Fertilizer Research **43**: 9–12, 1996.

The agronomical and physiological efficiency of nitrogen applied for arable crops in Poland

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Key words: nitrogen efficiency, cereals, potatoes, beets

Abstract

The common relation yield / nitrogen dose can be broken into two relations: nitrogen uptake / nitrogen dose and yield / nitrogen uptake. Such procedure narrows the original variation and separates it in two different and easier to recognise categories, external and internal. The results of permanent field experiments conducted in Poland with all the most important arable crops has been re-examined according to this idea. The model for fertilizer recommendations in respect to nitrogen was proposed.

Introduction

The recommendation system for nitrogen fertilization in Poland is based on response curves. The most common is quadratic polynomial model, though spline model in the form of two broken lines was used as well (Fotyma, 1988). The coefficients of the response equations are calculated from the results of field experiments with several nitrogen doses. By pooling the results of many experiments with the same crop the poor fit of experimental date with the response curve (low correlation coefficient) is usually recorded. It can be partly explained by the broad scatter of yields in the control treatments due to the differences in natural soil fertility and partly by climatic and agronomic factors influencing the slope of the response curves in individual experiments. Instead of describing the relation between nitrogen dose and yield in one step Janssen (1990) proposed to break it in two partial relations corresponding to steps II and III.

step I: nitrogen dose – yield
step II: nitrogen uptake – yield
step III: nitrogen dose – nitrogen uptake

In step III the problems that cause a low efficiency of the crop in taking up the nitrogen from fertilizers are reflected (external or agronomical nitrogen efficiency). Step II gives insight into the problems that cause low efficiency of the crop to utilize nitrogen already taken up from fetilizers (internal or physiological nitrogen efficiency). Janssen's idea was tested in reference to the results of numerous field experiments in Poland.

Methods

Permanent field experiments in four-crop rotations with 6 consecutive doses of nitrogen were carried on since 1985 in 4 Experimental Farms belonging to the Institute of Soil Science and Plant Cultivation in Pulawy. The description of the experimental sites and the preliminary results for the years 1985–1989 were presented in former publications (Fotyma, 1992, 1992a). This paper covers the experimental period 1985–1992 and all results have been re-examined in respect to Janssen's formula. Three basic equations (quadratic polynomials) were calculated for each crop separately:

$$Y = a + bN + cN^2 \quad (1)$$

$$U = a' + b'N + c'N^2 \quad (2)$$

$$Y = a'' + b''U + c''U^2 \quad (3)$$

where:
Y – yield of main crop product in t·ha^{-1} (kg $\times 10^3$·ha^{-1})
U – total uptake of nitrogen by crop in kg N. ha^{-1}
N – nitrogen dose in kg N·ha^{-1}

The respective response curves are presented in the form of four quadrants diagrams (Janssen, 1990)

Table 1. The statistics of variation of nitrogen uptake (V kg N ·ha^{-1}) in control treatment

crop	average	coeff. of variation	minimum	maximum
winter wheat	86	29	49	136
triticale	65	37	33	128
winter rye	62	29	36	102
spring barley	70	36	32	118
spring wheat	70	37	23	130
oats	79	31	37	118
potatoes	67	57	6	157
sugar beets	149	49	73	407
fodder beets	161	49	64	338

leaving one quadrant empty. Agronomical (external) and physiological (internal) nitrogen efficiencies were calculated from the formulas:

$$AE = dY/dN \quad (4)$$

$$AF = dY/dU \quad (5)$$

where:

