Nitrogen Use Efficiency as an Agro-Environmental Indicator

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Abstract

The growing world population demands increasing food production. According to the projections of the United Nations Food and Agricultural Organization (FAO, 2006), the production of cereals will increase by 60% from 2000 to 2050. More crops require more plant nutrients. As a consequence also fertilizer consumption will increase considerably. Fertilizers are applied to balance the gap between the permanent export of nutrients from the field with the harvested crops and the nutrients supplied by the soil. However, not all of the applied fertilizer ends up in the crop. Part of the fertilizer nutrients are lost to the wider environment and contribute to environmental problems such as loss of biodiversity or climate change.

This is why society and policy ask for more efficient use of plant nutrients in agriculture. The United Nations Economic Commission for Europe (UNECE) currently revises its so-called “Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone”. Nitrogen use efficiency (NUE) will be a key indicator in this international convention in order to assess the efficacy of measures to decrease nitrogen (N) losses while maintaining agricultural productivity.

Nitrogen use efficiency can be defined as the ratio between the amount of fertilizer N applied and the amount of N removed with the harvest. However, different definitions of NUE are used. Even more important than the way of calculation is the interpretation of the results. Examples from field trials show that very high as well as low NUE values represent unsustainable crop production systems and that the interpretation of NUE values requires a qualification scheme.

This study examines

- how NUE can be determined,
- the NUE of different N application rates in a long-term field trial,
- how these results can be interpreted and qualified, and
- the transfer of this approach to public available data on country or regional level.

Introduction

The growing world population demands increasing food production. According to the projections of the United Nations Food and Agricultural Organization (FAO, 2006), the production of cereals will increase by 60% from 2000 to 2050. More crops require more plant nutrients. As a consequence also fertilizer consumption will increase considerably. Fertilizers are applied to balance the gap between the permanent export of nutrients from the field with the harvested crops and the nutrients supplied by the soil. However, not all of the applied fertilizer ends up in the crop. Part of the fertilizer nutrients are lost to the wider environment and contribute to environmental problems such as loss of biodiversity or climate change.

In order to assess the efficiency of agricultural crop production to convert applied fertilizer nitrogen into harvested products, the indicator "nitrogen use efficiency" should be used. N use efficiency (NUE) can be calculated as the ratio between the amount of fertilizer N removed with the crop and the amount of fertilizer N applied.

Nitrogen use efficiency and N balance – two different agro-environmental indicators

The N balance is already an established OECD indicator (OECD, 2008). It shows the difference between N inputs (fertilizer, manure etc.) and N outputs (arable, permanent and fodder crops) and is usually expressed in kg N per hectare. The N balance provides information about the absolute flow of nitrogen that is not captured in agricultural products and therefore potentially available for losses. However, the N balance gives no information on the efficiency of nitrogen fertilizer utilization in a production system or a country.

N use efficiency (NUE) is another agro-environmental indicator used in the agro-policy context, e.g. during the current revision of the UNECE Gothenburg Protocol to reduce acidification, eutrophication and ground-level ozone. NUE can be calculated as the ratio between the amount of fertilizer N removed with the crop and the amount of fertilizer N applied. It can be expressed in %. NUE provides information about the relative utilization of additional N applied to an agricultural production system of a country or region. Table 1 shows the N balance and NUE for three European countries.

Table 1. Nitrogen use efficiency and N balance in selected European countries

Country	N balance (kg N/ha)	NUE (%)
Portugal	47	40
Sweden	48	64
France	54	63

Sources: OECD (2008), own calculation based on FAO (2010) and IFA (2010)

The data reveal that a low N balance does not always relate to high N use efficiency. For example the N balance of France is 7 kg N/ha higher than that of Portugal. At the same time the NUE value for Portugal is only 40% whereas that of France is at 63%. A reason for this contradictory result is that in France both, N input with mineral fertilizer and the N removal with arable and permanent crops is higher than in Portugal. As a result the relative efficiency of fertilizer N use in France is higher but also the absolute N surplus of inputs compared to outputs is higher than in Portugal. This means that N balance and NUE do not necessarily lead to the same conclusions. It can be concluded that the NUE considers the productivity level more than the N balance, which focuses on the absolute difference.

