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Climate, nitrogen and grass. 3. Some effects of light intensity on nitrogen metabolism

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Summary

The interaction of light intensity and nitrogen fertilization on the chemical composition of grass was studied in an experiment with a two-year-old sward of *Lolium perenne* cut at an age of four weeks.

It appeared that with short supply of nitrogen higher light intensity exhausted nitrate reserves in the grass and diminished the crude-protein content, but greatly increased the percentage of water-soluble carbohydrates.

However with ample supply of nitrogen, higher light intensity decreased nitrate content, but increased both crude-protein and water-soluble-carbohydrate content. Similar effects were deducted from some literature references.

These results were discussed in the frame of nitrate reduction being mainly a photochemical process in the leaves of many plants.

Introduction

It is usually found that increased nitrogen fertilization enhances protein content and reduces soluble-carbohydrate content of forage grass, whereas higher light intensity generally causes the opposite. So it seems that light intensity and nitrogen fertilization affect the chemical composition antagonistically, without a significant interaction.

Before protein can be formed, nitrate taken up by the roots has to be reduced to ammonia. In some instances this reduction proceeds at the expense of sugars, but in many green plants photochemical reduction seems to be the major process (Bongers, 1956; Kessler, 1964; Spencer, 1958). The latter process implies that light energy is required for nitrate reduction which may indicate that at higher light intensities nitrate reduction and protein formation are stimulated, like CO_2 reduction and carbohydrate formation, and may result in both higher protein and soluble-carbohydrate content.

However this is seldom found, for soil nitrogen supply is usually limited, and dry-matter production is increased by higher light intensity to such an extent that the grass runs short of nitrogen and reveals depletion of nitrate and low protein and high soluble-carbohydrate concentrations (Alberda, 1965; Deinum, 1966).

Van Burg (1962) investigated the relation between the concentration of nitrate and Kjeldahl nitrogen which he called the nitrochore, showing that increased nitrogen fertilization enhances $^0/_0$ NO_3 and $^0/_0$ N distinctly. However this relationship is not constant and may be influenced by age, nitrogen source, soil type, K and P fertilization, water shortage etc. However, he was not able to study the effect of light intensity.

On the other hand, Alberda (1965) showed a distinct relationship between the % NO_3 and % water-soluble carbohydrate in *Lolium perenne,* suggesting that nitrate reduction proceeds at the expense of sugars.

In order to investigate whether light intensity definitely stimulates protein formation in grass both in quantity and concentration and whether there is a definite interaction between light intensity and nitrogen fertilization, an experiment was carried out with different light intensities and nitrogen-fertilization treatments. The results are mentioned in this paper using the nitrochore and the relation between nitrate and water-soluble carbohydrate concentration as ways of description.

Material and methods

The experiment was carried out in a two-year-old sward of *Lolium perenne* on a heavy clay soil from 18 May–29 June 1966, set out in a split plot design at three light intensities and four nitrogen treatments. The experiment was carried out during the period of stem elongation.

The light intensities expressed as average daily quantity of total radiation in cal . cm^{-2} . day^{-1} between 18 May and 15 June, the period to which most attention will be paid in this paper, were:

normal light intensity: 390 cal . cm^{-2} . day^{-1}

low light intensity: by shading with cheese cloth: 88 cal . cm^{-2} . day^{-1}. The average daily maximum and minimum temperature inside the crop were about 4° C lower and about 2° C higher respectively than at normal light intensity.

high light intensity: normal + additional light during the day with 5 Philips HPLR 400 W lamps per m^2 allowing a total light quantity of 711 cal . cm^{-2} . day^{-1}. The average daily maximum and minimum temperature inside the crop were about 2.5° C and 1° C higher than at normal light intensity.

The nitrogen treatments were superimposed on the light-intensity treatments and are mentioned in Table 1.

The reason for the different nitrogen treatments at the three light intensities is that at low light intensities it is difficult to obtain nitrogen deficiency, whereas at high light intensity it is difficult to prevent it. As a reference it may be mentioned that 160 kg N/ha is about sufficient for maximum production of a grass crop during four weeks of growth under average summer conditions. Nitrogen was applied in the form of nitro-chalk with 23% N; the size of each plot was 1.60 × 3.40 m.

Table 1. Data on the light intensities and nitrogen-fertilization treatments.

Nitrogen treatments (kg N/ha) →	Light intensity (cal. cm^{-2} . day^{-1})		
	low 88	normal 390	high 711
N_1	20	40	80
N_2	40	80	160
N_3	80	160	240
N_4	160	320	360

On 1, 15 and 29 June three clippings of 0.25 × 1.00 m each per plot were made, after which the grass was immediately weighed and dried in a forced draught oven at 70° C and ground through a 1-mm sieve. In addition the 29 June clipping was separated into leaf lamina, flowering and non-flowering stems after drying.

After grinding the samples were analysed for % total N, % NO_3-N, % ash, % water-soluble carbohydrates (% wsc) and % crude fibre (% cf); % organic nitrogen (% org. N) was calculated as the difference between % total N and % NO_3-N.

Results and discussion

Only the results of the 15 June clipping will be mentioned here, the other clippings revealing the same picture. Table 2 mentions the effect of light intensity and nitrogen fertilization on dry-matter production and crude-fibre content.

