 11). On the average for 1976—77 the largest part of the total yield came from the second cut of the 4-cut system, followed by the first and third cuts respectively. However, the cuttings did not statistically differ from each other (Fig. 12).

Nitrogen increased the dry matter yield significantly for all the cutting systems for 1976—77. The average increase in the grand total yield for 1976—77, based on the nitrogen fertilizer change of 130 kg ha^{-1}—260 kg ha^{-1}, was 2 271 kg ha^{-1} (Fig. 13). Adding nitrogen had the tendency of evening out the yield differences between cuttings in each cutting system. What was significant was that in the first cuttings there were no statistically significant differences such as those which showed up in later cuttings (Table 11, Fig. 12).

Table 10. Dry matter yields (DM, kg ha^{-1}) of the stand in 1976 and 1977.

Seeding rate kg ha^{-1}	2-cut 130N	2-cut 260N	2-cut Avg.	3-cut 130N	3-cut 260N	3-cut Avg.	4-cut 130N	4-cut 260N	4-cut Avg.	Cuts avg. 130N	Cuts avg. 260N	Cuts avg. Avg.
1976												
7.5	7 278a	8 240a	7 759a	5 992a	6 213a	6 102a	4 873a	5 017a	4 945a	6 048a	6 490a	6 269a
15	7 671a	8 354a	8 013ab	6 132a	7 142b	6 637ab	4 931ab	5 234ab	5 083ab	6 245ab	6 910ab	6 578b
30	7 915ab	8 414a	8 164ab	6 606a	7 621b	7 114b	5 218ab	5 931bc	5 573bc	6 580bc	7 322bc	6 951bc
60	8 430b	8 777a	8 604b	6 464a	7 365b	6 915b	5 661b	6 229c	5 945c	6 852c	7 457c	7 155c
Avg.	7 824a	8 446b	8 135C	6 299a	7 085b	6 692B	5 171a	5 603b	5 387A	6 437a	7 045b	6 738
1977												
7.5	9 123a	10 497a	9 810a	7 911a	9 651a	8 781a	6 698a	8 559a	7 629a	7 911a	9 569a	8 740a
15	9 865ab	11 412a	10 639b	7 963a	9 773ab	8 868ab	7 021a	9 147ab	8 084ab	8 283ab	10 111ab	9 197b
30	9 810ab	10 896a	10 353b	8 548a	10 039ab	9 294ab	6 985a	9 130ab	8 058ab	8 448ab	10 022ab	9 235b
60	10 468b	10 762a	10 615b	8 606a	10 408b	9 507b	7 111a	9 731b	8 421b	8 728b	10 300b	9 514b
Avg.	9 816a	10 891b	10 355C	8 258a	9 968b	9 113B	6 954a	9 142b	8 048A	8 343a	10 001b	9 172

		Cuts	N-fert.	Density	CxN	CxD	NxD	CxNxD
1976	F-value	xxx	xxx	xxx	NS	NS	NS	NS
	$LSD_{.05}$	621	218	307				
1977	F-value	xxx	xx	x	NS	NS	NS	NS
	$LSD_{.05}$	540	590	370				

F-years*, $LSD_{.05}$ = 545

The yield level rose slightly with increases in the seeding rate from 7.5 kg ha^{-1} to the highest one of 60 kg ha^{-1} (Fig. 9). However, the statistical maximum yield for the 2-cut system in both production years and, on the average, was achieved with the seeding rate of 15 kg ha^{-1}. At the higher nitrogen level the lowest seeding rate (7.5 kg ha^{-1}) was enough to obtain the statistical maximum yield, but on the average at the lower nitrogen level the highest seeding rate (60 kg ha^{-1}) was needed (Fig. 11).

Table 11. The relative proportions (%) of individual cuts in the total dry matter yields in 1976—77.

Cuttings		% of total yield 130N	260N	Avg.
2-cut	Cut 1.	69.8	59.9	64.6
	Cut 2.	30.2	40.1	35.4
3-cut	Cut 1.	54.1	42.0	47.6
	Cut 2.	20.3	27.1	21.0
	Cut 3.	25.6	36.3	31.4
4 cut	Cut 1.	31.9	24.4	27.8
	Cut 2.	36.0	30.1	32.8
	Cut 3.	20.5	28.7	25.0
	Cut 4.	11.6	16.8	14.4

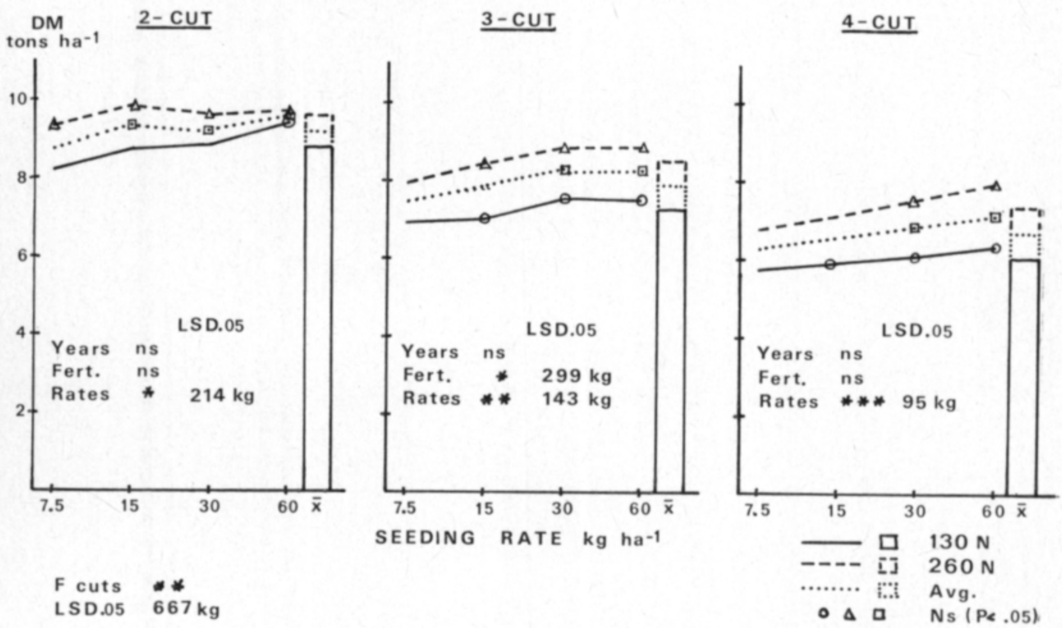

Fig. 11. Average dry matter yields (DM tons ha^{-1}) of three cutting systems at four population densities and two levels of nitrogen.

Table 12. Raw protein content (%) in dry matter in 1976 and 1977.

