NITROGEN, CHLORINE AND POTASSIUM IN PERENNIAL RYEGRASS AND THEIR RELATION TO THE MINERAL BALANCE [1]

W. DIJKSHOORN

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

SUMMARY

The results are discussed of a pot culture experiment with perennial ryegrass on the effect of increasing nitrogen fertilization at three potassium chloride levels.

Chloride fertilization caused an increase in the concentration of the anionic and cationic elements in the yield, but did not lead to any change in the cation-anion ratio. With the highest addition of chloride, there was no further increase in the high cation content when increasing amounts of nitrogen were also added to the dressing. The potassium in the fertilizer had no effect on the total cation concentration in the yield, but only caused an alteration in the relationships of the individual cations.

Increasing nitrogen fertilization caused a decrease in the concentration of the $Cl + P + S$ anions in the yield and an increase in the nitrogen concentration. The increase in the total anion content $Cl + P + S + N$ was relatively greater than the increase in the cation content $K + Na + Mg + Ca$, so that with an increasing nitrogen level there was a certain decrease in the cation-anion ratio.

Among the antagonistic effects which counteracted an excessive anion uptake at higher chloride levels, there was a reduction in the sulphur content, and at higher nitrogen levels also a reduction in the nitrogen content.

INTRODUCTION

It has been demonstrated in previous reports that larger amounts of the nitrate and chloride anions were absorbed from a fertilizer dressing. The considerable rise in the concentration of the anionic elements was accompanied by the same relative increase in the cationic elements, so that the dressing had no marked effect on the cation-anion ratio in the yield of herbage (DIJKSHOORN, 1957a and b).

Since nitrogen and chlorine are components of commonly used fertilizers, in the experiment described here a further investigation was made into their effect on the composition of the yield of herbage. Use was made of mixtures of pure salts whose composition resemble nitrolime and 40 per cent muriate of potash, the most commonly used commercial fertilizers. Moreover a wider fertilization range was investigated in order to include the effect of applying very heavy dressings.

EXPERIMENTAL

The effect of increasing quantities of nitrogen in the fertilizer was examined at three different potash levels.

The potash fertilizer used was a solution of potassium and sodium chloride containing 40 parts of K_2O per 100 parts of salt mixture, viz. it corresponded to 40 % muriate of potash.

The nitrogen fertilizer used was a solution of ammonium nitrate, and in addition calcium carbonate was applied. The quantities of ammonium nitrate and calcium carbonate were added in a sufficient ratio for the fertilizer to constantly contain 20 parts of nitrogen per 100 parts of ammonium nitrate + calcium carbonate. In this way the composition of the nitrogen fertilizer corresponded to that of nitrolime.

For each culture vessel 5 kg of air-dry soil were mixed with the calculated quantity of calcium carbonate. The remaining salts were mixed into the soil in solution in the quantity of water added. The soil used was a sandy one poor in nitrogen and chlorine and having an organic matter content of 4 per cent.

Three series of pots were prepared each of which contained a nitrogen fertilization range of from nil to 2.1 gm N per pot, the amount of calcium carbonate added being increased in proportion from nil to 4.5 gm per pot.

The first series contained no potash fertilizer; this series is hereinafter referred to as K0. The vessels of the second series (K1) received an addition of 235 mg K_2O, and 1410 mg K_2O were added to the pots in the third series (K2).

The pots were uniformly planted with shoots of perennial ryegrass (pasture type) which after remaining in the shade for three days was clipped to a height of 3 cm above the soil. The plants were then kept on the greenhouse shelves for four weeks and the herbage produced was harvested by clipping to the original height.

DISCUSSION

In Fig. 1 Kjeldahl nitrogen (N), the anions A (= Cl + P + S), the cations C (= K + Na + Mg + Ca) and the total anions A + N in mg equivalents per kg of dry matter produced are plotted against the amount of nitrogen in gm of N per pot added in the dressing. Nitrogen was thus taken up in the balance as a monovalent anion.

Use was again made of a logarithmic scale for checking by means of graphs BEAR's (1950) rule relating to the constant cation-anion ratio.

The bottom graphs show that at first there is a sharp increase in the nitrogen content with increasing nitrogen dressing, but that in the last part of the fertilization range a final level is reached above 1.2 gm N per pot. The upper graphs show that after this final level has been reached in the nitrogen content, a further increase in the given amount of nitrogen also causes no further change in the cation and anion content of the yield.