Table 2 reveals the positive effects of nitrogen fertilization and light intensity on dry-matter production, although there are some irregularities due to the small sampling units and the small number of replicates. However, the data show that the effects decrease with higher applications of nitrogen and light energy. In addition Table 2 shows that % cf is decreased by higher light intensity as found earlier (Deinum, 1966), whereas higher nitrogen fertilization tends to diminish the concentration of this constituent, especially at high light intensity. Maybe the negative effect of light intensity on % cf would have been greater if the temperatures had been equal at the three light intensities, for temperature has a positive effect on % cf (Alberda, 1965; Deinum, 1966). The negative effect of nitrogen fertilization on % cf is rather exceptional in this kind of grass, for van Burg (1962) usually found a positive effect; only in very young grass lower crude-fibre concentrations were found at higher nitrogen fertilizations.

Fig. 1a, b and c show the relationship between % org. N versus % NO_3-N (nitrochore, plotted on a linear scale), % wsc versus % NO_3-N according to Alberda (1965) and % org. N versus % wsc, respectively. However, van Burg (1962) used % Kjeldahl-N in the nitrochore which is only equivalent to % org. N in grass free of nitrate.

Fig. 1a shows that with increasing nitrogen fertilization % NO_3-N increases, whereas % org. N also increases until it approaches a maximum concentration. (The small open arrows in the lines indicate the direction of increasing nitrogen fertilization.) At rising light intensity this relationship will show rising org. N concentrations, however, this is only found at the higher N fertilizations. At fertilizations of 160 kg N and

Table 2. Effect of light intensity and nitrogen fertilization on dry-matter production (g/m²) and crude-fibre content (% of dm) of grass.

	Dry-matter production			Crude-fibre content		
Light intensity →	low	normal	high	low	normal	high
Nitrogen treatment						
N_1	360	580	730	33.8	31.2	30.4
N_2	390	720	910	32.8	31.4	30.1
N_3	420	860	820	31.7	31.8	28.9
N_4	430	760	950	32.3	29.8	28.6

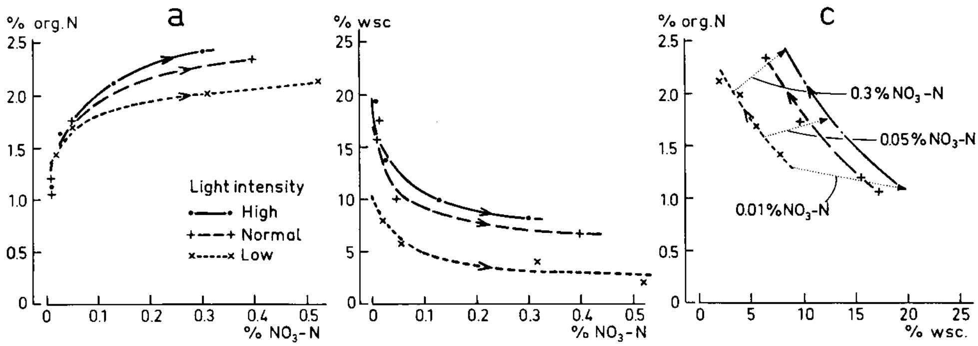

Fig. 1. The relationship between different chemical constituents of *Lolium perenne* as effected by nitrogen fertilization and light intensity.
a. % organic nitrogen versus % nitrate nitrogen.
b. % water-soluble carbohydrates and % nitrate nitrogen.
c. % organic nitrogen versus % water-soluble carbohydrates.

lower, higher light intensities caused depletion of nitrate and diminishing of % org. N. The figure indicates that with sufficient fertilizer nitrogen, higher light intensity causes higher protein concentrations (= % org. N × 6.25).

Fig. 1b shows similar effects of nitrogen fertilization and light intensity. A distinct relationship between % NO_3-N and % wsc is effected by nitrogen fertilization, showing higher % NO_3-N and lower % wsc at higher N treatments. At higher light intensities this line shows higher soluble carbohydrate concentrations.

Fig. 1c is a combination of Fig. 1a and 1b and shows the relationship between % org. N and % wsc. There is a good relationship between both constituents showing that with higher fertilization the org. N increases and % wsc decreases. At higher light intensities this line moves away from the origin, however this takes place in such a way that with ample supply of nitrogen both % org. N and % wsc are enhanced, indicated by the small dotted line of 0.3 % NO_3-N. However, with short supply, % org. N is diminished somewhat and % wsc is increased considerably, as shown by the small dotted line of 0.01 % NO_3N.

Almost identical results were found in the 1 June and in all the components of the 29 June clippings, as well as in three other experiments in which light intensity and nitrogen fertilization were varied to high quantities (Deinum unpublished data). They can be inferred also from Nowakowski's experiment (1965), with *Lolium multiflorum*. This positive effect of light intensity on % org. N is also present in the experiments of Bathurst and Mitchell (1958) with *Trifolium repens* and of Ehara et al. (1968) with *Cynodon dactylon*.

In addition a study of Alberda's experiment (1965) reveals the same effects of light intensity and nitrogen in the leaves of *Lolium perenne*. However, it is not present in the stubble and roots. This may indicate that nitrate reduction in stubble and roots is a respiratory process, whereas in the leaves light energy may be the major energy donor for nitrate reduction. Nevertheless, these experiments are not conclusive in this respect.

Fig. 1 shows that the major constituents of the cellular contents, % protein and % water-soluble carbohydrates, are increased by higher light intensity at ample supply of nitrogen. This may cause a decrease of the percentage of cell-wall constituents which appears to be present in the percentage of crude fibre as shown in Table 2.

In conclusion, all these experiments indicate that the negative influence of higher light intensity on the protein content is only present with short supply of nitrate nitrogen. However, when the nitrate nitrogen supply of the plant is large, then high light intensity may increase the protein content of the plant.

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