Fluid Fertilisers Injection and Groundwater Protection–Can CULTAN reduce the Leaching of Nitrate?

Injektionsdüngung und Grundwasserschutz – Kann die Nitratauswaschung durch CULTAN-Düngung reduziert werden?

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Introduction

The nitrate content in drinking water must not exceed 50 mg nitrate/L. 70 % of the drinking water in Germany is supplied by groundwater withdrawal. Intensive agriculture and especially intensive vegetable cultivation often cause an N surplus which can be leached to the groundwater. Hence, there is a potential conflict between farmers and water providers.

CULTAN (Controlled Uptake Long Term Ammonium Nutrition) supposedly has a higher plant use N efficiency due to the banding of fluid fertiliser. Therefore, CULTAN may have the potential to reduce the nitrate losses to the groundwater without yield reductions. This would have two benefits:

(i) The groundwater quality increases.

(ii) Farmers’ costs are reduced due to more efficient fertiliser use.

Several water providers try to decrease the nitrate leaching by the introduction of the CULTAN technique. We compared the nitrate losses below the root zone between CULTAN and conventional fertilisers to test the differences with a variety of crops in three projects in Baden-Württemberg.

Material and Methods

General design of the experiments

We chose a comparable design in all three projects. Two plots are installed on each field to ensure a direct comparability. These plots are treated in the same way and get the same amount of N-fertiliser. We applied fluid fertiliser injection (“CULTAN”) on one plot and the local standard (“Conventional”) on the other plot of the same field. We used an ammonium nitrate urea solution (“Ammoniumharnstofflösung”) or urea ammonium sulphate solution (“Harnstoffammoniumsulfatlösung”) for CULTAN. The conventional fertiliser usually was

calcium ammonium nitrate (CAN, “Kalkammonsalpeter”). For maize in the Rhine valley experiment we used Urea.
We installed at least five field replicates and continued the experiments for at least two years to cover different soil properties and different weather conditions.

Measurement of nitrate leaching: Self-integrating accumulators (SIA)

The nitrate-N loss with the percolating water is directly measured using Self-Integrating Accumulators (SIA, Bischoff, 2007) below the main rooting zone (Figure 1). The SIA measure the accumulated, area-representative fluxes of nitrate in the soil in semi-annual periods. Ten SIA replications are installed in two or three profiles in each treatment on every field. The profiles represent comparable positions within the two treatment plots. The installation period of the SIA covers the vegetation period (usually ca. March/April to September, indicated as “summer”) and the non-vegetation period (usually ca. September to March/April, indicated as “winter”). Water leaching is close to zero during the summer period due to high evapotranspiration. Groundwater recharge is taking place mostly during the winter period.