AE – agronomical efficiency in kg of product for 1 kg N in fertilizers

AF – physiological efficiency in kg of product for 1 kg N taken up by the crop

dY – increase of the yield

dN – range of nitrogen doses

dU – increase of nitrogen uptake

Utilization coefficient for nitrogen was calculated according to difference method

$$UC = (dU/dN) \times 100 \quad (6)$$

Results and discussion

The response curves for 9 most important arable crops in Poland are presented on Fig. 1a–i. The best fit of experimental to theoretical date was found for the relation yield/uptake, which confirms Janssen's (1990) idea. Potential (maximal) crop yields of about 4.7 t·ha^{-1} spring cereals, 5.0–5.9 t·ha^{-1} winter cereals, 37 t·ha^{-1} potatoes and 50–73 t·ha^{-1} beets were recorded. With the potential yield cereals and potatoes took up 120–170 kg N·ha^{-1} and beets about 300 kg N·ha^{-1}. The uptake of nitrogen with the potential yield calculated for yield unit was quite similar for all cereals and fell in the range 2.7–2.9 kg N per 100 kg of grain. This unit uptake amounted 0.3 kg N, 0.4 kg N and 0.5 kg N per 100 kg tubers and/or roots of potatoes, fodder beets and sugar beets, respectively. From the total amount of nitrogen taken up by cereals and potatoes 60–80 kg N originates from the soil (in control treatment) and the rest from fertilizers. The share of soil nitrogen was much higher in case of beets and accounted for 140–160 kg N·ha^{-1}. For a particular crop the uptake of nitrogen in control treatment, called by Janssen (1990) potential nitrogen supply showed a very broad variation from year to year and between experimental fields. The statistical characteristic of this variable is presented in Table 1.

The identification and quantification of the sources of this variation is now examined. The utilization coefficient of nitrogen depended on crop species and fertilizer dose. For optimal nitrogen dose this coefficient was about 80% for beets, 60% for all cereals but rye and 50% for rye and potatoes. The agronomical (external) efficiency of nitrogen decreased with increasing doses of fertilizers which is a quite common phenomena. The average agronomical efficiency for optimal nitrogen dose fell in the range 11.5–12.5 kg grain per 1 kg N in fertilizers for all cereals but oats (10.5 kg grain per 1 kg N) and triticale (16.5 kg grain per 1 kg N) and 85–98 kg tubers and/or roots per 1 kg N for row crops. The physiological (internal) efficiency decreased as well with increasing fertilizer doses. It can be explained by widening the straw/grain or roots/leaves ratio and accumulation of nitrogen in crop products.

Conclusions

Splitting the common relation between yield and nitrogen dose in two partial relations: nitrogen dose/nitrogen uptake and nitrogen uptake/yield offers a new approach to model of fertilizer recommendations. The model can be presented in the form of simple equation:

$$Nopt = (Up - Ns)/UC \quad (7)$$

where:

$N\,opt$ – recommended dose of nitrogen fertilizers

Up – uptake of nitrogen with the potential crop yield

Ns – soil nitrogen supply

UC – utilization coefficient of nitrogen from fertilizers

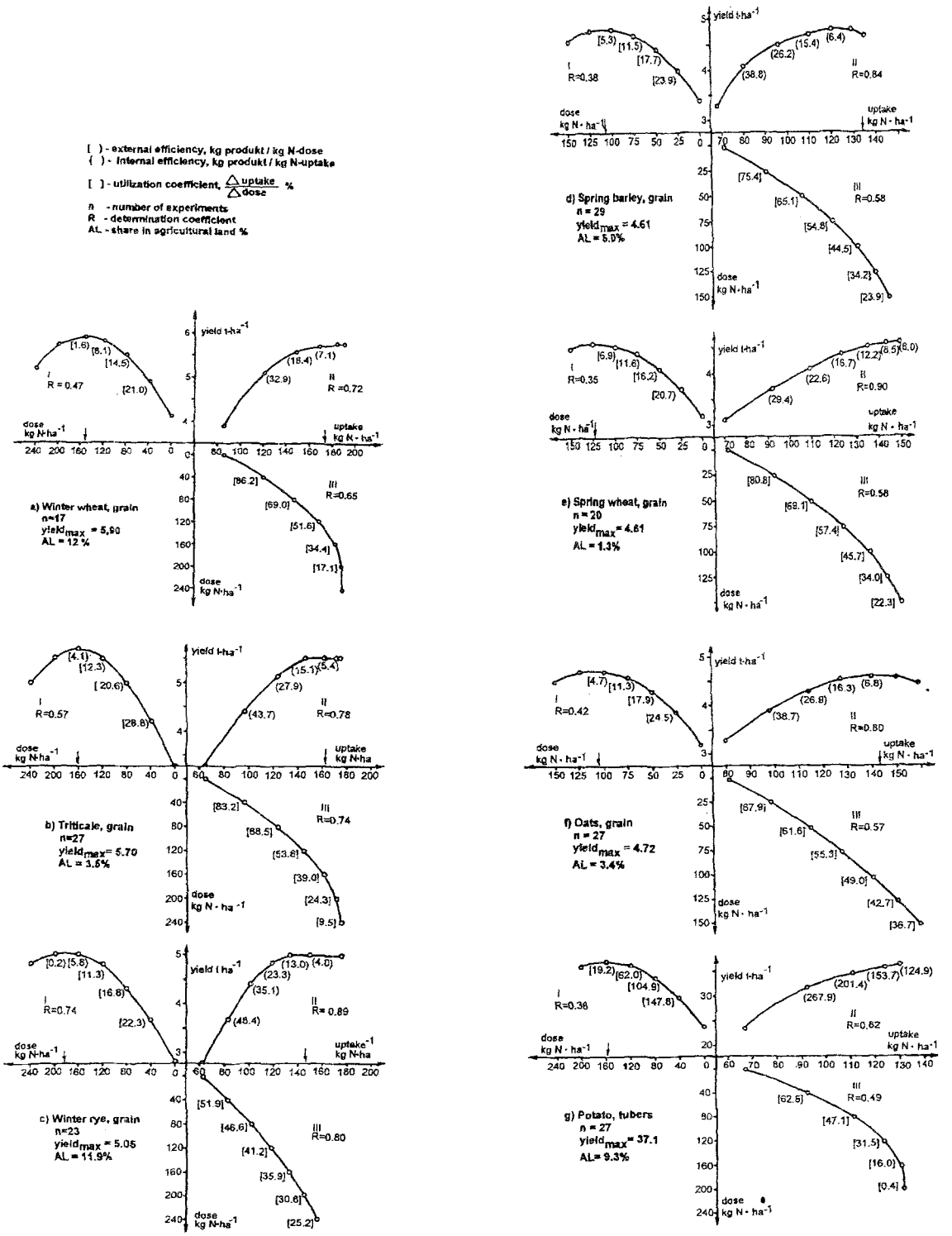

Fig. 1. Diagrams of N-fertilizer efficiency

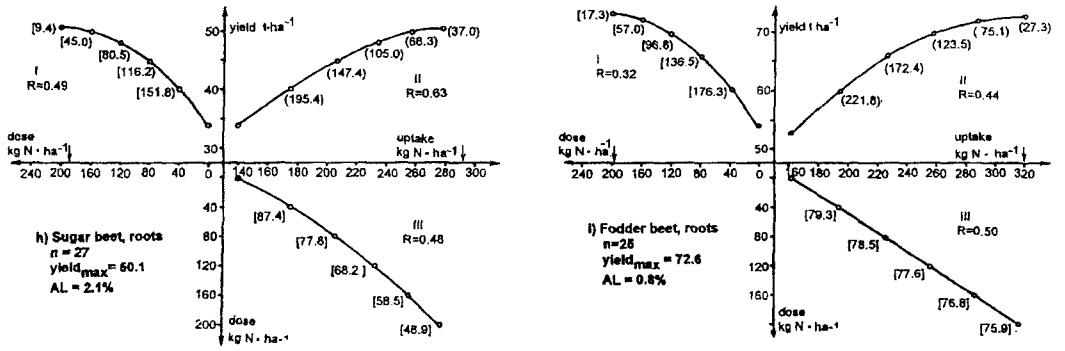

Fig. 2.

Acknowledgements

This work was sponsored by Polish State Committee for Scientific Research in form of the grant no 5S30205004 " Principles of nitrogen fertilization in integrated system of crop production ".

The authors are very much indebted for this helpful and kind support.

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