Seeding rate kg ha^{-1}	2-cut 130N	2-cut 260N	2-cut Avg.	3-cut 130N	3-cut 260N	3-cut Avg.	4 cut 130N	4 cut 260N	4 cut Avg.	Cuts avg. 130N	Cuts avg. 260N	Cuts avg. Avg.
1976												
7.5	9.1a	12.5a	10.8a	10.8a	14.4a	12.6a	14.6a	18.7a	16.7a	11.5b	15.2a	13.4a
15	9.2a	13.1a	11.2a	10.8a	14.8a	12.9a	14.8a	19.2a	17.0a	11.6b	15.7a	13.6a
30	9.0a	12.8a	10.9a	10.6a	14.4a	12.5a	13.6a	18.7a	16.2a	11.1ab	15.3a	13.2a
60	8.1a	12.9a	10.5a	10.1a	14.8a	12.5a	13.7a	19.1a	16.4a	10.6a	15.6a	13.2a
Avg.	8.9a	12.9b	10.9A	10.6a	14.6b	12.6A	14.2a	18.9b	16.6B	11.2a	15.5b	13.4
1977												
7.5	9.9a	13.2a	11.6a	12.6a	17.0a	14.8a	13.7 a	17.5a	15.6a	12.1a	15.9a	14.0a
15	9.8a	13.7a	11.8a	12.2a	17.7a	15.0a	13.8a	17.5a	15.7a	11.9a	16.3a	14.1a
30	9.7a	13.5a	11.6a	12.0a	16.4a	14.2a	13.9a	17.3a	15.6a	11.9a	15.7a	13.8a
60	9.5a	13.6a	11.6a	11.9a	16.1a	14.0a	13.6a	17.2a	15.3a	11.7a	15.6a	13.7a
Avg.	9.7a	13.5b	11.6A	12.2a	16.8b	14.5B	13.8a	17.4b	15.6B	11.9a	15.9b	13.9

	Cuts	N-fert.	Density	CxN	CxD	NxD	CxNxD
1976 F-value	x	xxx	NS	x	NS	NS	NS
LSD$_{.05}$	1.9 %	0.2 %					
1977 F-value	x	xxx	NS	NS	NS	NS	NS
LSD$_{.05}$	1.8 %	0.3 %					

F-years*, LSD$_{.05}$ = 0.5 %

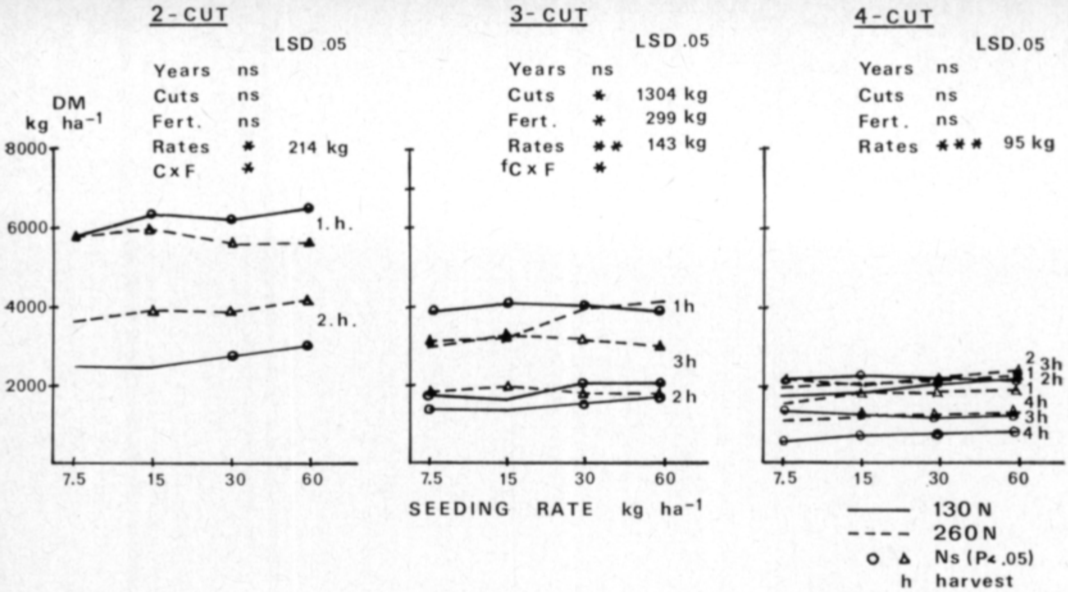

Fig. 12. Average dry matter yields (DM tons ha^{-1}) of individual cuts in three cutting systems seeded at four population densities and two levels of nitrogen

For the 3-cut system the statistical maximum yield in both production years at the higher nitrogen level was got with the seeding rate of 15 kg ha^{-1} (Table 10). At the lower nitrogen level the lowest seeding rate was sufficient for maximum yield. However, on the average the rate of 30 kg ha^{-1} was required for the statistical maximum yield in production years 1976–77.

In the 4-cut system the seeding rate had an especially significant influence on the yield. For the maximum yield in 1976 at the low level of nitrogen the seeding rate of 15 kg ha^{-1} was needed and at the high level, 30 kg ha^{-1}. In the following year to achieve the coinciding maximum yield levels the seeding rates needed were: 7.5 kg ha^{-1} and 15 kg ha^{-1} (Table 10). On the average, the maximum yield for these years at the low level of nitrogen was reached with the seeding rate of 15 kg ha^{-1}, and at the high level with 30 kg ha^{-1} (Fig. 11).

4. 3. 3. Raw protein content of dry matter

The protein content of the total dry matter yields was highest in both years in the 4-cut system and lowest in the 2-cut one (Table 12). On the average for 1976–77 the differences in protein content between all cutting systems were statistically significant (Fig.14).

In 1976–77 the differences between cuttings regarding protein content in the 2-cut system favored the fall cutting by 1.3 % units. The difference was not statistically significant (Fig. 15). In the 3-cut system the highest protein content was obtained in the second cutting and the lowest in the fall cutting. However, the differences were not statistically significant. There were no statistical differences between the cuttings of the 4-cut system during 1976–77, although, if ranked according to results they would be first, third, fourth and second cutting.