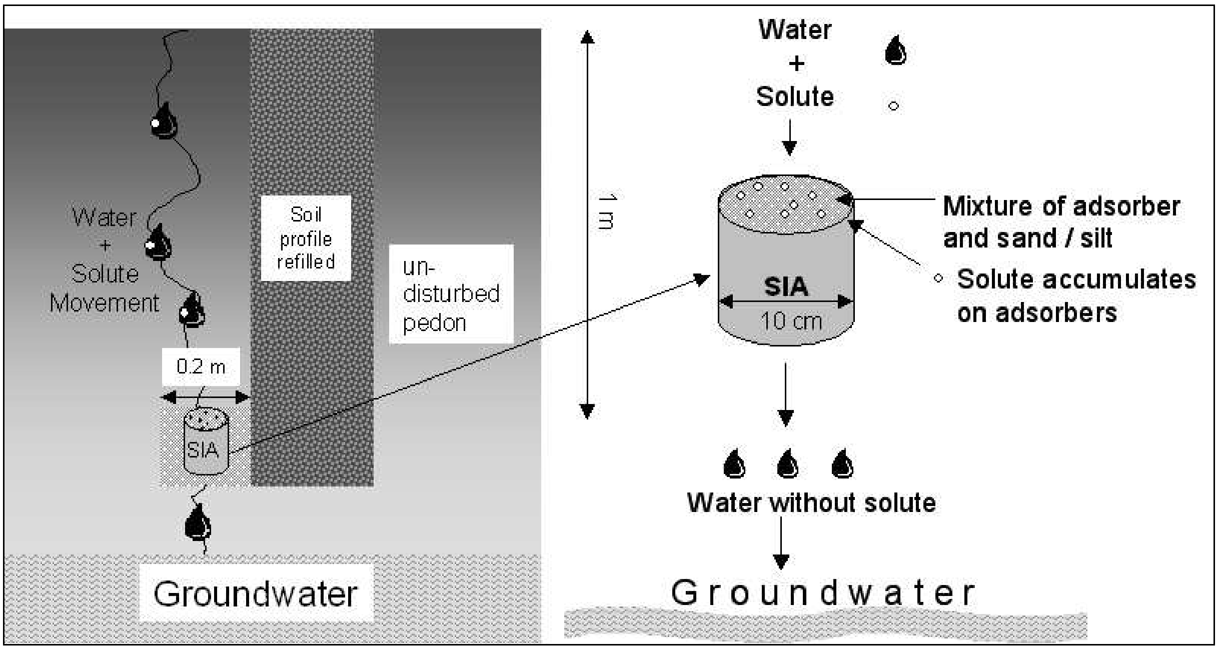

Figure 1: Installation and functional principle of the Self-Integrating Accumulator (SIA): The SIA is located below the undisturbed soil and surrounded by material with the same hydraulic properties. Solutes are extracted out of the water by (specific) sorption, while water passes through (Bischoff, 2007).

