◀주제 1▶

상수원보호구역 유기농법 실천농가를 위한 토양진단 최적시비 전략

마틴 큐케
(독일연방농업연구쎈터 작물·초지학 연구소)

Problems with water quality and actual legislation in Europe and Germany

5,7 Mrd. m^3 water is pumped annually to meet the drinking water demand of the German population, of which about 64% derive from ground water, 28% from surface waters and 8% from spring waters, with differences between the different German federal states(FREDE and DABBERT 1998). To protect the water resources from unnecessary pollution, different legislations have been passed by the European Union and the member states, either to protect drinking water but also to protect surface and ground waters outside of drinking water areas for ecological reasons.

The nitrate concentration of 50mg NO_3/l(limit value for drinking water) is exceeded in about 10% of the German ground water control net(Fig. 1 a). This value is representative for all ground water resources in Germany, but numerous of these are located below forest areas or have denitrifying conditions in the subsoil. Regarding only the ground water resources in intensively cropped agricultural areas gives an impression about the influence of intensive farming on water quality : In such areas with ground water tables near to the soil surface, about 60% of the ground water samples contain nitrate concentrations 〉 50mg NO_3/1(Fig. 1 b). The annual increase in the nitrate concentration is about 0.5 to 1mg NO_3/1 in some drinking water dwells. However, in situations with denitrifying conditions in the subsoil, a low nitrate level in the water is no reliable indicator to conclude that no nitrate is leached from agricultural land. Nitrate concentrations in ground water in some areas with intensive vegetable cropping sometime reach 600mg NO_3/1.

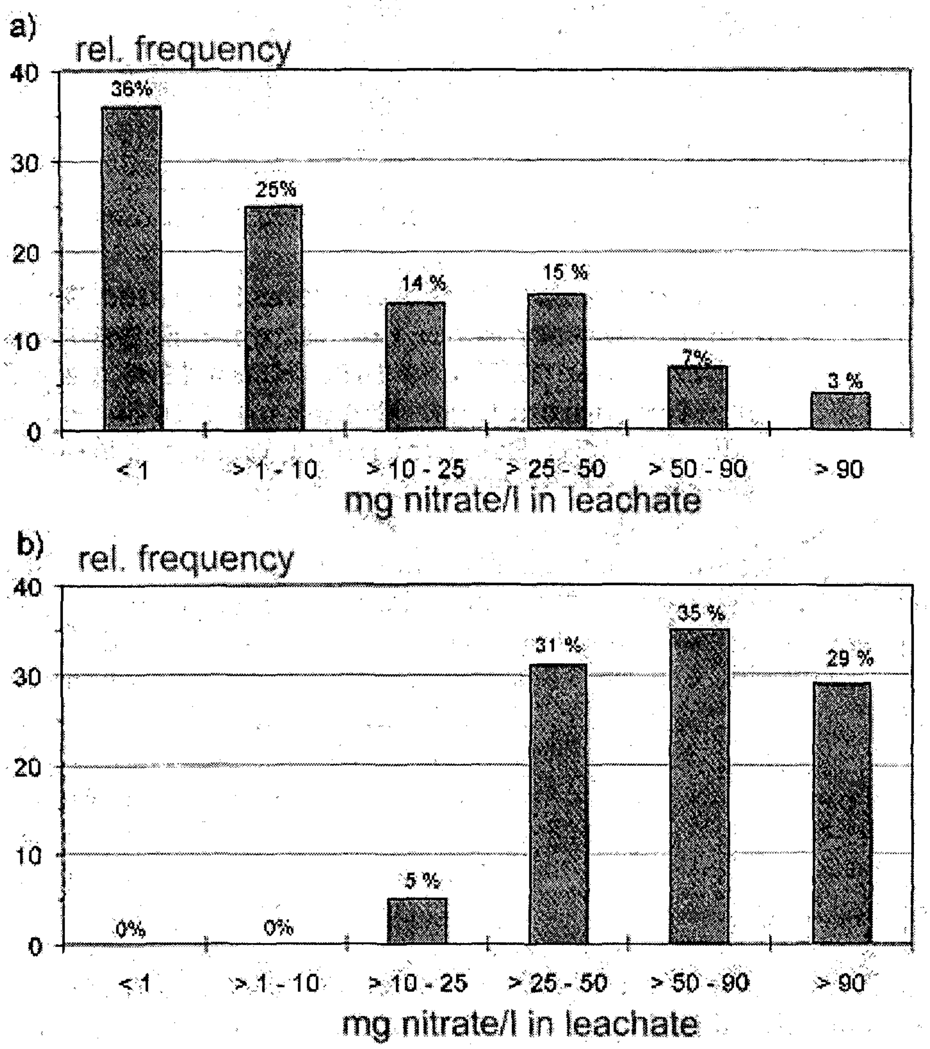

Fig. 1. Frequency of nitrate concentrations in leachates in Germany
a) ground waters in general
b) in shallow ground water under intensively cropped farmland