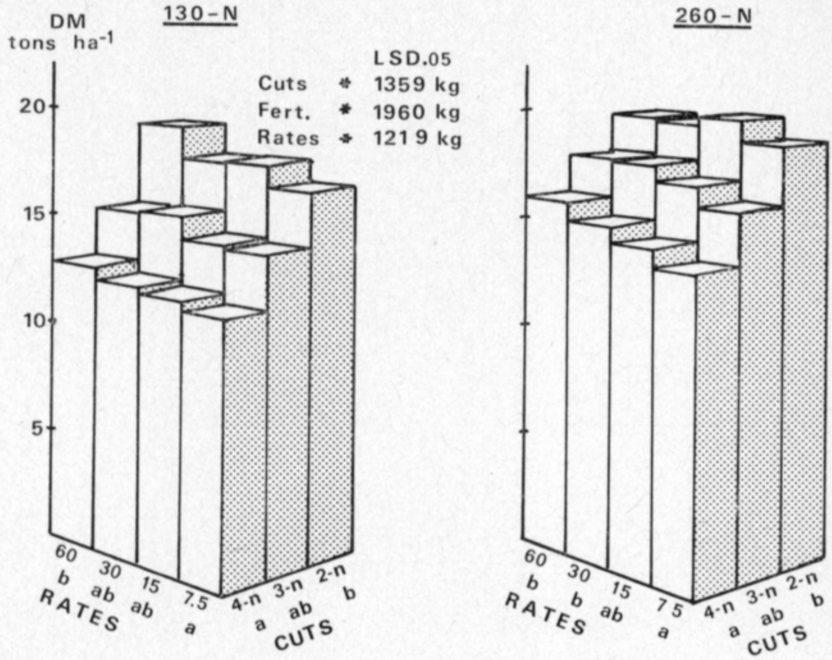

Fig. 13. Total dry matter yields (DM tons ha^{-1}) in 1976—77 of three cutting systems seeded at four population densities and fertilized at two levels of nitrogen.

Nitrogen fertilizer raised the protein content by 4.1 percentage units on the average; a very significant amount. The addition of nitrogen fertilizer produced average increases of 3.9, 4.3 and 4.2 percentage units in the 2-, 3- and 4-cut systems respectively.

For 1976 it was observed that the fertilizer's and cuttings' combined effect was such that additional nitrogen increased the protein content in the second cutting of the 2-cut system and in the third cuttings of both the 3- and 4-cut systems. The seeding rate had very little significance for the protein content of the dry matter yield.

4. 3. 4. Raw protein yields

In 1976 (the year after seeding), all three cutting systems produced close to the same amount of protein per unit of surface area. In 1977 statistically significant differences occurred between all of the cutting systems. On the average for 1976—77, protein yield differences were not observed, 2-cut system, 1 052 kg ha^{-1}, 3-cut system, 1 097 kg ha^{-1}, 4-cut system, 1 086 kg ha^{-1} (Table 13). Also in the grand total yield for 1976—77 there were no statistically significant differences between the cutting systems (Fig. 16).

Nitrogen fertilizer increased the protein yield by an average of 364, 608 and 486 kg ha^{-1} for 1976, 1977 and 1976—77 respectively. The amount of the 1976—77 combined protein yield was influenced very significantly ($P = 0.001$) by the nitrogen fertilizer.

Table 13. Raw protein yields (kg ha^{-1}) in 1976 and 1977.

Seeding rate kg ha^{-1}	2-cut 130N	2-cut 260N	2-cut Avg.	3-cut 130N	3-cut 260N	3-cut Avg.	4-cut 130N	4-cut 260N	4-cut Avg.	Cuts avg. 130N	Cuts avg. 260N	Cuts avg. Avg.
1976												
7.5	666a	1 032a	849a	648a	894a	771a	710a	938a	824a	675a	956a	816a
15	703a	1 115ab	909a	668a	1 056b	862b	730a	1 001ab	866ab	700a	1 057b	879b
30	714a	1 073ab	894a	698a	1 093b	896b	709a	1 109bc	909bc	707a	1 092bc	900bc
60	685a	1 140b	913a	654a	1 091b	873b	778a	1 188c	983c	706a	1 140c	923c
Avg.	692a	1 090b	891A	667a	1 034b	851A	732a	1 059b	896A	697a	1 061b	879
1977												
7.5	901a	1 389a	1 145a	996a	1 644a	1 320a	918a	1 499a	1 209a	938a	1 511a	1 225a
15	966a	1 560b	1 263b	975a	1 731a	1 353a	972a	1 603ab	1 289ab	971a	1 631b	1 301b
30	949a	1 475b	1 212b	1 029a	1 649a	1 339a	970a	1 584ab	1 277ab	983a	1 569b	1 276b
60	990a	1 469b	1 230b	1 026a	1 677a	1 351a	970a	1 676b	1 323b	995	1 607b	1 301b
Avg.	952a	1 473b	1 213A	1 007a	1 675b	1 341C	958a	1 591b	1 275B	972a	1 580b	1 276

		Cuts	N-fert	Density	CxN	CxD	NxD	CxNxD
1976	F-value	NS	xxx	xxx	NS	NS	xx	NS
	L D.05		33 kg	40 kg			57 kg	
1977	F-value	x	x	xx	NS	NS	NS	NS
	L D.05	60 kg	107 kg	49 kg				

F-years**, $LSD_{.05}$ = 215 kg

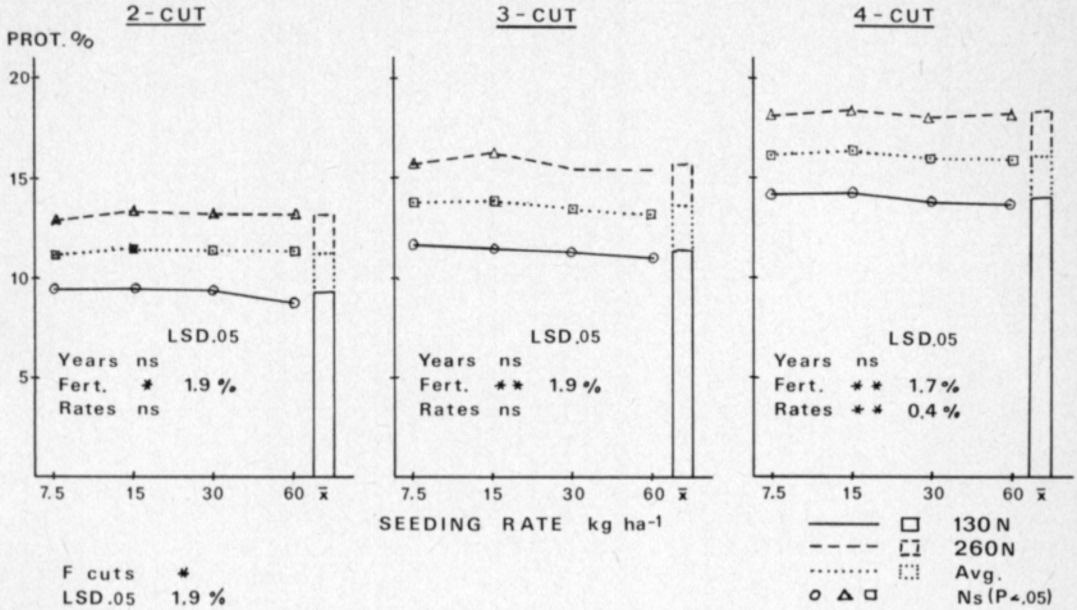

Fig. 14. Average protein content (prot. % in DM) of three cutting systems at four population densities and two levels of nitrogen.