Overview

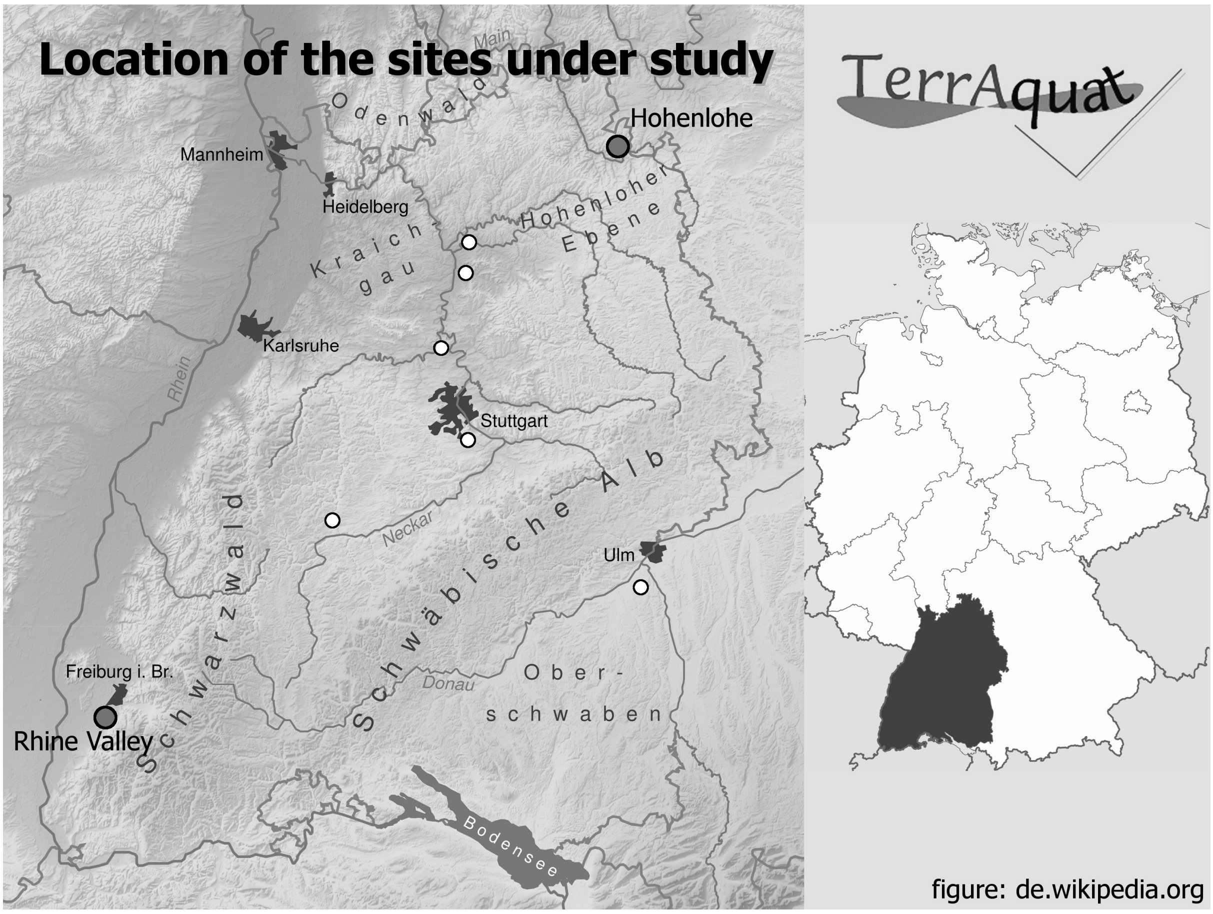

Figure 2: Map of Baden-Württemberg showing the location of the sites in the three projects. Hohenlohe: Rotation of three crops. Rhine Valley: Corn and potato fields. White dots: Sites of the vegetable cultivation project.

Baden-Württemberg: Vegetable cultivation

We tested CULTAN-fertilization in vegetable growing funded by the Ministerium für Ernährung und Ländlichen Raum, Baden-Württemberg, Germany. Local farmers as well as research institutions cultivated the twelve sites under study at six locations in Baden-Württemberg (Germany, Figure 2). 16 measurement periods in summer and 11 in winter between 1999 and 2004 were evaluated.

Hohenlohe: Rotation of rape, winter wheat, catch crop, and spring barley

The project was initiated by a local water provider, the Wasserversorgungszweckverband Grünbachgruppe (WZG). It lasted from 2003 to 2006 and included nine fields with a three-year crop rotation: rape, winter wheat, catch crop, and spring barley. The aim also was to reduce the nitrate losses to the groundwater. The sites were located between

Tauberbischofsheim and Würzburg in the Northeast of Baden-Württemberg (Figure 2) and are characterized by triassic limestone (Muschelkalk) covered with ca. 0.60 m Loess. Conventional fertiliser (CAN) was compared to urea ammonium sulphate solution (“CULTAN”) on two adjacent plots on each field. The applied amounts were 80 % of the normal N recommendation in this region for both fertilisers. Yield quantity and quality (not shown in detail) as well as nitrate leaching in 0.60 m depth were determined. The N balance of the experimental sites is calculated as input (fertiliser) minus output (harvest plus leaching).

Rhine valley: Grain maize and potatoes

This ongoing project is funded by the Badenova AG & Co. KG, the regional water plant in southwest Baden-Württemberg and focuses on two main crops in the region: grain maize and potatoes. The experiment aims to reduce nitrate losses to the groundwater and to increase N efficiency by using CULTAN-fertilization.

The experiments are conducted between Freiburg and Bad Krozingen (Figure 2). For each of the crops five sites are simultaneously under study comparing conventional fertiliser (urea for maize and CAN for potatoes) with Ammonium nitrate urea solution as “CULTAN” in two plots. The experiments with grain maize have started in 2008 and last for three years, the experiments with potatoes have started in 2009 and will last for two years.

The selected sites represent the variety of soils in the region, ranging from sediments with a high proportion of sand and gravel up to soils derived from Loess and weathered Loess.

Yield quantity and quality are measured by the Landratsamt Breisgau-Hochschwarzwald and ANNA (see contribution of Maier and Müller-Sämann). The SIA are installed in 1.20 m (grain maize) or 0.60 m (potatoes) depth, respectively.

Results and discussion

Baden-Württemberg: Vegetable cultivation

The nitrate leaching in vegetable cultivation (*Figure 3*) is noticeably higher than in agriculture. This is caused by the intensive use of N-fertiliser in vegetable cultivation to reach the required quality standards.