The general pattern of the effect of the nitrogen dressing agrees with the earlier described effect of the nitrate dressing. The observations are so far in agreement with the rule of the constant cation-anion ratio that the great increase in the nitrogen content is again accompanied by a decrease in the anions A and an increase in the cations C. However, closer inspection of the gradient of the cation content C and the total anion content A + N shows that this may be best represented by two lines which clearly diverge as the nitrogen dressing is increased. In the method of graphical representation employed here this divergence shows that the cation-anion ratio grows smaller with an increasing nitrogen content.

It might be asked whether this deviation from BEAR's rule may not be connected with an incomplete inventory of the elements. In BEAR's original equation silica was also included in the total anion content. If the plants with

132

a lower nitrogen content were to contain relatively more silica the gradient of the total anion content A + N + Si might be smaller, and in this way the lines representing C and A + N + Si might possibly follow a more parallel course than was found for C and A + N.

If silica is included in the ionic balance, a decreasing silica content with an increasing nitrogen content would have to be interpreted as a nitrate-silicate antagonism. In this case an anion such as chloride, which is also capable of effecting a considerable rise in the anion content, might possibly also lead to such an antagonism. If the observed decrease in the cation-anion ratio with an increasing nitrogen level were only due to the absence of silica in the ionic balance, a certain decrease in the cation-anion ratio might also be found when the concentration of the anionic elements undergoes a considerable rise as a result of an increase in the chlorine content.
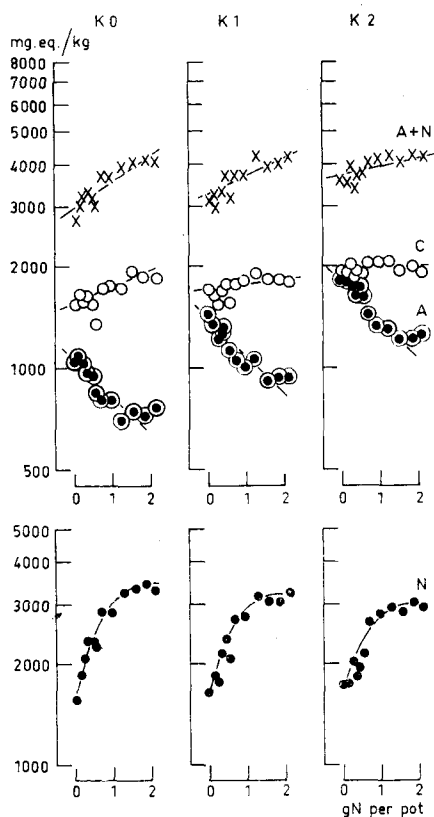

FIG. 1   NITROGEN N, ANIONS A (= Cl + P + S), TOTAL CATIONS C (= K + Na + Mg + Ca) AND TOTAL ANIONS A + N IN MG EQUIVALENTS PER KG OF DRY MATTER PRODUCED, PLOTTED AGAINST THE AMOUNT OF NITROGEN SUPPLIED IN THE FERTILIZER.
K0 : no chloride fertilizer.
K1 : moderate potassium-sodium chloride fertilization.
K2 : heavy application of potassium-sodium chloride.

Fig. 1 shows that the chloride dressing caused a marked increase in the anion content. In the series containing the greatest amount of chloride fertilizer (K2) the initial level of the anions A is about 800 mg equivalents higher

than in the series without chloride fertilizer (K0), and the total anion content
A + N is correspondingly higher in the K2 series. This increase is entirely
due to an increase in the chlorine content of the yield.

The data showed that the chloride dressing had no clear effect on the
cation-anion ratio. When the yields from the three series were derived from
the same nitrogen dressing there were no systematic differences between them
as regards the cation-anion ratio. This is also reflected in the graphs, since
the linear distance of the plots for the cations C and the total anions A + N
is the same in all three series when they are compared at the same level of
nitrogen dressing.

It might be argued from this that the observed decrease in the cation-anion
ratio is a specific effect of nitrogen. It is difficult to state what part silica
plays in the ionic balance so long as it is uncertain whether the equivalent
weight attributed to it corresponds to the form in which the silicate anion
is absorbed by the plant. It is not altogether impossible that most of it migrates
in the plant in the colloidal state, for instance along the cell walls, avoiding
the protoplasmatic barriers. In this case the polyacid absorbed, corresponding
to the formula $HO.OSi-(SiO_2)_n-OSiO.OH$, might have a large equivalent
weight and thus contribute very little to the sum of the anion equivalents
even when the plant contains larger amounts of silica. For this reason silica
was always omitted from the ionic balance [2]).