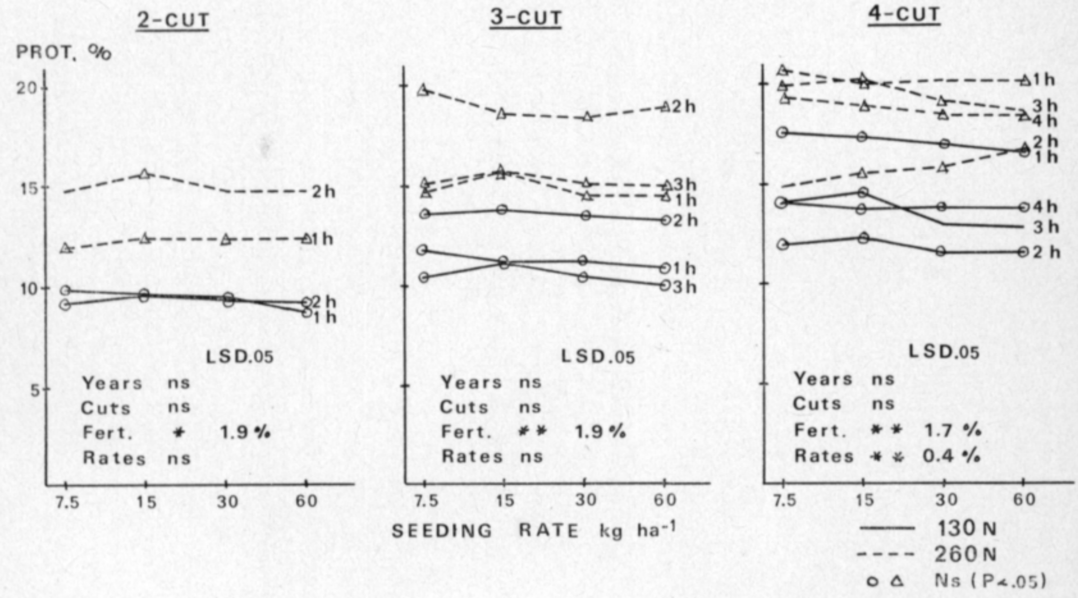

Fig. 15. Average protein content (prot. % in DM) of individual cuts in three cutting systems seeded at four population densities and fertilized at two levels of nitrogen.

Table 14. Cellulase digestibility of dry matter in 1976 and 1977.

Seeding rate kg ha^{-1}	2-cut 130N	2-cut 260N	2-cut Avg.	3-cut 130N	3-cut 260N	3-cut Avg.	4-cut 130N	4-cut 260N	4-cut Avg.	Cuts avg. 130N	Cuts avg. 260N	Cuts avg. Avg.
1976												
7.5	51.4a	53.5a	52.5a	55.1a	57.5a	56.3a	63.3a	63.3a	63.2a	56.6a	58.1a	57.4a
15	51.2a	53.4a	52.3a	54.7a	57.4a	56.1a	63.8a	64.6a	64.2a	56.6a	58.5a	57.6a
30	50.9a	51.0a	51.0a	56.5a	58.3a	57.4a	64.6a	65.2a	64.9a	57.3a	58.2a	57.8a
60	50.9a	51.3a	51.1a	57.1a	58.2a	57.7a	64.2a	66.2a	65.4a	57.4a	58.6a	58.0a
Avg.	51.1a	52.3a	51.8A	55.9a	57.9a	56.9AB	64.0a	64.8a	64.4B	57.0a	58.4a	57.7
1977												
7.5	46.9a	47.8a	47.4a	53.5a	56.9a	55.2a	60.8a	61.4a	61.1a	53.7a	55.4a	54.6a
15	46.2a	48.2a	47.2a	55.2a	56.6a	55.9a	61.1a	62.9a	62.0a	54.2a	55.8a	55.0a
30	45.4a	48.4a	46.9a	56.6a	55.5a	56.1a	60.5a	61.4a	61.0a	54.2a	55.1a	54.7a
60	45.4a	48.3a	46.8a	55.3a	54.5a	54.9a	59.6a	60.5a	60.1a	53.4a	54.4a	53.9a
Avg.	46.0a	48.2b	47.1A	55.2a	55.9a	55.5B	60.5a	61.6a	61.1C	53.9a	55.2b	54.6
Avg. years												
7.5	49.1a	50.7a	49.9a	54.3a	57.2a	55.8a	62.1a	62.3a	62.2a	55.2a	56.8a	56.0a
15	48.7a	50.8a	49.8a	55.0a	57.0a	56.0a	62.5a	63.8a	63.2a	55.4a	57.2a	56.3a
30	48.2a	49.7a	49.0a	56.6a	56.9a	56.8a	62.6a	63.3a	63.0a	55.8a	56.7a	56.3a
60	48.2a	49.8a	49.0a	56.2a	56.4a	56.3a	61.9a	63.3a	62.6a	55.4a	56.5a	56.0a
Avg.	48.6a	50.3a	49.5A	55.5a	56.9a	56.2B	62.3a	63.2a	62.8C	55.4a	56.8a	56.2

	Cuts	N-fert.	Density	CxN	CxD	NxD	CxNxD	years
1976 F-value	x	NS	NS	NS	NS	NS	NS	
LSD$_{.05}$	9.9 %							
1977 F-value	xxx	x	NS	x	NS	NS	x	
LSD$_{.05}$	1.0 %	0.7 %						
1976—77 F-value	xxx	NS	NS	NS	NS	NS	x	xxx
LSD$_{.05}$	0.8 %						2 1 %	0.4 %

Table 15. Wintering ability of the stand under different management practices in 1976–77 (Scale: 10 = no damage, 0 = completely disappeared).

Seeding rate kg ha^{-1}	After first winter			After second winter											
	100N	200N	Avg.	2-cut			3-cut			4-cut			Sits avg.		
				130N	260N	Avg.	130N	260N	Avg.	130N	260N	Avg.	130N	260N	Avg.
7.5	9.4	7.8	8.6	9.3	9.0	9.1	9.4	8.5	9.0	9.6	9.6	9.6	9.4	9.0	0.2
15	9.2	7.6	8.4	9.6	9.0	9.3	9.8	9.2	9.5	9.8	9.8	9.8	9.7	9.3	9.5
30	9.6	8.1	8.8	9.8	9.3	9.5	9.8	9.7	9.8	9.8	9.8	9.8	9.8	9.6	9.7
60	9.6	8.4	9.0	9.9	9.3	9.6	9.6	9.2	9.4	10.0	9.8	9.8	9.8	9.4	9.6
	9.5	8.0	8.7	9.7	9.2	9.4	9.7	9.2	9.4	9.8	9.8	9.8	9.7	9.3	9.5

	Cuts	N-fert.	Density	CxN	CxD	NxD	CxNxD
F-value							
First winter		xxx	NS			NS	
Second winter	NS	xx	xxx	NS	NS	NS	NS