Table 1. Legislations of the European Union and Germany for water protection

	Water legislation	Fertilisation legislation	Pesticide legislation	Other legislations
EU legislation	• Nitrate directive [1] • Drinking water directive [2] • Water frame directive [3]	Nitrate directive [5]	Permission guideline	
German legislation	Water budget legislation [4]	• Fertiliser law [6] • Fertilisation decree [7]	• Plant protection law • Plant protection Expertise decree • Plant protection handling decree	• Munipical sewage sludge legislation [8] • Waste recycling legislation [9]
Federal state legislation	Different water budget legislation in Federal states			

1 Regulation to protect the ground water from nitrate pollution from agriculture
2 contains 56 limit values for chemical compounds in drinking water(e.g. 50mg NO_3/l)
3 contains limit values for emission from agriculture to surface and ground waters, which can be achieved only by a further reduction of agricultural emissions
4 measures that might cause pollution to surface and ground water, might be restricted
5 forces member states to define "good agricultural practice" according to[1]
6 fertiliser merchandisers have to register their fertilisers according to fertiliser types (e.g according to nutrient contents)
7 defines "Good Agricultural Practice" for Germany according to[1,5], maximum farmyard manure application is limited to 170kg N/ha on arable land and 210kg N/ha on grassland(170kg/ha are discussed actually)
8 limits the application of munipical sewage sludge and composts to 12 t dm/ha in 3 years

Moreover, the limit value for herbicides(0.1㎍ for a single compound, 0.5 ㎍ for all types of compounds) in water was exceeded in about 10% of the ground water samples taken in a ground water sampling net(UBA 1995). Since this ground water control net does not contain all ground water resources, this value can be regarded only as rough estimate.

As a reaction on steadily decreasing water quality and with the aim a) to protect the water resources and b) to keep or improve water quality and c) to avoid further contamination, numerous legislation have been passed in the EU(Tab. 1).

The major legislation that have to be regarded by German farmers – conventional or organic – are

- **restrictions for the application of organic fertilisers**
  - ○ not more than 170kg N/ha annually on arable land
  - ○ not more than 210kg N/ha annually on grassland(it is assumed that this amount will be restricted to 170kg N/ha annually in the future)
  - ○ no application of liquid manures between Nov. 15 and Jan. 15(main leaching period in Germany)
  - ○ not more than 80kg N/ha after the harvest of the main crop, but only to straw layers or to intercrops and main crops sown before winter(not on bare soils)

- no application of liquid manures on wet or frozen soils
- liquid manures have to be incorporated immediately into the soil after application to avoid ammonia volatilisation
- surface runoff and direct flux into surface waters has to be avoided
- the nutrient content of organic fertilisers has to be determined by analysis or by estimation of an official an local survey service
- on soils with high P and K content in the plough layer only that amount P and/or K by manure can be applied that can be taken up by the following crop(to avoid further increase of the P and K status in the soil)

- **obligation for soil tests**
  - each year on arable fields for mineral nitrogen
  - once in a crops rotations, at least every 6 years, for P and K

- **obligation for the calculation of nutrient balances**
  - on farms > 10 ha for N annually
  - for P and K for the last 3 years

Leaching of nitrate

Nitrate is leached from soil under the following conditions only : There must be nitrate in the soil profile and water must percolate downwards in the soil profile to transport the nitrate below the rooting zone. Leaching in Germany mainly is observed in the winter period between November and February. The amount of water that is leached depends on the amount of precipitation, the evapotranspiration and the water storage capacity of the soil. In situations of low water storage capacity of a soil(e.g. sandy soils), high rainfall intensity and little or no crop growth, leaching can also be observed during summer periods(BUCH et al. 1995). As the water evapotranspiration cannot be affected by cropping measures effectively during winter, most effort to develop strategies for water protection have to concentrate on reducing the amount of nitrate in the soil before the leaching period.

The major sources for nitrate in the soil profile are mineral and organic fertilisation, mineralisation from the soil organic matter, mineralisation from crop residues and to a small amount from N input from the atmosphere. In organic farming systems, the dominant sources are from N_2 fixation from legume crops and the application of organic manure and other organic fertilisers.