The dressing applied was ammonium nitrate. Disregarding nitrification, when
the nitrogen dressing is increased there is an increased chance of nitrogen
having been absorbed in the form of ammonium. Since all the nitrogen is
included in the total anion content, that is, it is regarded as absorbed nitrate,
the relatively excessive increase in the total anions might also be related to
an increasing ammonium uptake.

It is probable, however, that the decrease in the cation-anion content is
unconnected with this, since SCHARRER and JUNG (1955) using ryegrass in quartz
sand cultures with a nitrate dressing without ammonium found a similar
decrease in the cation-anion ratio when the nitrogen content of the plants
increases as a result of the fertilizer. These plants contained a negligible silica
content, so that silica was not included in the ionic balance. These authors
consider it likely that the nitrogen metabolism is responsible for this extra
anion uptake. Regarded in this way the cation-ratio may depend on the inten-
sity of the nitrogen metabolism during the uptake.

As a result of the increase in the anion content caused by the chloride
dressing the cation content also increases. The initial cation content in the
K0 series without chloride dressing is about 1,600 mg equivalents, whereas in
the K2 series with the heaviest chloride dressing a cation content of nearly
2,000 mg equivalents occurs at the lowest nitrogen levels. That this higher
cation content is unrelated to the potassium in the dressing follows from the
fact that a cation content of 2,000 mg equivalents is also reached in the K0
series without potassic fertilizer when the anion content has risen sufficiently

---

[2]) Difficulties in selecting the valency also occur in the case of phosphorus. Since mono-
valent ions are usually taken up more readily and monovalent phosphate will be available
at the pH value prevailing, it seems preferable to regard phosphorus as monovalent. In
accordance with the common practice in grassland research it is taken as being trivalent.
If the results are shown with monovalent phosphorus the effects remain relatively the same,
except that the cation-anion ratio is somewhat higher.

as a result of the nitrogen fertilizer. Thus the higher initial cation content of the plants in the K2 series is an effect of chloride. The potassium effect is only clearly reflected in a shift in the ratio of the individual cations in the favour of potassium, as will be shown below.

Owing to the high initial cation content in the K2 series there is no further increase thereof with an increasing nitrogen level. Hence the obvious relationship between total cation and nitrogen content, such as still exists in the K0 and K1 series, is practically nullified by the heavy chloride dressing. It would seem that at a cation content of 2,000 mg equivalents a limit is reached which is not subsequently exceeded.

In none of the three series does the total anion content A + N amount to more than about 4,000 mg equivalents. Owing to the higher initial content in the K2 series here the increase in A + N caused by the nitrogen dressing is less than in the other series. The plants' resistance to a total anion uptake exceeding 4,000 mg equivalents is also reflected in a somewhat lower nitrogen content of the plants in the K2 series. As shown by the bottom graphs in Fig. 1, the nitrogen content finally reached as a result of the nitrogen dressing decreases slightly but regularly in the order K0, K1, K2, i.e. in the presence of more chloride in the dressing. At the lower nitrogen levels there is no such distinct effect of the chloride fertilizer on the nitrogen content.

The nitrogenous fertilizer affects both the composition and the amount of dry matter produced. For this reason it is also instructive to investigate what effect the nitrogen fertilizer had on the total uptake of the various elements in the yield. These amounts can be calculated by multiplying the dry matter yield by the content per unit of weight.

The dry matter yield of the first member of each series (without nitrogen fertilizer) was 14 gm. The first part of the fertilization range gave an increase in the yield until a yield of 22 gm had been reached at approximately 1 gm of N per pot. There was no further increase in the yield, but in the K0 series this was again lower in the last part of the fertilization range. This must have been due to insufficient uniformity in the planting of the pots. For this reason it is better not to relate the calculated uptake directly to the fertilization, but to consider the uptake of the elements in relation to each other. The primary effect of the increasing nitrogen dressing is the increase in the nitrogen uptake, and the secondary effect the influence thereof on the uptake of the cations C and anions A, the latter being related to the plant's struggle to maintain a given cation-anion ratio.

Table 1 shows the change in the uptake of cations C and anions A in mg equivalents per mg equivalent of increase in the nitrogen uptake.