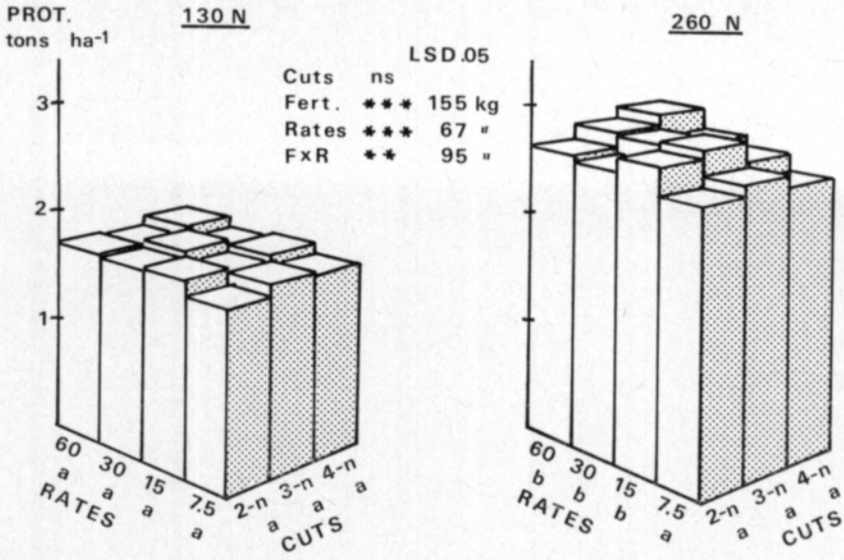

Fig. 16. Total protein yields (prot. tons ha^{-1}) in 1976—77 of three cutting systems seeded at four population densities and fertilized at two levels of nitrogen.

In 1976 the maximum protein yield was achieved with a seeding rate of 30 kg ha^{-1}, and in 1977 with 15 kg ha^{-1} (Table 13). At the low nitrogen level the seeding rate had no effect on the protein yield in any of the cutting systems. At the high nitrogen level the minimum seeding rate was not sufficient for reaching the maximum protein yield in the 2- and 4-cut systems. This same trend was found for all cutting systems at the high nitrogen level in the grand total yield (Fig. 16).

4. 3. 5. Cellulase digestibility of dry matter

The highest DM cellulase digestibility in both years was in the 4-cut system and the lowest in the 2-cut system. During 1976—77 all of the cutting systems differed from each other with very high significance (Table 14).

Differences between the invidual cuts of the cutting systems were found only in the 4-cut system (Fig. 17), where the highest digestibility in both years was in the first cutting and the lowest in the second.

Nitrogen fertilizer raised the dry matter's digestibility in 1976 and 1977, but a significant change was registered only for 1977. In 1977 also the combined effect (CxN) was significant, where the nitrogen fertilizer significantly raised the cellulase digestibility in the 2-cut system, but not in the 3- or 4-cut systems.

On the whole, the seeding rate had no statistically significant influence on the dry matter's cellulase digestibility in either year. From forage samples a part of the dry matter's digestibility in vitro was also determined. There was a very significant correlation between the cellulase digestibility and the in vitro digestibility (Fig. 18). The dependence between cellulase and in vitro digestibility determined for fescue corresponds well to correlations for clover-grass mixture and coach grass (Pulli 1976).

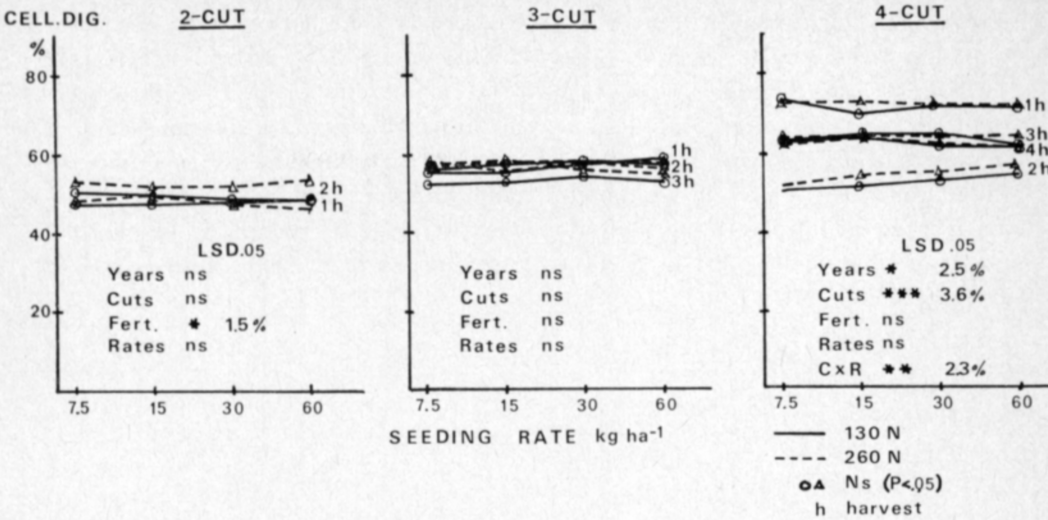

Fig. 17. Dry matter cellulase digestibility (%) of individual cuts in three cutting systems seeded at four population densities and fertilized at two levels of nitrogen.

4. 3. 6. Discussion

Number of cuttings

An increase in the number of cuttings means a per cutting and per growing season decrease in dry matter yield (Carter and Law 1948, Huokuna 1957, Brougham 1959, Heinrichs and Crark 1961, Laine 1965, Anslow 1967, Frame and Hunt 1971, Pedersen et al. 1974, Wolton 1976).

In this investigation significantly larger yields were gained with two cuttings as compared to three or four. A reduction in the number of cuttings, however, meant a noticeable drop in the quality of the yield, as described by high dry matter content, low protein content and low cellulase DM digestibility.

Instead, the number of cuttings showed, as in prior investigations (Saglamtimur and Bogdan 1970, Lawrence et al. 1971), that it had little influence on the protein yield per unit of area.

Diffirences in quality between cuttings were least in the 2- and 3-cut systems. The highest protein content and digestibility were with the 4-cut system, which also provided the most balanced yield per cutting because the early summer's rapid growth covered two cuttings. Dividing the fast growth phase between two cuttings means a reduction in the total yield (Huokuna 1964). The amount of the yield and its quality are tied by correlations to the different cutting systems. The distribution of the yields between different cuttings as is done in the cutting systems, affects the forage quality the most decisively.

Nitrogen fertilization

The increasing application of nitrogen fertilizer from 130 to 260 kg ha^{-1} raised the dry matter yield by an average of 1 110 kg ha^{-1} in 1976—77. One kilogram of nitrogen between the range 130—260 kg N ha^{-1} produced a dry matter yield increase of 8.5 kg. The yield increases obtained corresponded with previous investigations (LAINE 1966, HIIVOLA et al. 1974, RINNE 1971).