High nitrate levels in the soil profile are regularly observed

- ○ after high fertilisation, mineral and organic
- ○ after ploughing of grassland due to high mineralisation
- ○ after incorporation of legume crops
- ○ after cultivation of organic soils

Handling the nitrogen from organic sources like farmyard manure and N_2 fixation is much more complicated for the farmers than handling mineral fertilisers. In organic fertilisers as well as in the residues of N_2 fixing legumes, most of the nitrogen is fixed in organic compounds and not plant available at the time of application resp. incorporation. Part of the applied organic material will be incorporated into the soil organic matter, part of it will be mineralised to ammonium and subsequently nitrified to nitrate by the soil microorganism. The quantity and the dynamic of mineralisation is depending on the type of organic matter, the soil type, biological activity in the soil and climatic conditions like soil water content and soil temperature. The intensity of mineralisation can hardly be predicted in advance for every cropping situation, but some estimates are available. It is important to know that organic fertilisers are not completely mineralised in the year of application. Regular farmyard manure application therefore steadily increases the mineralisation potential in the soil(Fig. 2). This increased mineralisation is a steady nitrate source to the soil profile, which might severely increase the nitrate content in the soil profile during leaching periods.

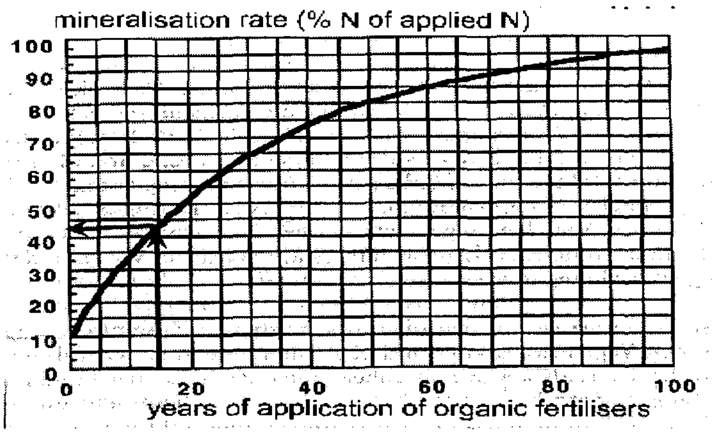

Fig. 2. Increasing mineralisation potential in the relation to continuous application of organic manure(DÖHLER 1996)

Due to this it is not surprising that the type of farming system has a remarkable influence on the amount nitrate in leaching waters(Fig. 3). Highest nitrate concentrations are regularly found in soils of farms with high cattle number per ha. The nitrate concentrations are clearly lower in farms without cattle(and therefore no organic manuring), in farms with organic cropping systems with limited cattle number per hectar and under grassland(KUECKE and KLEEBERG 1997). From table 2 which presents classes to evaluate the pollution risk in relation to the nitrate concentration in the leachate, it become obvious that systems with a high cattle number(Fig. 3, conventional with cattle) show a very high risk for ground water pollution while the risk for organic farms with limited cattle number as well as for grassland can be evaluated as low. Nevertheless, grassland is evaluated less critical if the meadow it cut and no animals graze on it. If the grassland is grazed, the amount of leached nitrate might severely increase(Fig. 4) due to the inhomogeneous release and distribution of animal excreta on the soil that leads to spots with extreme high nitrate concentrations in the grassland soil profile.

The risk of ground water pollution is regarded as low if the nitrate concentration in the leachate is below 15mg NO_3/l (Tab. 2), whereas the pollution situation is regarded as critical if the concentration reaches 25mg NO_3/l, especially in ground water resources where a steady annual increase in the concentration can be observed. The amount of leached nitrate that can be tolerated to keep the nitrate concentration in the leachate at 50mg NO_3/l can be calculated and is depending on the local soil and the climatic situation(Tab. 3) : The higher the amount of water leaching is during the year, the higher is the amount of nitrate that can theoretically be leached out of the soil profile.

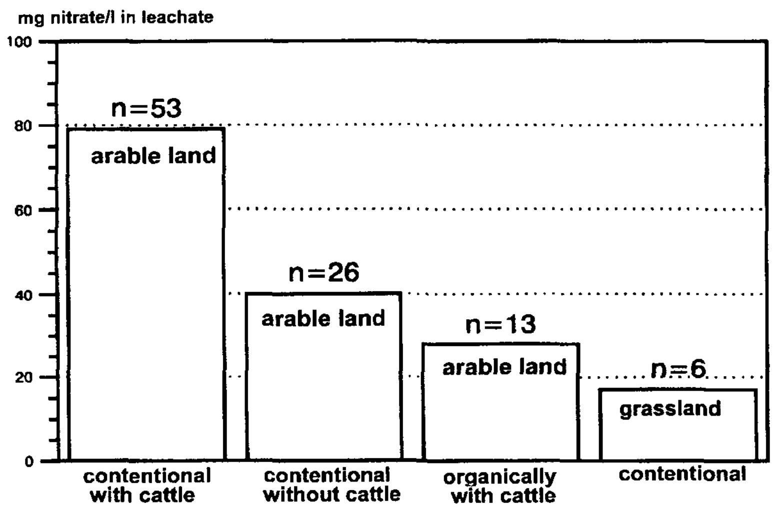

Fig. 3. Nitrate concentration in leachates from different farming systems(BRANDAUER and HEGE 1991)