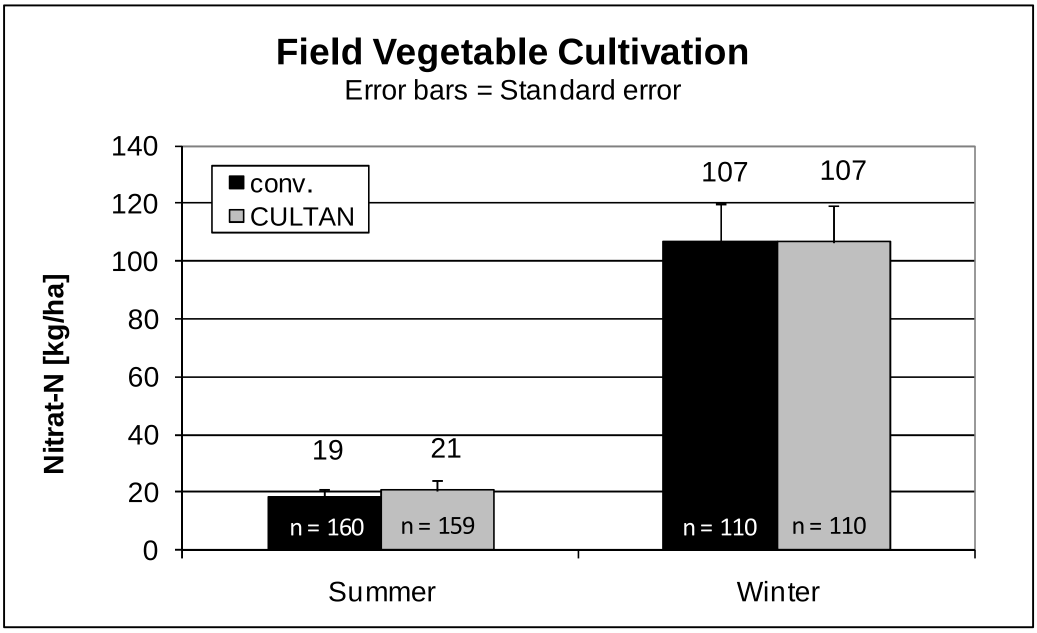

Figure 3: Mean nitrate-N leaching for field vegetable cultivation in Baden-Württemberg. No significant differences.

The use of CULTAN in the field vegetable cultivation does not show an effect on the nitrate leaching (*Figure 3*). We assume that the advantages of the CULTAN technique do not play a role in vegetable cultivation:

(i) The root system of vegetables is only weakly developed. Therefore, the CULTAN-depot cannot be surrounded by roots like in agriculture.

(ii) The cultivation time of vegetables is short. Therefore, the long-term character of CULTAN can even be a disadvantage.

(iii) The N input in vegetable cultivation is excessive to get good quality. Therefore, there is no chance to improve the fertiliser efficiency.

Hohenlohe: Rape, winter wheat, catch crop, and spring barley

The CULTAN-fertilization reduced the nitrate-N leaching from 23 to 21 kg N/(ha*a). This reduction by 9% was not statistically significant. The same applies to the crop yields in the Hohenlohe project.

