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# Development of the FBC model to estimate the nitrogen available from fertility-building crops in organic rotations

By S P CUTTLE

*Institute of Grassland & Environmental Research, Aberystwyth, SY23 3EB, UK*

## Summary

The FBC (Fertility Building Crops) model has been developed as a planning tool to provide organic farmers with information about how much nitrogen will be available in the soil at different stages following the ley phase of the rotation. It predicts the likely crop yields under this level of nitrogen supply and provides an estimate of how much nitrogen will be lost by leaching and denitrification so that if necessary the grower can examine the effects of modifying the rotation to improve the efficiency of nitrogen use and minimise losses. The model is easy to use and requires only the sort of information that is readily available to commercial growers. Although it appears to provide realistic simulations of a range of crop rotations and conditions, it has not yet been fully validated.

**Key words:** Crop rotation, mineralisation, model, nitrogen supply, organic farming, planning, yield

## Introduction

In organic farming rotations, it is important that the fertility-building phase and other fertility inputs should provide sufficient nitrogen to produce satisfactory yields during the arable cropping phase. It is equally important that soil nitrogen should not be wasted as losses to the wider environment. The FBC (Fertility Building Crops) model has been developed as a planning tool to provide organic farmers with information about how much nitrogen will be available to crops at each stage of the rotation and the likely crop yields under this level of nitrogen supply. It also provides an estimate of nitrogen losses by leaching and denitrification. The grower can use the model to explore how modifications to the planned rotation will influence crop yields and nitrogen losses. The model has been designed for use by farmers and advisors and only requires the sort of information that is readily available to commercial growers.

## Description of the Model

The FBC model is currently in the form of a spreadsheet-based model. It is intended for use with crop rotations where there is a clearly defined ley phase, followed by up to five years of arable cropping.

*Nitrogen accumulated by the ley*

The first part of the model provides an estimate of the quantity of nitrogen accumulated by the ley. Details of the ley phase are not modelled directly, instead the model uses the description of the ley provided by the user to select appropriate values of the amounts of nitrogen and carbon in the sward residues at the time of cultivation. The values contained in the FBC model were obtained using a separate model based on work by Whitehead *et al*. (1990). The estimated amounts of nitrogen in the soil after ploughing the ley set the starting conditions for the second phase of the model, which calculates the amounts of nitrogen mineralised from the ley and other crop residues during the arable phase.

*Nitrogen mineralisation during the arable phase*

This part of the model is based on the Stix model that was developed to predict nitrogen mineralisation from soil and crop residues in order to improve the accuracy of fertiliser recommendations for conventionally grown crops (J A King, ADAS, unpublished). It operates on a monthly time-step and divides the nitrogen in the ley residues into fast, medium and slow mineralisation rate fractions, based on the carbon:nitrogen ratio of the residue. In the FBC model, mineralisation of the fast and slow fractions proceeds as zero-order reactions, whereas that of the medium fraction is calculated as a first-order reaction. All reaction rates are temperature-dependent. The mineralised nitrogen from these fractions plus any mineral nitrogen carried over from the previous month provides an estimate of how much soil nitrogen is available for plant growth that month.

*Crop growth, nitrogen uptake and losses*

A simple crop growth model calculates the potential biomass production during the month, based on climate (temperature, solar radiation and soil moisture) and the defined growth parameters for the particular crop. The model then compares the nitrogen required for this amount of growth with the nitrogen available in the soil. If the soil nitrogen is less than this requirement, growth and nitrogen uptake are limited by the available nitrogen supply. If the soil nitrogen is equal to or greater than the crop requirement, growth and uptake are allowed to proceed at the potential rate. Any mineral nitrogen remaining in the soil after crop uptake is available for leaching or denitrification. Leaching occurs whenever the soil is saturated and rainfall exceeds evaporation. The hydrologically effective rainfall transports a proportion of the mineral nitrogen between successive 5-cm soil layers, the fraction that is mobile being determined by soil type. It is not possible to simulate denitrification satisfactorily using a monthly time-step as in the FBC model; however, denitrification can account for significant quantities of nitrogen and it is important that the model should provide the user with some indication of the scale of this loss. An estimate is obtained by assuming a potential denitrification rate for each soil type whenever the soil is fully saturated with water, which is then adjusted on the basis of soil mineral nitrogen content and temperature. Any mineral nitrogen that is not taken up by the crop or lost is carried over to the available nitrogen supply for the following month.

Growth continues in monthly time-steps until senescence or harvest, with the growth each month being determined by the soil mineral nitrogen supply, up to a maximum defined for each crop. Thus the final crop yield is determined by the nitrogen supply throughout the growth period. At harvest, crop nitrogen is partitioned between nitrogen removed in the harvested crop and that remaining in roots and stubble. Straw or other crop residues are either removed or returned to the soil. The crop components remaining after harvest form a fresh residue pool that is again divided into fast, medium and slow mineralisation rate fractions in the same way as for the ley residue. These then contribute to mineralisation in subsequent months.