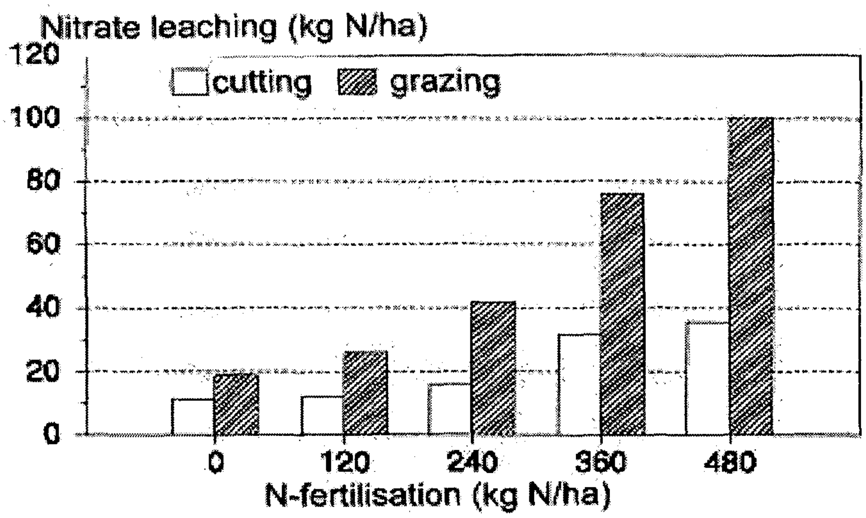

Fig. 4. Nitrate leaching in relation to N fertilisation on cut grassland compared to grazed grassland(BENKE 1992)

Compared to the amounts of nitrogen that are applied by fertilisation, these amounts are comparably low. One major problem is that time that is need until the nitrate reaches the ground water or a drinking water dwell, might last several years and even decades, and therefore positive effects of a potential reduction strategies on the soil surface can be observed not before the end of this time delay. Another problem is that none of the available methods to quantify nitrate leaching under field conditions delivers exact data (KUECKE et al. 1999), so the available data are more or less rough indicators for leaching potentials.

Table 2. Potentials for water pollution in relation to the nitrate concentration of leaching water(FREDE and DABBERT 1998)

Nitrate pollution risk	Nitrate concentration in leachate ($mg\ NO_3/l$)
Very low	$<$ 15
Low	15 − $<$ 25
Medium	25 − $<$ 35
High	35 − $<$ 50
Very high	$\geq$ 50

Table 3. Tolerable nitrate leaching potential to keep the concentration the leachate at 50mg NO_3/l in relation to different amounts of seepage water (FREDE and DABBERT 1998)

Leachate (liter per m^2 and year)	Tolerable amount of nitrate leached ($kg\ NO_3$-N/ha)
50	6
100	11
150	17
200	23
250	28
300	35
350	40

In a few cases positive effects of improved fertilisation strategies (e.g. balanced nitrogen fertilisation, fertilisation according to soil testing, improved application of organic fertilisers) and cropping systems (reduced soil cultivation, intercropping) could be observed as a reduction of nitrate concentration in some ground water bodies (Fig 4). Nevertheless as the example in figure 4 shows, the nitrate concentration in the ground water after 1990 is still above the nitrate limit value for drinking water, despite a significant decrease after 1987.

Organic farming and water protection in Germany

In Germany there are severe production rules obligatory for organic famers. The most important with regard to water protection are :

- No application of synthetic pesticides
- No application of industrial N fertilisers and chemically treated phosphate fertilisers
- The number of cattle per hectar is limited(〈 1,4 cattle units/ha), which means that the amount of farmyard manures that is applied to the fields is limited
- There are restrictions in the imports of organic fertilisers into a farm

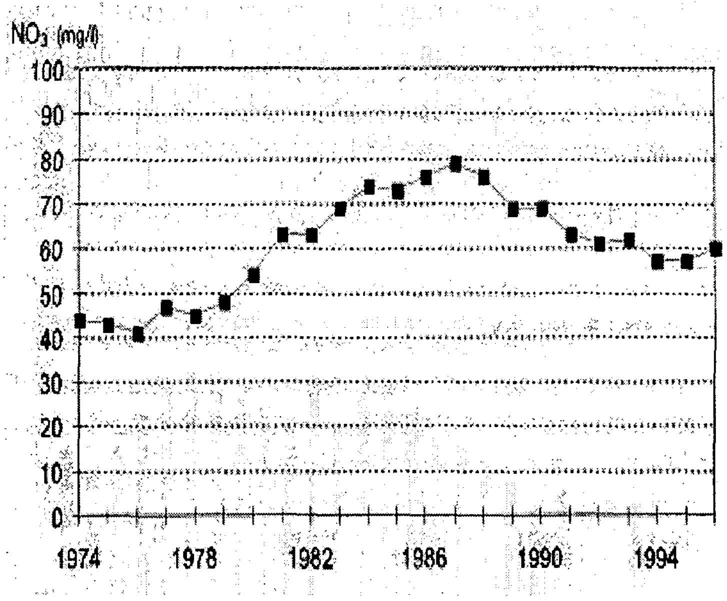

Fig. 4. Nitrate concentration over time in a flat ground water(SCHINDLER, 1997)