Definition of NUE and methods to derive NUE data

Different definitions of nitrogen use efficiency (NUE) are used. See e.g. Johnston & Poulton (2009) for an overview. In this study NUE is defined as the ratio between the amount of fertilizer N removed from the field by the crop and the amount of fertilizer N applied.

Also the methodologies to derive NUE values vary considerably. It is for example possible to measure NUE directly by labeling the applied nitrogen with ^{15}N. By this approach it is possible to trace the actual fate of applied N and to distinguish between crop uptake, soil retention and the different potential pathways of N losses to air and water. However, this method is precise, but expensive and is therefore only applicable in scientific experiments.

The so-called "difference method" includes an unfertilized crop in the calculation in order to account for the N uptake that occurs independently from fertilizer application. The calculation procedure is: (N crop uptake fertilized – N crop uptake unfertilized) / N fertilizer input. As an agro-environmental indicator in the policy context this method is not practical, because a "zero N" plot is only available in field trials. Furthermore, this approach is only valid for long-term field trials, since in short-term trials the unfertilized treatment may still benefit from former nitrogen application as can be shown from field experiments (e.g. Engels, 1992).

The target of an agro-environmental indicator in a policy context is rather to show developments in countries/regions over time and to compare countries/regions with each other. Therefore, the requirements for such an indicator are (1) that the same method should be used in all countries/regions, and (2) that data shall be easily available in order to enable an easy calculation and update of the indicator. Therefore, we propose to use an output-input ratio to calculate NUE on a country or regional scale. The ratio of crop N removal and mineral N fertilizer input is applicable under practical conditions and data are usually available from official statistics (e.g. FAO, EFMA, and IFA). However, as it will be shown in the following, the agro-environmental indicator "NUE" is not easy to interpret and therefore needs an additional interpretation scheme.

NUE describes the efficiency of N fertilizer utilization in crop production

Agricultural production has an internal nitrogen cycle which is driven by crops, soil and animals. This N cycle permanently looses nitrogen by the export of N with agricultural products and unavoidable N losses to the environmental (e.g. via leaching outside the growing season). On top of this, agriculture is expected to increase its overall production considerably (FAO, 2006), which requires additional nitrogen. Mineral N fertilizer is applied to compensate for this exported, lost and additionally needed nitrogen (Fig. 1).

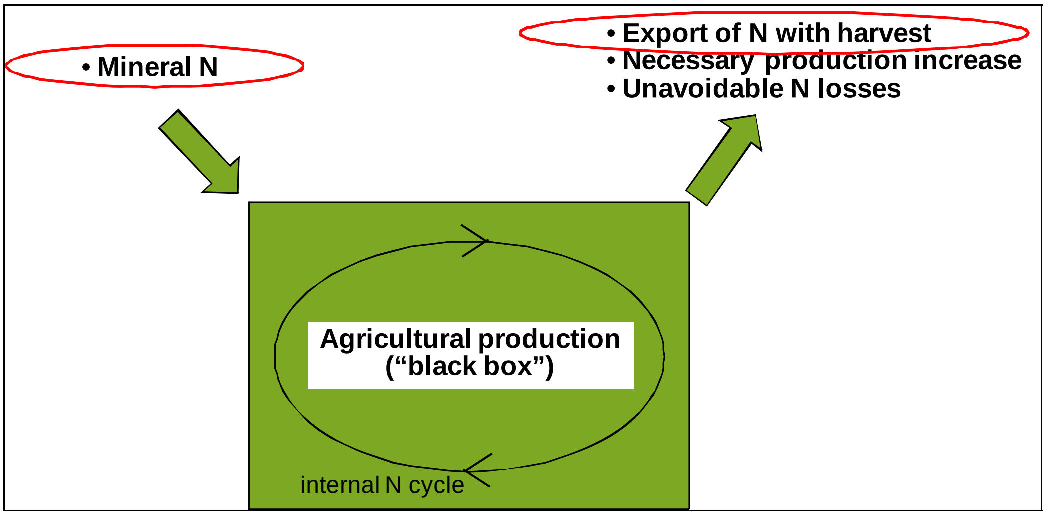

Fig. 1: Mineral fertilizer application compensates for exported, lost and additionally needed nitrogen

