

Abridged Version

Nitrogen is one of the most relevant yield-limiting factors in organic crop production. Thus, special attention must be paid to nitrogen cycles and nitrogen management on organic farms. N supply in organic arable systems essentially depends on legumes in crop rotations, and fodder legumes in particular. Conversion to organic farming usually implies a shift in crop rotations to extended legume shares at the expense of non-legume crops, such as maize or cereals. Mixed farms with cattle can most easily implement these changes, and this farm type has been the general orientation in organic farming. Fodder legumes can be used as economically ratable feedstuff on these farms, and manure as the most important 'soil fertilizer' becomes available. Specialized arable or pig/poultry farms without cattle cannot use fodder legumes directly, which provokes a reduction of fodder legume shares in crop rotations, and/or a substitution with grain legumes. This situation can lead to a deficit in nitrogen supply to arable soils and crops. Therefore, sustainable nitrogen management must be considered a basic challenge on specialized organic farms, and solutions have to be identified to ensure sustainable productivity.

The basic intention of this paper is to outline the fundamental relevance of legumes for nitrogen supply in organic crop production. Further, requirements for the successful and functional cropping of fodder legumes and legume-grass mixtures will be discussed. In particular, we refer to the availability and supply of trace elements for legumes, and to limitations of legume shares in rotations caused by self-intolerance of the crops. Our study is based on field experiments at Gladbacherhof research farm (Hesse, Germany), as well as on a comprehensive survey in organic farming practice in Germany.

The main conclusions are:

1. The analysis of nitrogen cycles in organic crop production must refer to the whole farm as a system. The analysis of nitrogen cycles within the farm (with consideration of soil N changes) and the calculation farm-gate nitrogen balances are effective tools for the assessment of nitrogen supply and nitrogen management.
2. The Organic Arable Farming Long-Term Field Experiment (OAFEG, started 1998), which compares mixed and stockless farming systems, provides valuable information on N cycles in different organic farm types: Clover-grass at the 'mixed farm' achieved an N input of 414 kg N/ha in the first full stand year via symbiotic fixation, while the same mixture used as green manure in the 'stockless farm with ley in the rotation' only brought 256 kg N/ha. Grain legumes in the 'stockless farm with cash crops only' fixed between 144 and 195 kg N/ha. Legume/non-legume mixtures as catch crops realized N inputs between 116 and 142 kg N/ha (cf. tab. 3.2).

3. Calculated nitrogen field balances for the 2nd crop rotation in the OAFEG prove the superior performance of the 'mixed farm' treatment with regard to productivity and the maintenance of soil organic matter as a basic soil quality indicator. Moreover, this treatment had the lowest N losses (41 kg/ha annual average), and the highest N use efficiency in the soil-plant system (83 % of available N), respectively [N use efficiency in the soil-plant system considers N additions (fertilizers, symbiotic fixation, atmospheric deposition) and available N from soil organic matter mineralization on the input side, and N uptake of crops as well as incorporation into soil organic matter on the output side]. The two stockless farm treatments did not attain the performance of the mixed farm treatment, even though organic matter supply to soils was not sufficient to maintain soil organic matter levels (cf. tab. 3.4 and fig. 3.2). A disregard of soil N changes would have biased the calculation of field balances (cf. tab. 3.5).
4. Farm-gate balances strongly support the essential role of legumes in nitrogen supply to the N cycle in organic arable farming systems. Legume-N accounted for 87 % of total N supply in the mixed farm treatment (133 kg N/ha annual average). The remaining 13 % came from seed material and atmospheric deposition. Organic matter supply in this treatment was sufficient to maintain soil organic matter levels. Even though crop rotations in the two stockless farm treatments must be considered optimal with regard to the inclusion of legumes on main and catch crop positions, legume-N inputs were only 93 kg N/ha (annual average) in the treatment with mulches clover-grass, and 85 kg N/ha (annual average) in the treatment with the full cash crop rotation (cf. tab. 3.2 and 3.6).
5. Farm-gate balances illustrate that N amounts in farmyard manure cannot be considered as a nitrogen input to the system, but are a pool in the internal N cycle on the farm. Nitrogen in farmyard manure originates from previous legume cropping (of course, farmyard manure can contain N from purchased feed or from grazing on grassland – this possible situation has not been considered in the balance calculations for the OAFEG, even though it may be quite important on real farms). Further, even though a continual mineralization of soil organic matter occurs in turnover, this input cannot be considered as a nitrogen source, if soil organic matter levels are to be maintained. The maintenance of soil organic matter levels requires the supply of organic matter of equal quality for the replacement of mineralized soil organic matter (cf. chapters 3.1.3 and 3.1.4).
6. A successful cultivation of legumes is dependent on optimal growing conditions for the crops. One important aspect is the supply of trace elements. Research at Gladbacherhof experimental farm and a comprehensive survey on organic farms in Germany showed that legume yields may often be affected by deficient sulfur availability. This deficit can result in a considerable decrease of symbiotic nitrogen fixation, implying negative effects on all crops in the rotation. More than 70 % of the sites in the survey had less than 30 kg sulfate-S/ha in 0-60 cm soil depth, and, thus, were below the threshold value for sufficient S availability (cf. fig. 3.5).

7. A supply of 40 kg S/ha as Kieserit (MgSO_4) to legumes in the 2nd stand year significantly increased N yields: in 2010, N in harvested legume biomass was 125 % higher with fertilization (331 kg N/ha compared to 147 kg N/ha without fertilization), and even 159 % higher in 2011 (412 kg N/ha compared to 159 kg N/ha). Sulfur concentrations and the sulfur-to-nitrogen ration were improved by Kieserit and reached optimal values (cf. figs. 3.8 and 3.9, tab. 3.18).
8. Yields of subsequent winter wheat were improved by the higher precrop value of the fertilized legume stands. In 2011, wheat yields after fertilized legumes were increased by 53 % (5.31 t/ha compared to 3.47 t/ha). In 2012, wheat yield increases were lower, but still amounted 20 % (cf. tab. 3.19).
9. The second essential condition for successful legume cultivation is the observation of cultivation intervals. In particular, soil-borne diseases limit the frequent cropping of the same or closely related legume species. Grain legumes suffer even more from this situation than fodder legumes (chapter 4.1).
10. Considering the better performance of fodder legumes compared to grain legumes in N supply, and further considering the more distinct limitations to grain legume cultivation compared to fodder legumes due to the interference of soil-borne diseases, we conclude that grain legumes alone are not capable of supplying organic crop rotations with nitrogen. Even increased cultivation of catch crops in rotations will probably not completely solve this problem. Therefore, we conclude:

“Fodder legumes must appear as main crops in every organic rotation!”

This classical know-how of organic farmers gets strong support from recent scientific insights (chapter 4.2).

11. Concluding, viable suggestions for sufficient shares in crop rotations of different farm types are made in chapters 4.2 and 4.3. Opportunities to utilize fodder legume material on farms without cattle are presented. Still, it will often be necessary for specialized farms to purchase fertilizer in accordance with organic farming regulations in order to achieve a sustainable nitrogen management.