The consequences of this regulations for the cropping systems are :

- The nitrogen from N_2 fixing legumes are the first major source for nitrogen fertilisation
- The nitrogen from manures which are basically from fodder crops produced inside the farm are the second dominant N source for fertilisation
- The cropping systems are in general nitrogen limited
- The farmer must take special care to prevent nitrogen losses from the soils after legume cropping and after manure application
- More crops are found in the crop rotations than in conventionally cropping systems, usually rotating N_2 fixing legumes with non N_2 fixing crops.

o The farmers accept lower yields due to the limited nitrogen application, higher herb competition and increased risk of diseases.

The major consequences for ground water protection are :

o There is no leaching of pesticides from organic farmers fields!

o The N balance excess is usually lower in organic farms(but the N_2 fixation by legumes can hardly be estimated so N inputs can hardly be quantified exactly)

o The number of cattle is limited, so the amount of organic fertilisers applied is limited

o The use of farmyard manures is usually more cautiously than in conventional farming systems.

Nevertheless even in organic farms problems might rise with regard to water protection from the cultivation of N_2 fixing legume crops, especially from a soil cultivation after legume cropping before periods of high precipitation and little growth of the following crop, moreover in an incorrect storage and application of organic fertilisers. Therefore organic farming is sometimes regarded as critical for ground water protection in drinking water protection zones(FREDE and DABBERT 1998).

Relevance of soil testing for mineral nitrogen (N_{min}) for water protection

By soil sampling for mineral nitrogen the amount of plant available nitrate and ammonium is measured, usually to the rooting depth of a crop(e.g. 60cm or 90 cm soil depth). In Germany the soil testing method for mineral nitrogen(N_{min}−method) has become a basic tool for the correct quantification of the mineral N fertilisation in conventional farms of almost all field crops in Germany. It was originally developed for the quantification of the first nitrogen fertilisation to winter cereals(winter wheat, winter barley), but nowadays for almost all arable crops(with the exception of N_2 fixing legumes) N fertilisation strategies have been developed, taking into account numerous differences between different soils, crop rotations and climates. Moreover, the N_{min} soil test method has become a very effective tool to evaluate the ecological relevance of agronomic measures for nitrate leaching : There is no doubt that high levels of nitrate in a soil profile indicate a high risk for nitrate leaching out of the rooted soil profile to the ground water, especially in periods without vegetation(winter) and in period with heavy rainfall(KUECHE and KLEEBERG 1997, KUECKE et al. 1999).

The basic principle of the N_{min}-method in Germany is

1. quantify the amount of nitrogen that is needed by a specific crop for optimum growth and yield = N demand(kg N/ha) (this has to be done by numerous N fertilisation field experiments and specifically for different regions)
2. at the fertilisation date measure by soil testing down to the rooting zone of the crop how much mineral nitrogen(ammonium and nitrate) is in the soil profile of the site where the crop is grown = amount of N_{min}(kg N/ha). This nitrogen is plant available.
3. Calculate the amount of N fertilisation by subtracting the amount of Nmin from the crop N demand

optimum amount of N fertilisation = N demand - amount of Nmin (kg N/ha)

During the recent years the N_{min} method has been improved due to an increasing knowledge about the N turn over in different soils and cropping systems(Tab. 4). Actually the quantification of the N fertilisation regards also the soil type specific N mineralisation, the N release from previous crop residues, organic fertilisers and intercrops. Tables to get a realistic estimates for the intensity of these processes of the N turnover are available for the farmers and the extension services for use in their fertilisation calculation.

The use of soil testing is a basic method and – according to the fertilisation decree(Tab. 1) – obligatory for all arable crops that require N fertilisation. If the farmer uses other methods to quantify the N_{min} content that are officially accepted and recommended by extension services(e.g. computer simulation programmes) he is allowed to do so.