Nitrogen fertilization improves the quality of the yield. The fertilizer reduced the dry matter content in all cutting systems, but only significantly in 4-cut system. Increasing the nitrogen from 130 kg to 260 ha^{-1} correspondingly raised the forage's protein content by 4.2 percentage units, or in other words an average of 0.3 percentage units for every 10 kg N ha^{-1} increase. The corres pondent increase in protein yield was 485 ha^{-1}, which agrees with HIIVOLA et al. (1974).

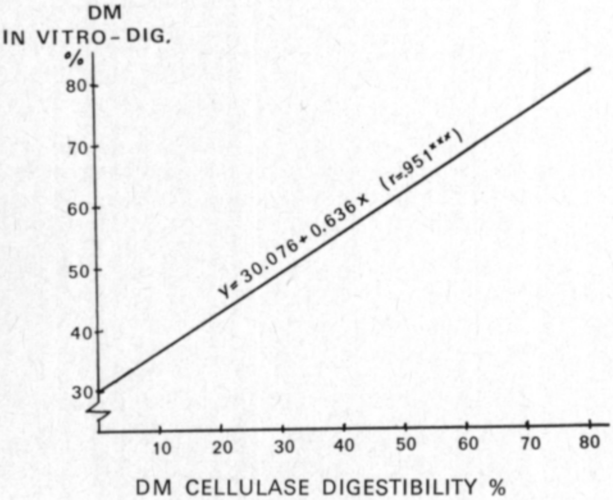

Fig. 18. The relationship between the dry matter cellulase digestibility and the dry matter *in vitro* digestibility of meadow fesque (Festuca pratensis) stand at different stages of maturity.

At the low nitrogen level the protein yield ranged from 667 kg to 1 007 kg, and at the high level from 1 034 kg to 1 675 kg for all cutting systems. On the average the low nitrogen level produced 835 kg ha^{-1} of protein and the high level 1 320 kg ha^{-1}, resulting in 3.7 kg of protein for every kg of nitrogen between the nitrogen levels of 130—260 kg N ha^{-1}.

Nitrogen had the least effect on the dry matter digestibility in the 4-cut system and the best in the 2-cut system. The N-fertilizer raised the dry matter cellulase digestibility an average of 1.4 percentage units. According to STEEN (1972), nitrogen fertilizer improves mostly protein digestibility.

Population density effects

During the first year the densest stand is the most productive, but in the following years the highest yields are obtained from the less dense stands (DONALD 1956). A corresponding phenomena was observed in this investigation. In the seeding year the greatest yield was achieved with the seeding rate of 60 kg ha^{-1} (2 600 seeds m^{-2}). During the first actual production year the statistical maximum was achieved with the rate of 30 kg ha^{-1} (1 300 seeds m^{-2}) at both nitrogen levels. In the second production year the maximum yield required only a seeding rate of 15 kg ha^{-1} (650 seeds m^{-2}). These results agree

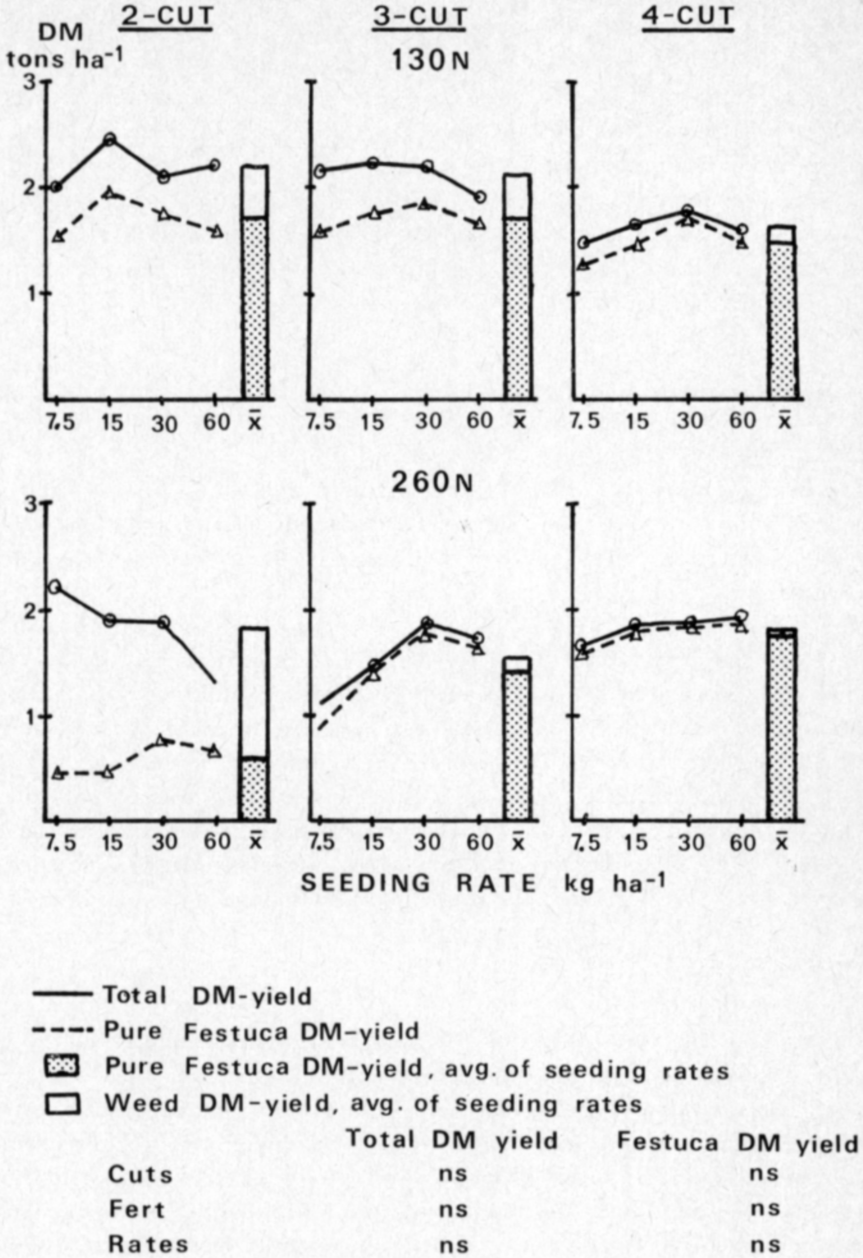

Fig. 19. The management post effects on the total and pure meadow fesque yield three years after seeding.

well with the results of LAINE (1958) and JÄRVI (1977). As LAINE (1958) showed, the third year's statistical maximum yield was achieved with the rate of 7.5 kg ha^{-1} (Fig. 19). In general it was so that with an increase in the number of cuttings the statistical maximum yield required a slightly larger rate of seeding. The exception was the 2-cut system, where delaying the first cutting created competition at high growing densities which in turn raised the dry matter content so much that the yield level sharply climbed all the way to the levels characteristic for the highest seeding rates. This phenomena was noticeable particularly at the low level of nitrogen. Applying nitrogen as experienced by DONALD (1951) and NORRINGTON and DAVIES (1969) increased the seeding rate requirements for the maximum yield.