Table 1 Change in the total number of mg equivalents of cations C and anions A present in the yield per mg equivalent of increase in the amount of nitrogen absorbed.

	K0 series	K1 series	K2 series
Cations C	+ 0.29 ± 0.03	+ 0.37 ± 0.05	+ 0.37 ± 0.06
Anions A	− 0.09 ± 0.06	− 0.04 ± 0.06	− 0.00 ± 0.09

There is no change in the uptake of the anions A with increasing nitrogen uptake. The increase in the yield from 14 gm to 22 gm in the first part of

the fertilization range implies a dilution factor of 0.36. According to Fig. 1, in all series there is a decline in the anion content A in mg equivalents per kg of dry matter produced. In the three series this reduction covers the same linear section of the logarithmic ordinate, corresponding to 0.4 times the initial content when nitrogen = nil. Hence this decline is somewhat greater than the dilution factor calculated from the increase in the yield, this being related to the fact that there is a further slight increase in the nitrogen content beyond the largest yield, and a slight continuance of the corresponding decrease in A.

Thus although the yield increases there is substantially no effect on the amount of the anions A taken up. As was also found earlier in the nitrate fertilization experiments, the extra anion uptake connected with the increase in the yield is almost entirely monopolised by nitrogen, so that there is a decrease in the anionic concentration A in the yield.

Table 1 shows that the compensating cation uptake does not exceed 0.4 equivalents per equivalent increase of nitrogen uptake from the fertilizer. In the case of each series the initial value for the cation-anion ratio (without nitrogen fertilizer) was 0.55. Thus the nitrogen uptake shows a lower cation compensation than would correspond to the original cation-anion ratio, with the result, as referred to previously, that this ratio decreases with an increasing nitrogen level. It seems that this lower cation compensation is characteristic of the nitrogen uptake. It is possibly related to nitrogen metabolism, as suggested by SCHARRER and JUNG (1955).

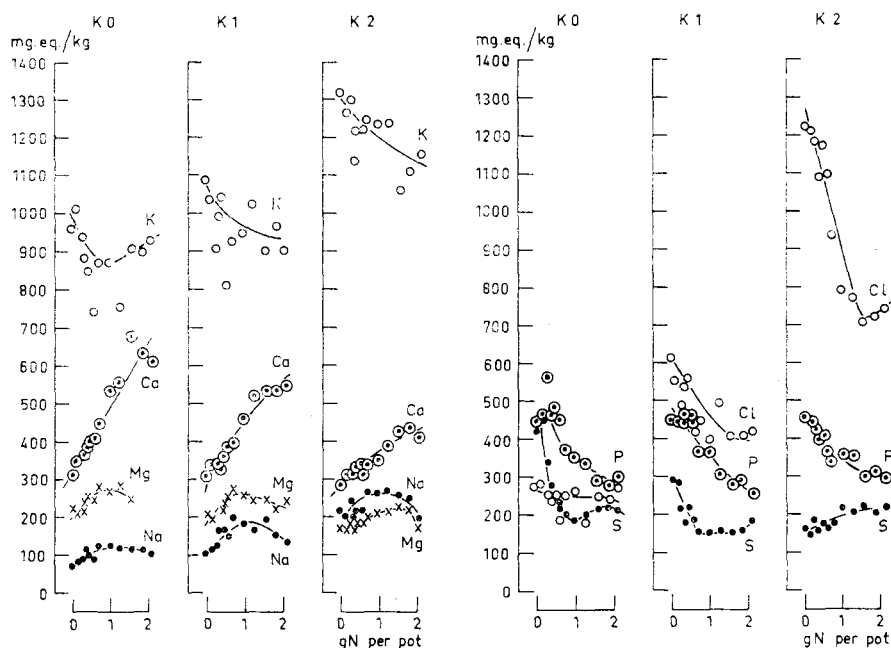The concentration of the individual cations and anions present in the yield are plotted in Fig. 2.

FIG. 2   INDIVIDUAL CATIONS AND ANIONS IN MG EQUIVALENTS PER KG OF DRY MATTER IN THE YIELD OF THE SERIES K0, K1 AND K2, PLOTTED AGAINST THE AMOUNT OF NITROGEN APPLIED IN FERTILIZATION. PHOSPHORUS TRIVALENT.

The potassium content is higher the more potassic fertilizer is added in the series, viz. in the order K0, K1, K2, and the calcium and magnesium contents decrease in the same order. The sodium content is higher the more potassic fertilizer is applied. Since perennial ryegrass absorbs sodium with relative ease, its presence in the potassic fertilizer can be discovered from the mineral composition of the yield.