Table 4. Principe to quantify the amount of N fertilisation for arable crops

Quantification of the N fertilisation for arable crops
Amount of N fertilisation = N demand for the harvest products according to a realistic yield ecspectation + demand for crop residues **- amount of N_{min} in the soil at first fertilisation date** – N mineralisation from crop residues from previous crops, organic fertilisers and intercrops – N mineralisation from soil organic matter
= amount of N fertilisation(mineral and organic)

Soil sampling for mineral nitrogen in the soil profile follows to intentions :

- by soil testing before nitrogen fertilisation the amount plant available nitrate in the soil profile that can be taken up by the crops
- by soil testing at begin of the leaching period the risk for ground water pollution shall be evaluated

The difference to the soil testing methods for plant available phosphate and potassium(and other nutrients) is that these nutrients are mainly concentrated in the plough layer. For the quantification of the P and K fertilisation demand, a sampling of the topsoil is sufficient. In contrast to this, soil sampling for mineral nitrogen essentially needs deeper sampling depth : For fertilisation recommendation, a sampling according to the rooting depth of the crops is needed(0~30cm, 0~60cm or 0~90cm depending on the crop type). Sampling below 90cm soil depth is not recommended and usually ineffective. Such deep soil sampling is a hard business for farmers and survey services, but machinery has been developed to make sampling less strenuous.

It is also urgently essential that soil samples for mineral nitrogen analysis are cooled at about refrigerator temperature(2~4℃) from the moment of sampling until the samples arrive the laboratory. If the samples are not cooled down, they will warm up and the nitrate content in sample will increase rapidly due to enforced mineralisation.

For routine soil testing on mineral nitrogen on numerous farmers fields, an effective laboratory organisation must be available. For fertilisation quantification, farmers need the results at least within one week or less, otherwise they will not accept the method. The transport way to the next laboratory as well as the time until the farmer gets the analytical results should be as short as possible. Sampling and analytical programmes are well organised in Germany by national and private survey services.

Strategies for ground water protection with special regard to organic farming and the relevance of soil testing on mineral soil nitrogen

Fertilisation strategies for water protection need at least 4 components :

1. Nutrient balances for each field and crop must be calculated annually to determine excessive nutrient application
2. N_{min} soil testing down to the rooting depth should be used to determine a critically low content for crop growth in spring (before fertilisation) of each crop.
3. N_{min} soil testing down to 90 cm soil depth before leaching periods should be used to detect critically high nitrate concentrations in the soil profile. Analysis of the crop rotation or farmers practice will deliver reasons for high nitrate concentrations in the soil. This procedure allows the development of improved cropping and fertilisation strategies.
4. Regular soil sampling and analysis on mineral phosphorus and potassium allows to detect fields where high amounts of organic fertilisers have been applied.

The simplest way to calculate nutrient balances is to calculate according to the formula

Nutrient input by fertilisation (kg/ha) - nutrient export by harvest products(kg/ha)
= Nutrient balance kg/ha

Nutrient balances are always calculated on the basis of total nutrient concentrations, not on basis of plant available compounds. For calculating nutrient balances it is necessary to know the amount and the nutrient concentrations in the fertilisers. This is easy for mineral fertilisers but for organic fertilisers a chemical analysis for total nutrient content(not for plant available nutrient concentrations!) is urgently need. In Germany some data are available that can be used to estimate roughly the nutrient content in organic fertilisers and different types of farmyard manure, specifically for different species of cattle, cattle keeping systems and feeding regimes. N_2 fixation by legumes has also be regarded as N input, and data for different legume varieties are also available for balance calculations.

Different ways to calculate nutrient balances(field specific balances, farmyard balances) are in use and recommended(KUECKE and KLEEBERG 1996), and to meet the legislation, the farmer can decide which way of calculation he prefers. A positive balance value is a potential risk for environmental pollution if the soil is saturated with nutrients. A positive balance excess is that amount of the nutrient input(to a farm or to a field) that has not been exported from the field by harvest products. With regard to nitrogen some investigations have shown that the amount of nitrate in the soil profile after harvest is positively related to the balance excess above a critical value(Fig. 6).

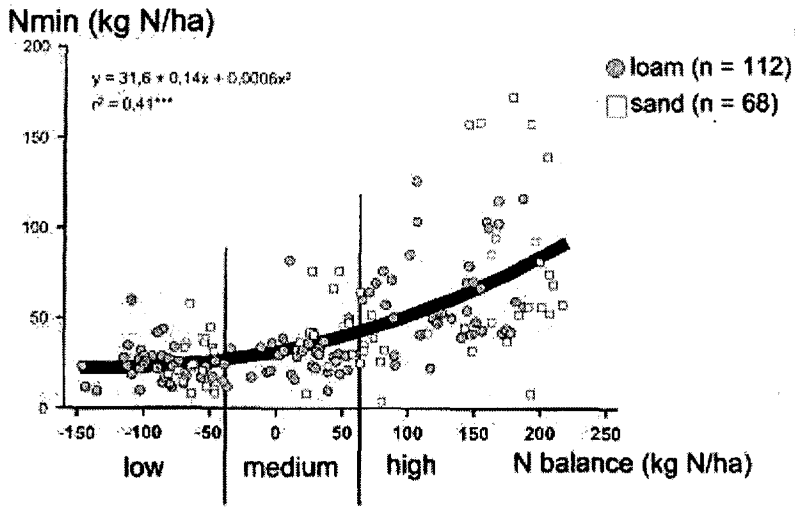

Fig. 6. Soil mineral nitrogen content(N_{min}) after harvest of winter wheat in relation to N balance(ENGELS 1983)