The export of N with the harvest of arable and permanent crops and mineral N fertilizer are the major the major flows in and out of this system. The ratio between both can therefore be used to describe the efficiency of N fertilizer utilization in crop production. In a theoretical system without any N losses to the environment, a NUE of 100% would be ideal, since the inputs would exactly match the outputs. However, in practice this is not possible because agriculture operates in an open environment with a continuous exchange of nutrients between the environmental compartments soil, water and air. Therefore, N losses are partly unavoidable since crops are not permanently requiring all the nutrients that are cycling in the agricultural system.

For the present study, NUE has been calculated according to following equation.

NUE = N removal with harvest / mineral N input * 100

With

- N removal = yield of arable and permanent crops (FAOstat) x avg. N content
- Mineral N input = N fertilizer consumption (EFMA/IFA statistics)

NUE of mineral fertilizer application – an example from a long-term field trial with different N application rates

Table 2 shows the NUE of different mineral fertilizer application rates in a long-term field trial with winter wheat. At low N application rates the N removal with the harvested wheat grain exceeds the N input, i.e. NUE is higher than 100%. This situation can be described as "soil mining", i.e. soil fertility and as a consequence also yields are declining. Such systems are not sustainable and should be avoided in order to maintain agricultural productivity and soil fertility.

Table 2: NUE of different mineral fertilizer application rates in a long-term field trial with winter wheat

N application rate (kg N/ha)	N removal (kg N/ha)	NUE (%)	Interpretation

0 48	26 56	- 116	Soil mining
96	92	96	Risk of soil mining
144 192	126 151	88 79	Balanced in- and outputs
244	166	69	Risk of high N losses

Source: Calculated based on Data from the long-term “Broadbalk Experiment”, Rothamsted/UK, winter wheat, avg. yield of 1996-2000 (Brentrup, 2004)

At an application rate of 96 kg N/ha the removal with the wheat grain is almost equivalent with 92 kg N/ha. The resulting NUE is 96%. NUE values of 90-100% still represent a risk of soil mining, because the additional N requirements for roots and straw are not met by N input, and also unavoidable losses e.g. due to leaching during the non-vegetation period are not compensated for. At application rates of 144 and 192 kg N/ha NUE is at ~80-90%, which can be evaluated as well balanced inputs and outputs. N application rates with NUE values below 70% include an increased risk of nitrogen losses and should be avoided in order to protect the environment.

Use of output-input ratio to calculate NUE for different regions

Figure 2 shows the development of NUE for different regions between 1987 and 2006. The regions have been selected to show examples of different situations and developments with regard to N fertilizer use, production of arable and permanent crops and the resulting NUEs. In Africa N removal with crop production permanently exceeds the N input with mineral fertilizer. The development shows that NUE even further increases over time from 120% to about 140%. This means that today 40% more nitrogen is removed from the agricultural system in Africa than what is replaced by mineral N fertilizer. In China the situation is the opposite. NUE decreased from about 50% in 1987 to less than 40% in 2006. This corresponds with increasing crop production but even more increasing N application rates. In Europe, NUE increased from around 40% in 1987 to more than 60% in 2006, mainly due to improved agricultural practices. The global average NUE remained relatively stable at 50-55% between 1987 and 2006.