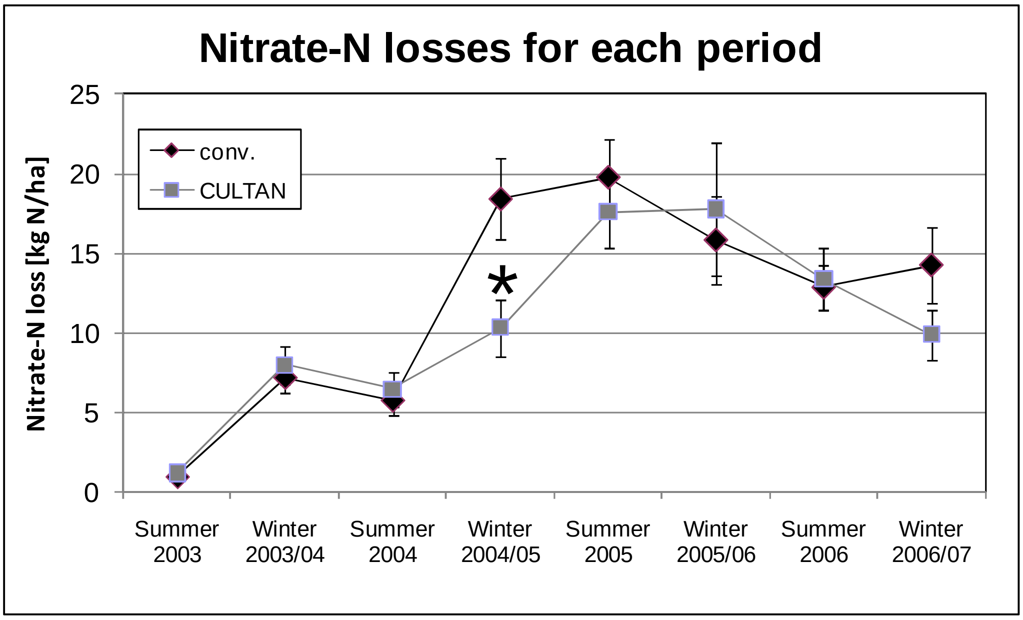

Figure 4: Mean nitrate-N leaching for all measurement periods. Error bars indicate the standard error. Significant differences ($p < 0.05$) are marked with "".*

However, for two measurement periods (winter 04/05 and winter 06/07), CULTAN reduces the nitrate-N leaching by more than 30 % (Figure 4, significant for winter 04/05, $p < 0.05$). These two winters are characterised by above average winter precipitation.

Our view to this is that the soil water retention capacity is high enough in most of the years for most of the soils in this dry region to retain the water and consequently the dissolved N inside the upper 60 cm. In contrast, water rich years produce a flush, where excess N is leached out of the soils on all sites.

This is supported by the coincidence of high yields and high N_{min} autumn data (not shown) with the lowest N leaching losses for the best three sites and vice versa for the poorest site.

With regard to the overall N mass balance, we observed an N surplus for rape and winter wheat, but a negative balance for barley (Figure 5). The balance was slightly positive for the whole crop rotation with an insignificant difference between CULTAN and CAN.

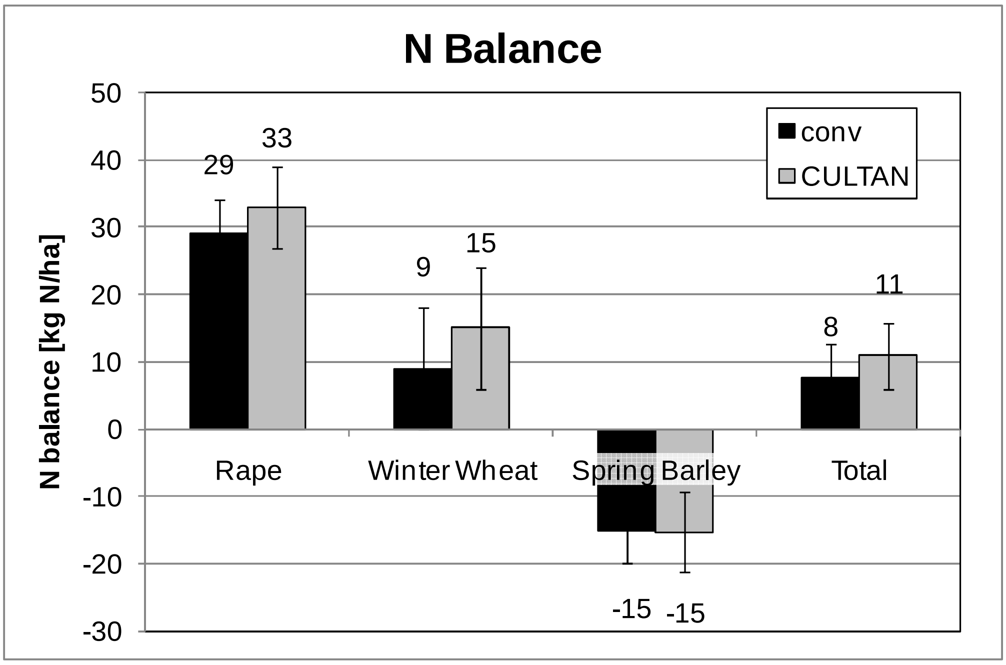

Figure 5: Yearly N balance for the four-year experiment. Error bars indicate the standard error. No significant differences between the fertilisers. n = 66.