Soil testing for the quantification according to the German N_{min} method can be used in the same way in Korean climatic conditions in conventional cropping systems(SOHN et al. 1995, SOHN and KUECKE 1996). If the organic farming system is nitrogen limited, the use of the N_{min} method in spring for the determination of the N fertilisation demand is not as essential in all situations as in conventional farming systems as the mineral nitrogen content can be expected be low. In organic farms with an import of manure and other organic fertilisers it must be assumed that this soil test method can be used to determine if the N_{min} status of the soil is as high that no additional fertilisation is necessary or fertilisation can be reduced. To determine critical values for such fertilisation strategies in organic cropping systems, additional research is urgently needed.

Without any doubt the N_{min} method can be used successfully to determine and evaluated the sustainability of a cropping system with regard to water protection. A nitrate content 〉 40kg N/ha at the start of the leaching period is regarded as critical with regard to water protection.

Soil testing can also indicate a regular inhomogeneous distribution of organic manure inside a farm. It is widely observed in Germany that more farmyard or liquid manure are applied to fields close to the farmyard area due to the lower transport distance. Such inhomogeneous distribution inside a farm might cause water pollution even if the farm gate balance is zero or even negative. Soil sampling for soil nitrate(Fig. 7) – but also for mineral phosphate – can clearly indicate such non ecological situation.

Each strategy to optimise fertilisation with regard to water protection issues must be accompanied by new strategies for soil cultivation(e.g. no soil cultivation after legume cropping and no application of organic manures before leaching periods or on bare soils) and cropping systems. An urgently recommended way to avoid high nitrate levels after the vegetation period is intercropping, which can effectively reduce the mineral nitrate content in the soil profile before start of the leaching period(Fig. 8).

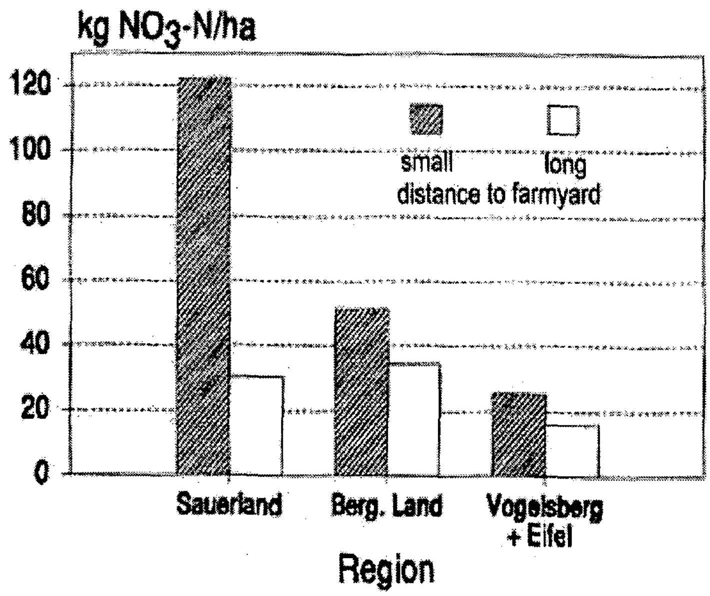

Fig. 7. Nitrate in the soil profile (0~150cm) in autumn 1989 in different regions and in relation to the distance from the farmyard (HOMM 1994)

The aim of this paper was to demonstrate the tools that are used in Europe and Germany to optimise fertilisation with regard to water protection. Fertilisation strategies are closely linked to the cropping systems. Due to the differences in climate, crop rotations, soil conditions and agricultural traditions not all measures can be adopted uncritically for Korean agriculture. Further evaluation of the ecological risk potential of Korean farming systems should be done by calculating nutrient balances for different systems. First encouraging results have been made with the Nmin soil testing method(KUECKE and SOHN 1995), but for optimal use more research has to be focussed on this method.