The seeding rate had very little influence on the quality of the yield, and did not affect either dry matter content or cellulase digestibility at all. Increasing the seeding rate reduced the protein content very little as compared to the findings of van BURG (1962) and ALBERDA (1965 a).

4.4. Management Post Effects

4.4.1. Wintering

The seeding rate and the nitrogen fertilizer applied in the seeding year influenced the wintering that followed the seeding year. In spring 1977 an influencing factor, in addition to the previous factors, was also the cutting frequency.

Obervations showed (Table 15) that the nitrogen fertilization had the greatest effect on wintering in both years. The application of 100 kg N ha^{-1} did not thin the crop at all, whereas the application of 200 kg N ha^{-1} thinned the stands at all densities. The most severe decrease in plant density occurred in the stand with the lower seeding rate. The influence of nitrogen fertilizer during the second winter was less than that for the seeding year, but still statistically significant. The stand was thinned most when cut twice at the high level of nitrogen. When cutting four times, the nitrogen fertilizer had the least negative effect on wintering. A statistically significant combined effect (CxN) was not observed.

4.4.2. Productivity

To establish the post effects of the treatments, all plots received 75 kg N ha^{-1} and were cut at the same time in the spring of 1978.

At the low level of nitrogen the total dry matter yield decreased with an increase in the number of cuttings (Fig. 19). At the high levels of nitrogen this trend was milder. The lower nitrogen level produced 253 kg ha^{-1} more dry matter than the high one. More regrowth, in addition, was found if the cutting frequency or nitrogen level was raised with one exeption being the 2-cut system with the low level of nitrogen. In the 4-cut system fescue comprised 93.7 % of the total yield and in the 2-cut system only 56.2 %. The most stressing treatment was the 2-cut system at a high level of nitrogen and at low rate of seeding.

4.4.3. Discussion

The disruptive effects of a high level of nitrogen begin to manifest themselves in the yield development and in the wintering of the stand (HUOKUNA and HIIVOLA 1974). According to this investigation the application of 100 kg N ha^{-1} in the second cutting during the seeding year damaged wintering stands.

During the second winter the nitrogen fertilizer did not have a decisive effect in any of the cutting systems. It can be seen from the regrowth, however, that in the 2-cut system the 130 kg N ha^{-1} application per cutting was too much for fescue survival. In accordance with previous studies (HUOKUNA 1974, HAKKOLA 1978) when increasing the cutting frequency at a certain level of nitrogen, the amount of nitrogen per cutting decreases and the stand survival improves.

5. Summary and conclusions

The investigation of meadow fescue was carried out at the University of Helsinki in Viikki in 1975—78. The main objective was to study the rhythm of the growth and yield formation pattern of a forage crop and the relationship between growth pattern and growth factors during different phases of the growing season. The management techniques studied were the number of cuttings, use of nitrogen, requirements of population density and the relationships of management factors to the changes in the quantity and quality of forage yield. The following results have been drawn:

1. The most important factors concerning the LAI and height increase of spring growth in the seeding year were the temperature sum in degree days and the total radiation. The seeding year's fall LAI and height correlated weakly to the growing time and temperature sum. The late summer height growth during the seeding year was significantly influenced by nitrogen fertilizer beyond the temperature sum range of 500° C.

2. Differences in growing densities based on seeding rates disappeared in the dry growing conditions eight weeks after seeding. However the seeding year yield level can be raised with increasing population density.

3. During the production years after the seeding year the most important yield formation variables during spring growth were the growing time, the temperature sum in degree days and the total radiation. For midsummer and fall growth the following determinants described growth the best: precipitation, amount of nitrogen for the cut and the precipitation during the week before the prior cut.

4. During spring growth at a temperature sum of 750° C the yield level obtained was 6 tons ha^{-1} with the following quality characteristics: dry matter content 30 %, protein content 10 % and cellulase digestibility of dry matter 50 %. The summer growth yield level at a temperature sum of 700° C was 4 tons ha^{-1} with the characteristics: dry matter content 22 %, protein content 17.5 % and cellulase digestibility of dry matter 55 %. The fall growth temperature sum contains the second cutting of the 2-cut system. For the fall growth with the temperature sum of 1 200° C the obtained dry matter yield was 3.5 tons ha^{-1} and had quality characteristics of: dry matter content 29 %, protein content 12 % and cellulase digestibility of dry matter 50 %.

5. During midsummer and fall the crop's development was noticeably slower than in the spring. At this time the quality of the yield remained considerably steady, as the dry matter increase and the protein content decrease

were slight. For spring growth the dry matter content rise and protein content decrease were sharp in the temperature sum range of 150—350° C. The decrease in cellulase digestibility was strongest in the temperature sum range of 250—650° C.

6. A very significant correlation between dry matter yield and LAI existed throughout the growing period. The spring growth's maximum LAI was 8.5, which represents a temperature sum of 550° C. The summer and fall growths' LAI value of 7.5 represents temperature sums of 700 and 1 200° respectively. For spring, summer and fall growth a one unit increase in LAI created a dry matter yield increase of 715, 500 and 315 kg ha^{-1} respectively. The corresponding heights for the spring and summer periods were 85 sm, 60 cm. Because of height growth differences a smaller and smaller dry matter yield is obtained in the autumn at the same LAI value.

7. An increase in the number of cuttings signifies a smaller yield per cutting and per growing season but a considerable improvement in the quality of the yield. Increasing the number of cuttings from two to four decreased the yield by and average of 2 527 kg ha^{-1}. At the same time the protein content and dry matter cellulase digestibility increased an average of 4.8 and 13.3 percentage units respectively.

8. Increasing the nitrogen fertilizer applications from 130 to 260 kg N ha^{-1} raised the dry matter yield by 1 110 kg ha^{-1}, the protein yield by 485 kg ha^{-1}, the protein content by 4.2 percentage units and the cellulase digestibility by 1.4 units.

9. The influence of growing density on yield formation was more significant the more often the crop was cut. The seeding year's greatest dry matter yield was obtained with a seeding rate of 60 kg ha^{-1}. During the following growing season 15 kg ha^{-1} were needed to produce the greatest yield in the 2- and 3-cut systems and 30 kg ha^{-1} for the 4-cut system. In the third growing season 15 kg ha^{-1} produced the maximum dry matter yield in all cutting systems. To achieve the maximum yield a higher population density is needed if nitrogen fertilizer and the number of cuttings are increased. Not including the seeding year, the seeding rate had little effect on the yield's quality. In the fourth growing season the seeding rate had no statistical effect.