The greater increase in the calcium content observed in the K0 series is related to the greater tendency of calcium to contribute to the increase in the cation content as a result of the nitrogen fertilizer when there is less potassium and sodium available (DIJKSHOORN, 1957a).

It is not easy to discover a direct effect of the increasing amounts of calcium carbonate in the nitrogen fertilizer. One might be inclined to recognise this in the increasing calcium in the K2 series, since there is no marked increase in the total cation content in this series. The decrease in potassium would then be directly due to antagonism, but there is good reason for believing that sodium and magnesium would also decrease in this case, since these cations can certainly not be absorbed with greater ease than potassium. In the beginning, of the fertilization range, however, there is an increase in sodium and magnesium, which indicates that the pattern is determined by a relative shortage of a cation which is more readily absorbed, viz. potassium. The decrease in potassium is therefor mainly due to the increase in the yield, as a result of which the amount absorbed does not increase in proportion to the amount of dry matter produced, and there is consequently a decline in the potassium concentration in the yield. The fact that the potassium uptake does not increase in proportion to the yield is a typical aspect of the behaviour of this element of which much of the amount available is absorbed, so that a relative shortage at a higher yield level is very soon reflected in a lower potassium concentration in the yield [3]). Thus the general tendency of a higher internal nitrogen level to induce a higher cation content need not always be accompanied by a higher potassium content. Should potassium decrease with an increasing yield we may expect an increase in the other cations.

For this reason the direct effect of the calcium carbonate in the nitrogen fertilizer is more readily seen in the last part of the fertilization range in which the yield showed no further increase. In this case when there is a further increase in calcium, there is a decrease in sodium and magnesium. This indicates that here the increase in calcium is directly related to the increasing supplies of calcium carbonate in the fertilizer.

The amounts of calcium carbonate added in the fertilizer had not affected the pH of the soil as measured after harvesting ($pH_{H_2O} = 5.0 \pm 0.05$).

The chlorine, phosphorus and sulphur anions show a decrease with increasing nitrogen. An exception is formed by the sulphur content in the K2

---

[3]) This tendency becomes also apparent in the increase in potassium beyond the minimum at the level of 1 g N per pot in the fertilizer in series K0. This is an artifact resulting from lower yields in the range of higher nitrogen appliccation, caused by planting errors. This unexpected reduction in the yield permits potassium uptake again to proceed to somewhat higher internal levels. This assumption is supported by the fact that the preceding very low potassium values relate to two individuals with relatively to high yields. The sensitivity of the potassium balance to fluctuations in the yield introduces the reproducibility of the yield as the main source of error in the pot experiments.

series, the lower initial content being related to the higher chlorine content. There was also a marked chlorine-sulphur antagonism in the experiments previously described (DIJKSHOORN, 1957b), and it was assumed to be associated with the fact that the sulphate anion is more difficult for plants to absorb and transport, so that it is more sensitive to the antagonistic effect than is the phosphate anion.

In discussing the nitrogen content it was pointed out that the chloride dressing only had an effect on nitrogen in the range of the higher nitrogen levels. The occurrence of a marked chlorine-sulphur antagonism in the K2 series shows that even at lower nitrogen levels, the total anion content is so high that there is a marked anion antagonism. It seems that in the lower nitrogen levels nitrogen has little sensitiveness to the presence of chloride. In this range nitrogen occurs as a fertilizer component which is very readily absorbed by the plants. Each successive increase in nitrogen in the dressing represents an amount which is absorbed with relatively greater difficulty, so that in the end the increase in the nitrogen uptake ceases (cf. Fig. 1). Since this is the range in which an accumulation of nitrate in the plants is usually observed, the limit in the utilisation of the absorbed nitrogen is apparently reached. The fact that the effect of chloride on the nitrogen content is only seen in the higher nitrogen levels might thus be related to the fact that in this range additional amounts of nitrogen are absorbed with greater difficulty.

REFERENCES

BEAR, F. E. : Agronomy Journ. 42 (1950) 176.
DIJKSHOORN, W. : Neth. Journ. of Agric. Sci. 5 (1957a) 81.
— — : Neth. Journ. of Agric. Sci. 5 (1957b) 233.
SCHARRER, K. and J. JUNG : Ztschr. Pflanzenern., Düngung, Bodenk. 71 (1955) 76.