Grain legume nitrogen fixation and balance model for use in practical (organic) agriculture

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Abstract

Measurements in the literature of grain yield, harvest index, N_2 fixation, N content, N surplus, N_{min} content of the soil, etc., were compiled. Correlation analyses were then carried out with *Vicia faba* L. and *Pisum sativum* L. data sets from conventional and organic field trials performed in Central European. Grain yield or N output, N_{min} content before sowing, and the N harvest index proved to be the most effective driving variables for developing a calculation model for plant nitrogen fixation and the surplus amount. All the variables mentioned are listed in farmers' plot card indices, with the exception of the N harvest index, an essential variable which is not detectible by the farmer. Therefore, the N harvest index was indirectly determined through the effects of grain yield and N_{min} content using non-linear multiple regression analyses. Comparing calculations between common and the improved forms of models showed significantly better conformity between measured and calculated datasets of grain legumes.

Introduction

The importance of nutrient balance calculations in various agricultural systems is growing. The snag is that either common calculation models for the nitrogen fixation of grain legumes are too inaccurate (e.g. Albert et al., 1997, see Fig. 2), require a regionally adapted system for experimental N uptake data collected annually from non-fixing reference crops, or these methods are too complex to be used in agricultural practice (Evans & Heenan, 1998; Korsaeth & Eltun, 2000; Jost, 2003).

Materials and methods

A dataset for field-grown *Vicia faba* L. (n=44) and *Pisum sativum* L. (n=41) grain legume investigations (Schmidtke and Rauber, 2000) was collected for root- and shoot-derived variables as shown in Table 1. Air-derived nitrogen (N_{dfa}) was calculated from ^{15}N-isotope dilution and difference methods (McAuliffe et al., 1958; Stülpnagel, 1982); soluble soil nitrogen (N_{min}) was extracted with $CaCl_2$ (VDLUFA, 1991). Statistical analysis was carried out with SPSS (SPSS, Munich, Germany).

Results

Correlation analyses show highly significant relations between N_{min} content before sowing in spring and the soil-derived nitrogen (N_{dfs}) of the plant as a whole, as well as between grain yield and nitrogen output, the nitrogen uptake of the plant as a whole and the N_{dfa} (Table 1). The variables N surplus and N output also closely correlate with most of the variables recorded. However, initial model constructions using solely these variables gave disappointing results when the results calculated were compared with experimental results as well as findings from previous methods (not shown). When compared with previous methods the values calculated were of far lower dispersion, although conformity with the measured values was no better.

Further analysis indicated that a substantially better relationship between measured and calculated data could only be achieved if information on the nitrogen harvest index (N_{hi}) was included in the model configuration. N_{hi} only showed highly significant positive correlation with grain yield and nitrogen output, along with negative correlation with the nitrogen surplus (Table 1). Detailed multiple regression analyses indicated that the grain yield and in addition the N_{min} content of the soil needed to be significantly integrated into the equation to determine the N_{hi} indirectly. The correlation coefficient grew from single r=0.421*** to multiple r=0.777*** for *Vicia faba* and to r=0.923*** for *Pisum sativum* (Table 1, Fig. 1). Although the N_{hi} shapes between the two grain legumes were very similar (*Vicia faba* not shown), the niveaux were different, and so separate equations had to be calculated for every grain legume species as follows:

- *Vicia faba* $N_{hi} = 30.261 + 1.621 \text{ x grain yield} + 0.00526 \text{ x grain yield x } N_{min} - 0.02077 \text{ x grain yield}^2 - 0.001381 \text{ x } N_{min}^2$
- *Pisum sativum* $N_{hi} = 15.257 + 2.34 \text{ x grain yield} + 0.009296 \text{ x grain yield x } N_{min} - 0.03173 \text{ x grain yield}^2 - 0.002144 \text{ x } N_{min}^2$.

In the next step, relations were analysed between N_{hi} and other variables. The N surplus/N output ratio was closely correlated with the N_{hi}, and also with the N surplus. As these relations do not change with legume species, this ratio was used in multiple regression analyses as a further equation (r=0.864***) and the model was completed as follows:

- Ratio N surplus/N output = $3.264 - 0.008651 \text{ x } N_{min} + 0.01053 \text{ x grain yield} - 0.08141 \text{ x } N_{hi} + 0.00003076 \text{ x } N_{min}^2 + 0.000496 \text{ x } N_{hi}^2$.
- N output = grain yield x N content (derived from measured or table values for each legume species)
- N surplus = N output x N surplus/N output ratio
- N_{dfa} = N surplus + N output.