This four-year experiment shows that for these conditions

(i) CULTAN is equal to the optimised use of CAN in normal years (yield and leaching),

(ii) CULTAN reduces nitrate leaching significantly in winters with high precipitation,

(iii) the N reduction of 20 % did not affect the yields compared to other fields.

It is therefore a means for groundwater protection with the same certainty for yields even at lower N input intensities.

Rhine valley: Grain maize

In each of the three measurement periods between spring 2008 and autumn 2009, the nitrate-N leaching is reduced by the use of CULTAN (Figure 6). This reduction coincides with higher maize yields (see Maier & Müller-Sämann, 2010) and can be explained by more efficient plant uptake of the CULTAN-fertiliser. As yet, the differences are not statistically significant.

The nitrate-N leaching from the sandy sites is higher than from the Loess sites due to the lower water retention capacity and a higher hydraulic conductivity of the former (Figure 7). The leaching from the Loess sites was extremely low even during the winter period. This reflects the precipitation deficit during the experiments (Figure 8, Deutscher Wetterdienst): The rain during the measurement period “summer 2008” was 84 mm or 11 % lower than average resulting in low water storage in the soil in autumn. The following winter period was also drier than usual (– 29 mm/– 9 %). Therefore, infiltrating water filled up the reservoir in the soil but was retained in the Loess sites that have a high water retention capacity. The precipitation deficit was even higher in the following summer period with – 27 %. Therefore, there was only little leaching during summer 2009 for Loess as well as for sandy soils. Similarly to the Hohenlohe project we expect a flush of nitrate for the next year with precipitation that is at least on average.

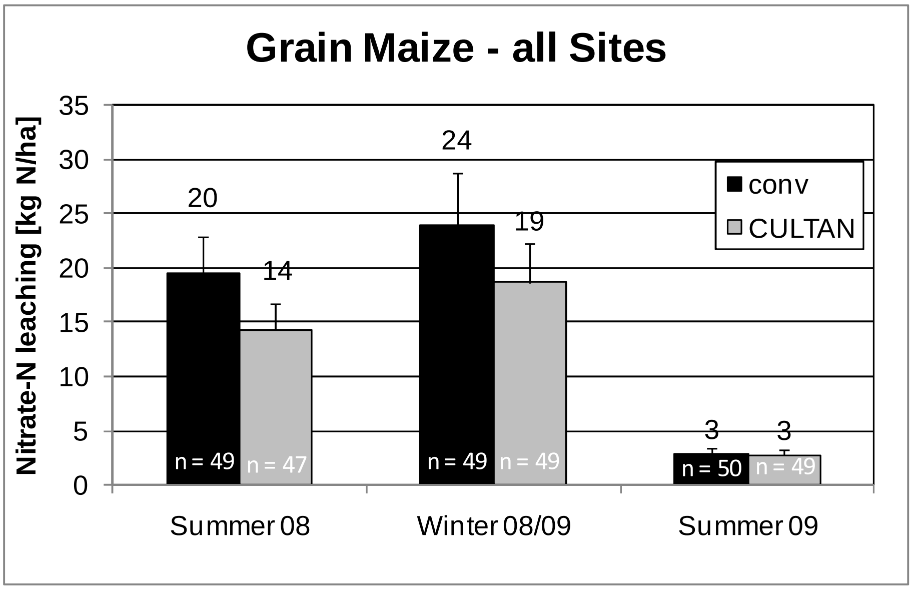

Figure 6: Mean nitrate-N leaching for grain maize in all measurement periods (5 sites). Error bars indicate the standard error. No significant differences.