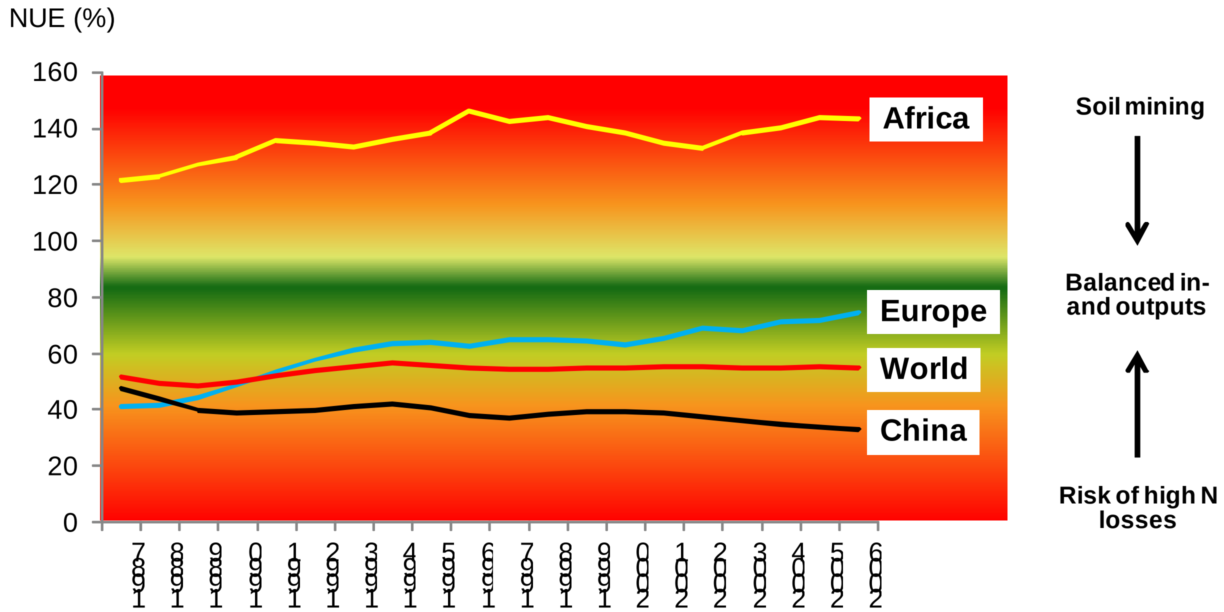

Fig. 2: NUE for different regions (moving average over 3 years, N removal with arable & permanent crops and N input with mineral N; source: own calculations based on FAOstat, 2009 and IFA, 2009)

NUE as an agro-environmental indicator in international policies

Two examples shall exemplify the increasing relevance of NUE as an agro-environmental indicator in international policies.

(1) The UNECE 1999 Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone, called “The Gothenburg Protocol”

The Gothenburg Protocol is currently under revision. Besides others, also ammonia emissions from agriculture contribute to acidification and eutrophication of ecosystems. Therefore, the protocol explicitly addresses ammonia (NH_3) emissions from agriculture and measures for reduction. In order to monitor the implementation of the revised Gothenburg protocol, the UNECE proposed NUE as a “legal instrument”.

(2) EU climate and bio-energy policies

The current EU climate and bio-energy policy includes a target of 10% biofuels components in vehicle fuels for 2020. The biofuels used should comply with sustainability criteria. Besides the already agreed criteria (e.g. minimum CO2 saving, no land use change), now also NUE is under discussion as an additional sustainability criterion.

Summary and conclusions

Nitrogen use efficiency provides information about the utilization of additional N applied to an agricultural production system of a country or a region. For this purpose NUE should be calculated as the ratio between the N removal with the harvested crops and the N input as mineral fertilizer. By using available statistical data, NUE can be easily calculated and regularly updated. However, NUE results need an interpretation scheme because very high as well as low NUE values represent unsustainable situations. NUE has already gained increasing importance as an agro-environmental indicator, e.g. in the revised UNECE Gothenburg Protocol.

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