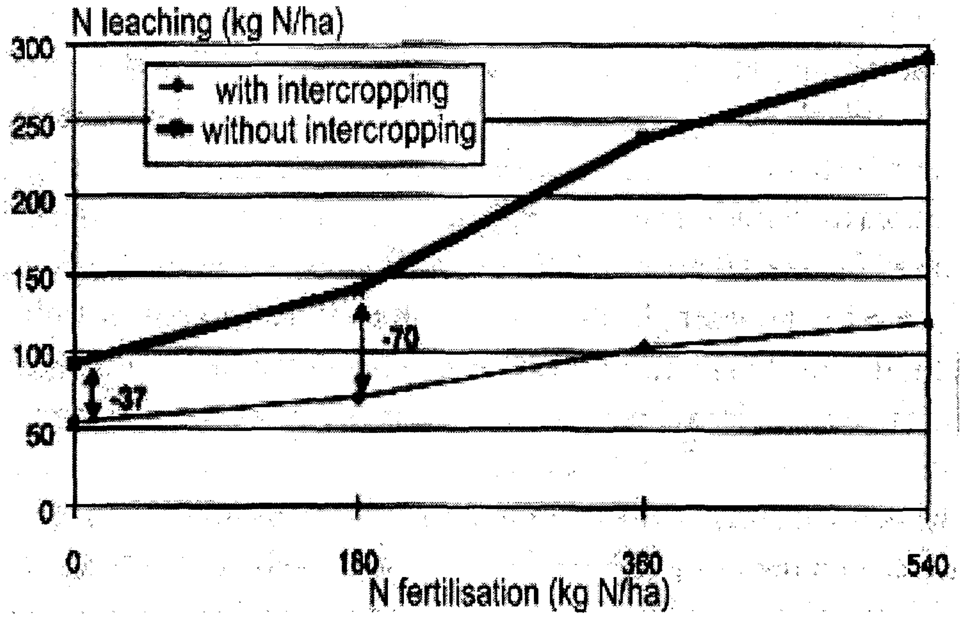

Fig. 8. Influence of intercropping on nitrate leaching during winter after increasing application of liquid manure(VETTER and STEFFENS 1983)

References

1. Benke, M. (1992) : Untersuchungen zur Nitratauswaschung unter Grünland mittels der Saugkerzenmethode in Abhängigkeit von der Nutzungsart (Schnitt/Weide), der Nutzungshäufigkeit, der Bestandeszusammensetzung (mit und ohne Weißklee) und der Stickstoffdüngung. Diss. Uni. Kiel.
2. Buch, M., M. Kücke. and E. Schnug. (1995) : The importance of rainfall events for the nutrient input into surface waters. Soil Fertility and Fertilizer Management, 9th Intern. Symp. of CIEC, 25–30. 9. 1995, Türkei, 299–308.

3. Engels. T. (1993) : Nitratauswaschung aus Getreide – und Zuckerrüäbenflächen bei unterschiedlichem N – Angebot. Verlag U.E. Grauer, Wendlingen.
4. Frede G. und S. Dabbert (ed) (1998) : Handbuch zum Gewässerschutz in der Landwirtschaft. ECOMED–Verlag 1998.
5. Homm, A. (1994) : Zur Variabilitat der Nitratmengen unter Weidennarben. Wissenschaftlicher Fachverlag Giessen.
6. Kücke, M., In A Han and S. M. Sohn (1996) : Implications of examinations of the mineral nitrogen dynamics in Korea and Germany for N fertilization recommendations and environmental protection in Asia. 2^{nd} Asian Crop Science Conference, Aug. 21–23, 1995, Fukui, Japan ; In : ISHII et al. (ed.) : Crop Research in Asia, 462–463.
7. Kücke, M. and P. Kleeberg (1996) : N fertilisation balances in two agriculturally used water catchment areas. Fertilisers and Environment 1996, 101–108, Kluwer Academic Press.
8. Kücke, M., B. Dilci, and C. Ramos (1999) : Can we measure nitrate leaching? Proceedings, 6^{th} Interntional Meeting on Soils with Mediterranian Type of Climate, 4.–9– July, 1999, 116–118.
9. Kücke, M. and P. Kleeberg (1997) : Nitrogen balance and soil nitrogen dynamics in two areas with different soil, climatic and cropping conditions. Europ. J. Agron. 6, 89–100.
10. Kücke, M. and S.M. Sohn (1995) : Investigations on the dynamics of mineral nitrogen in the soil under Korean cropping conditions and ist suitability for N fertilisation strategies and for environmental control. Final Report of the Research project funded by DFG and KOSEF.

12. Sohn, S.M., M. Kücke and In A Han (1995) : Dynamics of NO_3−N in Barley Rhizosphere and optimum Rate of Nitrogen Top Dressing based on N_{min} Soil Test. Korean J. Crop Sci. 40, 2, 185−194.

13. Sohn, S.M. and M. Kucke (1996) : Investigations on the dynamics of NO_3 in barley rhizosphere and its suitability for N fertilization strategies and for environmental control. 2nd Asian Crop Science Conference, Aug. 21−23, 1995, Fukui, Japan ; In : ISHII et al.(ed.) : Crop Research in Asia, 460−461.

14. UBA (1995) : Jahresbericht 1994. Umweltbundesamt Berlin.

15. Vetter, H. und G. Steffens (1983) : Stickstoffverlagerung nach Güulledüngung mit und ohne Zwischenfruchtanbau. VDLUFA−Kongressband 1983, Sonderheft 40, S 354−362.