10. In the seeding year's fall growth and in the 2-cut system, 100 and 130 kg N ha^{-1} respectively were too stressing for the stands. In regard to preservation of the crop's productivity, the yield quantity and quality, a management system involving a seed amount of 30 kg ha^{-1}, 3—4 cuttings per growing season and a fertilization level of 260 kg N ha^{-1} is recommended as the best.

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SELOSTUS

Viljelytoimenpiteiden ja kasvutekijödein vaikutus nurminadan kasvuun ja kehitykseen.

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Helsingin yliopiston Kasvinviljelytieteen laitoksella tutkittiin vuosina 1975–78 niittojen, N-lannoituksen ja kasvutiheyden vaikutusta nurminadan sadonmuodostukseen sekä kasvun ja kehityksen suhdetta kasvutekijöihin kasvukauden eri ajankohtina. Tutkimuksista voidaan vetää seuraavat johtopäätökset:

Kylvövuoden kevätkasvun tärkeimmät LAI:ä ja pituuskasvua selittävät muuttujat olivat kasvuajan lämpösumma ja säteilysumma. Kylvövuoden syyskasvun LAI ja pituus korreloivat heikosti kasvupäiviin ja lämpösummaan. Kylvövuoden loppukesä pituuskasvuun N-lannoitus vaikutti vasta, kun lämpötilasumma oli saavuttanut arvon 500° C.

Erot kylvömäärien välisissä kasvutiheyksissä hävisivät kuivissa olosuhteissa ankaran kilpailun vallitessa jo kahdeksan viikon kuluttua kylvöstä. Kuitenkin kylvövuonna on mahdollista kohottaa satotasoa lisäämällä kasvutiheyttä.

Kylvövuoden jälkeen nurmen kevätkasvussa tärkeimmät sadonmuodostusta selittävät muuttujat olivat kasvuaika ja kasvuajan lämpötilasumma ja säteilysumma. Keskikesällä ja syyskesällä parhaiten nurmen kasvua selittivät kasvuajan sademäärä, sadolle annettu N-lannotus sekä viikon aikana ennen edellistä niittoa saatu sade.

Kevätkasvussa lämpösummalla 750° C saavutettiin satotaso 6 tn ka. ha^{-1}. Kevätsadon laatuominaisuudet olivat: ka-pitoisuus 30 %, rv-pitoisuus 10 % ja ka-sellulaasisulavuus 50 %.

Kesäkasvussa lämpötilasummalla 700° C saavutettiin satotaso 4 tn ka. ha^{-1}. Kesäsadon laatuominaisuudet olivat: ka-pitoisuus 22 %, rv-pitoisuus 17.5 % ja ka-sellulaasisulavuus 55 %. Syyskasvussa lämpötilasummalla 1 200° C saavutettiin kuiva-ainesato 3.5 tn ha^{-1}. Syyssadon laatuominaisuudet olivat: ka-pitoisuus 29 %, rv-pitoisuus 12 % ja ka-sellulaasisulavuus 50 %.

Keski- ja syyskesällä nurmen kehitys oli huomattavasti kevätkasvua hitaampi. Tällöin myös sadon laatu pysyi pitkään tasaisena, sillä ka-pitoisuuden kohoaminen ja rv-pitoisuuden aleneminen olivat vähäisiä. Kevätkasvussa kuiva-ainepitoisuuden nousu ja raakavalkuaispitoisuuden lasku olivat voimakkaimpia lämpösumma-alueella 150–300° C. Sellulaasisulavuuden lasku oli voimakkain lämpösumma-alueella 250–550° C.

Kuiva-ainesadon ja LAI:n välillä vallitsi koko kasvukauden erittäin merkitsevä korrelaatio, Kevätkasvussa LAI:n maksimi saavutettiin arvolla 8.5, joka edustaa lämpösummaa 550° C. Kesäkasvun ja syyskasvun LAI:-arvot 7.5 edustivat lämpösummia 700° C ja 1 200° C. Kevät-, kesä- ja syyskasvussa yhdellä LAI-yksikön lisäyksellä saavutettiin lisäkasvut 715, 500 ja 315 kg ka. ha^{-1}. Kevät- ja kesäsadon pituudet olivat 85 ja 60 cm. Pituuskasvueroista johtuen samalla LAI-arvolla saadaan syksyä kohti yhä pienempi ka-sato.

Niittojen lukumäärän lisääminen merkitsee niittoa ja kasvukautta kohti pienempää satotasoa, mutta sadon laadun huomattavaa paranemista. Niittojen lukumäärän lisääminen kahdesta neljään alensi satotasoa keskimäärin 2 527 kg ka ha^{-1}. Samanaikaisesti rv-pitoisuus ja kuiva-aineen sellulaasisulavuus paranivat keskimäärin 4.8 ja 13.3 %-yksikköä.

Typpilannoituksen lisääminen 130 kg:stä 260 kg:aan hehtaarilla kohotti kuiva-ainesatoa 1 110 kg ha^{-1}. Sama typpilannoituksen lisäys nosti raakavalkuaissatoa 485 kg sekä sadon raakavalkuaispitoisuutta ja sellulaasisulavuutta 4.2 ja 1.4 %-yksikköä.

Kasvutiheyden vaikutus nurmen sadonmuodostukseen oli sitä merkittävämpi mitä useammin niitettiin.

Kylvövuoden suurin ka-sato saavutettiin kylvötiheydellä 60 kg ha^{-1}. Kylvövuotta seuraavana kasvukautena suurimpaan satoon 2- ja 3-niittosysteemeissä tarvittiin siemenmäärä 15 kg ha^{-1} ja 4-niittosysteemissä 30 kg ha^{-1}. Kolmantena kasvukautena kuiva-ainesadon maksimi saavutettiin kaikissa niittosysteemeissä kylvömäärällä 15 kg ha^{-1}. Maksimisatotasoon tarvittiin suurempi kasvutiheys, jos N-lannoitusta ja niittokertoja lisättiin. Sadon laatuun kylvötiheydellä oli kylvövuotta lukuunottamatta erittäin vähäinen merkitys. Jälkisadoissa neljäntenä kasvukautena ei kylvötiheyksillä ollut tilastollisia eroja.

Kylvövuoden syyskasvulle 100 kg N ha^{-1} ja 2-niittosysteemissä 130 kg N ha^{-1}/niitto olivat kasvustoa liiaksi stressaavia. Nurmen tuottokyvyn säilymisen sekä nurmen määrän ja laadun kannalta parhaimmaksi viljelyteknilliseksi vaihtoehdoksi saatiin menetelmä, jossa nurminatanurmi perustettiin kylvömäärällä 30 kg ha^{-1}, niitettiin 3—4 kertaa kasvukaudessa ja lannoitettiin 260 kg ha^{-1}.