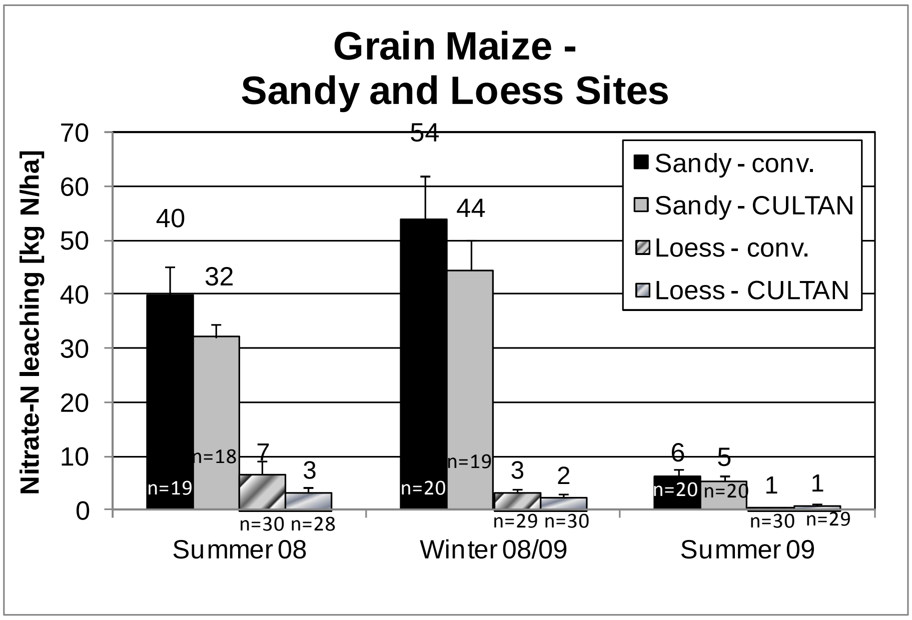

Figure 7: Mean nitrate-N leaching for grain maize in all measurement periods for sandy (2) and Loess sites (3 sites). Error bars indicate the standard error. No significant differences within the same texture.

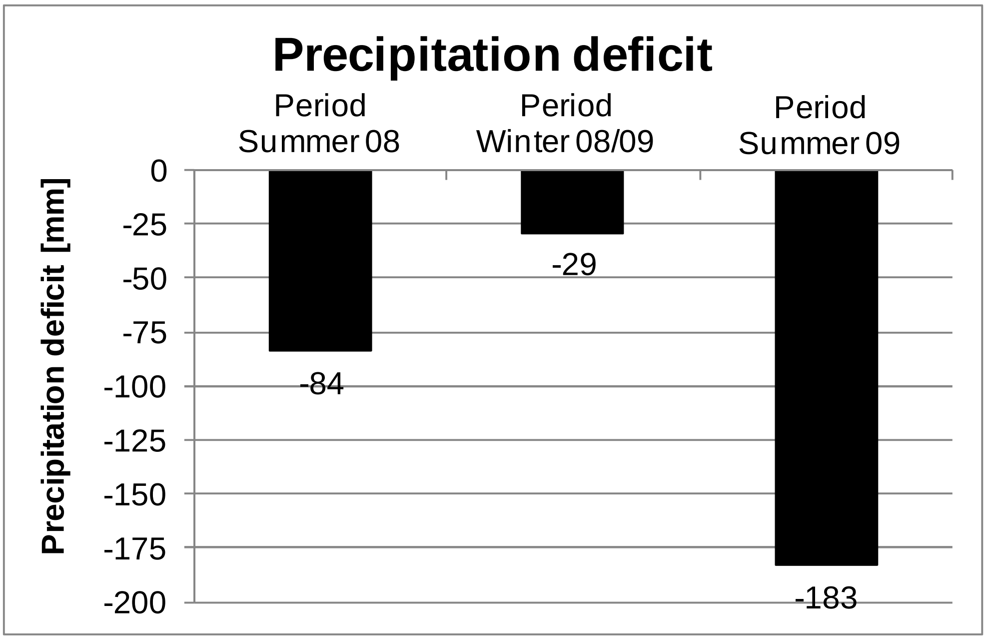

Figure 8: Precipitation deficit for each measurement period in the Rhine valley project (5 – 8 months per period). (source: Deutscher Wetterdienst)

Rhine valley: Potatoes

The experiments with potatoes have started in 2009. Leaching results are available only for one season that lasted from March to October 2009 (Figure 9).

