Development of nitrogen fertilizer recommendations for arable crops in the Netherlands in relation to nitrate leaching

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Abstract

In the Netherlands, current nitrogen fertilizer recommendations for arable crops are based on the amount of soil mineral nitrogen in early spring. The larger the amount of soil mineral nitrogen, the lower the recommended application rate of fertilizer nitrogen. A more refined method is to draw up a balance sheet in which the nitrogen requirement of the crop is given on the one side and the contributions of fertilizer nitrogen, soil mineral nitrogen, and the amount of nitrogen mineralized during the growing period on the other. The most refined method of nitrogen fertilizer recommendation is the use of a simulation model that predicts the daily crop nitrogen requirement and nitrogen supply to the crop from various pools during the growing period. A simulation model thus adds the time element to nitrogen fertilizer recommendations. Moreover, in contrast with the other two methods, a simulation model allows identification of environmental side-effects of nitrogen fertilizer application.

The current Dutch nitrogen fertilizer recommendations aim at predicting the economically optimum application rate of fertilizer nitrogen. From the environmental point of view it is interesting to know how much soil mineral nitrogen has accumulated in the soil at harvest, because this nitrogen is a potential loss to the environment through nitrate leaching during the subsequent winter period. If the economically optimum application rate of fertilizer nitrogen is applied to arable crops, it is unlikely that soil mineral nitrogen accumulates, except in the case of potatoes. Model calculations have shown that accumulation of soil mineral nitrogen after potatoes can be prevented when the recommended nitrogen application rate is reduced by 25%. In that case tuber yield is reduced by only 2%.

Introduction

Nitrogen, which is essential for crop growth, is taken up by plant roots from the soil solution mainly as ammonium or nitrate ions, but non-ionic nitrogen uptake by roots can occur in the case of urea nutrition [29]. Mineral nitrogen, i.e. ammonium and nitrate, present in the soil solution originates from mineralized soil organic matter, inorganic and organic fertilizers, and wet and dry deposition from the atmosphere (Fig. 1). Since the annual contribution of atmospheric deposition to the nitrogen requirement of crops is generally less than 25 kg N per ha and that of mineralized soil nitrogen about 100 kg N per ha, and since there are inevitable nitrogen losses (Fig. 1), nitrogen fertilizers are applied to meet the total nitrogen requirement, which varies between about 200 kg N per ha for a crop such as oats and about 400 kg N per ha for intensively used grassland.

In this review the development of nitrogen fertilizer recommendations for arable crops in the Netherlands is given. Three types of recommendation are discussed, which are, in increasing order of refinement, the Nmin-method, the
balance-sheet method, and the use of a simulation model. In view of the increasing concern for environmental effects of nitrogen fertilizer application, viz., nitrate leaching, it will also be shown to what extent mineral nitrogen accumulates in the soil when the current Dutch recommendations are followed. Mineral nitrogen present in the soil at harvest time, i.e. residual mineral nitrogen, can be regarded as a potential loss to the environment through nitrate leaching during the subsequent winter period.

Nmin-method

In 1914, Russell [26] was probably the first to recognize that soil mineral nitrogen affects the fertilizer nitrogen requirement of arable crops; after dry winters he found larger amounts of soil nitrate and higher yields of winter wheat than after wet winters. More than forty years later this was confirmed for sugar beet [5]. By covering parts of experimental fields during periods of rainfall, Van der Pauw [31] found that the weak response of potatoes and rye to added nitrogen after ‘dry’ winter periods could be attributed to the relatively large amount of mineral nitrogen present in the soil at the end of winter. After ‘wet’ winter periods, small amounts of soil mineral nitrogen were found, probably because nitrate was lost due to leaching. In the Netherlands these findings resulted in nitrogen fertilizer recommendations in the sixties which were corrected annually for the amount of rainfall between 1 November and 1 March. For cereals it was recommended to increase the usual amount of fertilizer nitrogen by 10–30 kg per ha after wet winter periods, and to decrease it by the same amount after dry winter periods [32].

To improve this indirect method of taking soil mineral nitrogen into account, research efforts were subsequently made to determine the relationship between soil mineral nitrogen at the end of winter and the optimum fertilizer nitrogen application rate for arable crops [24]. For this purpose, many series of field experiments with winter wheat, potatoes and sugar beet were conducted for several years on various soil types in the Netherlands [25]. In the experiments the amount of mineral nitrogen present in the soil at the end of winter was measured and various amounts of fertilizer nitrogen were applied to determine the optimum application rate of fertilizer nitrogen. For each individual trial the economical optimum was determined from a hand-drawn yield response curve to which a tangent was drawn, the slope of which depending on the magnitude of the ratio of the cost of fertilizer nitrogen to the price of crop produce (Fig. 2).

As an example, the derivation of the current nitrogen fertilizer recommendation for potatoes on clay and loam soils [18] is shown in Fig. 3. The recommendation is based on 77 trials, which were conducted in various regions in the Netherlands in the period 1973–1982. The relationship between the amount of mineral nitrogen in the 0–60 cm soil layer at the end of winter and the economically optimum application rate of fertilizer nitrogen is presented for all trials. The ratio between the cost of 1 kg fertilizer nitrogen and the price of 1 tonne crop produce was assumed to be 0.01 (Dfl. 2/Dfl. 200). The relationship between the amounts of soil mineral nitrogen present at the end of winter in the 0–30 cm soil layer and the optima was also determined. Since the relationship was better for the amounts in the 0–60 cm soil layer ($r^2 = 0.22$) than for those

Fig. 1. Diagram of nitrogen fluxes in arable farming. 1 = denitrification; 2 = ammonia volatilization; 3 = atmospheric deposition; 4 = fertilization; 5 = harvest; 6 = crop uptake; 7 = crop residues; 8 = immobilization; 9 = mineralization; 10 = nitrate leaching. A-C = soil/crop system; B-C = root zone.