If a grain legume, such as peas or beans, is grown during the arable phase, the model allows for a proportion of the crop nitrogen demand to be satisfied by biological fixation. Whether growth proceeds at the potential or at a reduced rate is determined by the soil's ability to satisfy the remaining nitrogen requirement after subtracting the portion supplied by fixation. The proportion derived from fixation is inversely related to the soil mineral nitrogen content (Korsaeth & Eltun, 2000). If weeds are present, they compete with the crop for the available soil nitrogen. Where manures are applied, the nitrogen content is divided between an immediately available mineral fraction and fast, medium and slow mineralisation fractions. Some of the immediately available nitrogen is assumed to be lost by ammonia volatilisation, the proportion being determined by the time between application and incorporation of the manure.

*Running the model*

All the input data required to run the model are entered on a single screen. These inputs are listed in Table 1. In the first section, the user describes the UK region and soil type. The climatic conditions used by the model are set by the choice of region, except that annual rainfall can be entered as a specific value for the site.

Table 1. *Input data required to run the FBC model*

| Inputs | Example |
|---|---|
| *Description of site and soil type* | |
| UK region | e.g. Midlands, SW England/S Wales |
| Annual rainfall | (optional, otherwise uses regional value) |
| Dominant soil type | e.g. sand, clay loam |
| *Description of the ley* | |
| Type of ley | e.g. white clover, red clover/grass |
| Age of ley | 1, 2, 3, 4 or more years |
| Proportion of legume | low, medium or high |
| Management | cut, grazed or mulched |
| Number of cuts per year | none to 3+ |
| Manure applied to the ley? | none, some years or every year |
| Previous cropping | long-term grass, arable or ley-arable |
| Date of incorporation of the ley | day/month/year |
| *Description of arable crops* | |
| Crop name | e.g. winter wheat, potatoes, cover crop |
| Sowing date | day/month/year |
| Harvest date | day/month/year |
| Expected yield | in tonnes $ha^{-1}$ (optional) |
| Proportion of weeds in crop | low, medium or high |
| Straw/residue removed at harvest? | yes or no |
| *Description of manure applications* | |
| Type of manure | e.g. cattle slurry, old farmyard manure |
| Application rate | in tonnes $ha^{-1}$ |
| Application date | day/month/year |
| Delay to incorporation | e.g. less than 6 hours, 3-6 days |

The second section requests details of the type of ley and how it is managed. This includes information about the proportion of legume in the ley but because commercial growers are unlikely to have more detailed information, the content is simply described as low, medium or high (< 20, 20–50 and > 50%, respectively, as estimated from a visual assessment). Similarly, farmers are not usually able to quantify production from the ley, particularly where cut or mulched. Quantities of sward residues under cutting, grazing or mulching are therefore estimated from the legume content. If the ley is cut and grazed, the user supplies information about the number of cuts, which determines the weighting between purely cut and purely grazed.

The third section requests information about the arable phase of the rotation. This allows for up to two crops to be grown each year and up to two manure applications per year. The model currently provides a choice of 24 crops but others can be added, provided that the necessary information is available to satisfactorily describe crop growth within the model.

Output from the model is presented as in Table 2, showing the potential nitrogen uptake for each crop if nitrogen supply were non-limiting; the actual nitrogen uptake achieved with the planned rotation; and the crop yield corresponding to this uptake. The Table also shows the annual losses by leaching and denitrification. Additional information is provided as two graphs showing; (i) the amounts of nitrogen mineralised each month from soil organic matter, ley and crop residues and from manures, and (ii) the monthly values of soil mineral nitrogen content, nitrogen uptake by each crop and losses by leaching and denitrification.

Table 2. *Example of output from the FBC model for the arable cropping phase of a rotation on a medium soil following a grass/red clover ley cultivated in autumn of Year 1*

| Year | Crop sown in years 1 - 4 | Potential crop N (kg ha$^{-1}$) | Crop N achieved (kg ha$^{-1}$) | Harvested yield (t ha$^{-1}$) | Leaching loss (kg N ha$^{-1}$) | Denitrification loss (kg N ha$^{-1}$) |
|---|---|---|---|---|---|---|
| 1 | Winter wheat | 154 | 130 | 5.2 | 40 | 10 |
| 2 | (1) Cover crop | 30 | 30 | 0.0 | | |
| | (2) Spring barley | 161 | 117 | 4.7 | 30 | 12 |
| 3 | Winter oats | 170 | 116 | 4.5 | 19 | 7 |
| 4 | Winter beans | 205 | 205 | 2.8 | 22 | 10 |

## Conclusions

The current version of the model produces realistic simulations of yields and losses for a range of rotations and conditions but it has not yet been fully validated. It has been well received at farmers' meetings and suggested improvements from earlier meetings have been incorporated into later versions of the model.


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