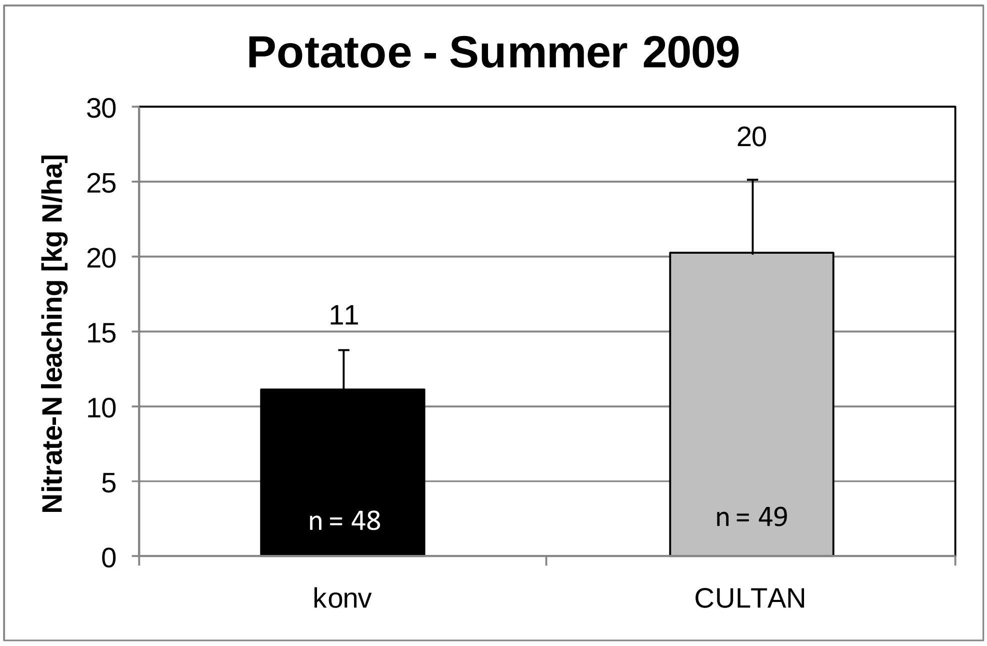

Figure 9: Mean nitrate-N leaching for potatoes in the first measurement period (5 sites). Error bars indicate the standard error. No significant differences.

The absolute amount of N losses is higher than in grain maize for the same period because of higher water percolation due to irrigation. The N leaching tends to be higher for CULTAN.

We assume that we have an effect comparable to the vegetable experiments: The N input exceeds the N requirement due to quality requirements. So, an increase in N efficiency increases the N surplus that can be leached. We expect that for CULTAN the fertiliser amount could be reduced without any yield depression.

Summary and Conclusions

In our experiments, the use of CULTAN in vegetable growing (and first results for potatoes) does not reduce the nitrate leaching. We assume that the short cultivation time and the poor root system are the physiological reasons. Additionally, there seems to be no effect in improving the efficiency of the fertiliser, because the cultivars get a high N.

CULTAN can reduce the nitrate leaching in spring barley, winter wheat, winter rape and probably maize while securing at least stable yields. The extent of the positive effects depends on several factors like site conditions, total N balance and weather. CULTAN can reduce nitrate losses especially in years with high winter precipitation and therefore high leaching risk and in fertilization strategies with a +/- neutral overall N balance. Introduced with due diligence it may therefore serve as a good means for groundwater protection.

Literature

Bischoff, W.-A. (2009): Development and Applications of the Self-Integrating Accumulators: A Method to Quantify the Leaching Losses of Environmentally relevant Substances. Hohenheimer Bodenkundliche Hefte 91, Ed.: Kandeler, E.; Kuzyakov, Y.; Stahr, K.; Streck, T.; Kaupenjohann, M., Universität Hohenheim, Stuttgart. 145 p.