The values shown were augmented by the addition of the N rhizodeposition, which is about 11% for *Pisum s.* and about 19% for *Vicia f.* of the N_{dfa} values, by using literature data (Jost, 2003). Data calculated by the new model show correspondence which, although not ideal, is still much better with the 1:1 ratio axis in Figure 2. Therefore the relatively simple model obtained can be used with a much higher degree of accuracy in broad agricultural practice. Only two input variables (grain yield and N_{min} content before sowing) are needed to drive the model, and they are available from farmers' familiar plot-card indices.

Table 1. Correlation matrix for the grain legume variables analysed (two-tailed significance for p = 0.05*, p = 0.01**, p = 0.001***)

	N_{min} 1)	Grain yield	N surplus	N output	N uptake	N_{dfs} 2)	N_{dfa} 3) index	N_{dfa} 3)	N_{hi} 4)	N stubble, roots
Grain yield (dt DM ha^{-1})	0.423*** 69	–								
N surplus (kg ha^{-1})	-0.077 69	0.035 84	–							
N output (kg ha^{-1})	0.318** 69	0.842*** 85	0.059 96	–						
N uptake whole plant (kg ha^{-1})	0.308** 72	0.754*** 87	0.388*** 96	0.882*** 97	–					
N_{dfs} 1) (kg ha^{-1})	0.700*** 72	0.468*** 87	-0.295** 96	0.414*** 97	0.524*** 102	–				
N_{dfa} 2) ratio (%)	-0.367** 72	0.350** 87	0.677*** 96	0.378*** 97	0.343*** 102	-0.557*** 102	–			
N_{dfa} 2) (kg ha^{-1})	0.123 72	0.714*** 87	0.580*** 96	0.847*** 97	0.916*** 102	0.154 102	0.657*** 102	–		
N_{hi} (%)	0.040 65	0.421*** 81	-0.604*** 92	0.344** 93	-0.068 93	-0.118 93	0.013 93	-0.033 93	–	
N stubble, roots (kg ha^{-1})	0.312** 69	0.307** 85	0.689*** 96	0.350*** 97	0.750*** 97	0.458*** 97	0.234* 97	0.653*** 97	-0.619*** 93	–
N surplus/ N output ratio	-0.121 69	-0.159 96	0.878*** 98	-0.128 98	0.197 98	-0.279** 98	0.576*** 98	0.360*** 98	-0.759*** 97	0.562*** 98

1) Soluble NO_3-N + NH_4-N in 0–90 cm soil depth; 2) N derived from soil; 3) N derived from air; 4) N harvest index

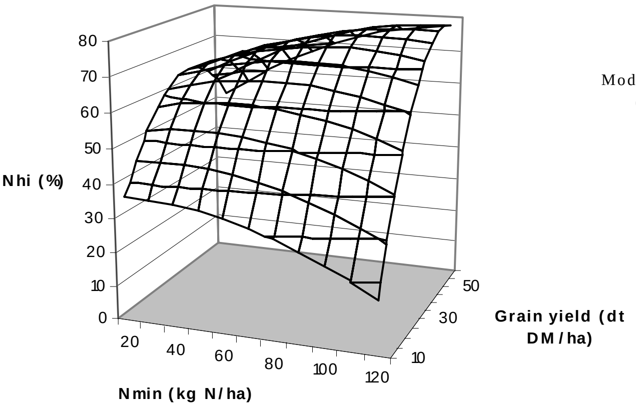

Figure 1. Calculated effects of the N_{min} content (0–90 cm soil depth) and the grain yield on *Pisium sativum* N harvest index

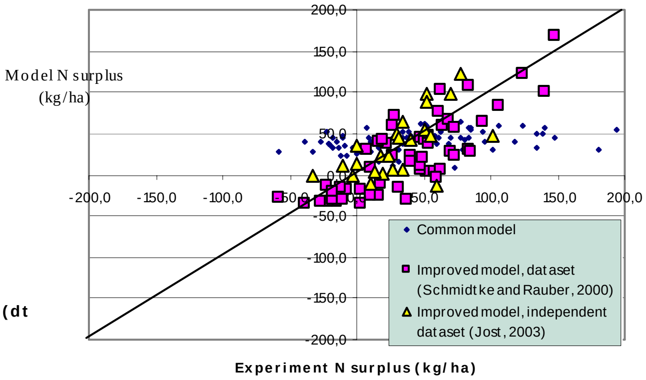

Figure 2. Comparison of experimentally derived N surplus with values calculated with the commonly used and the improved balance model for grain legumes

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