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# Effect of different weed control strategies on the nitrogen efficiency in cereal cropping systems

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**Summary**

Information on the long-term effect of a reduction of herbicides on the weed population, yield, and nitrogen balances are scarce. Therefore a 9-year field trial in Brandenburg, Germany, was conducted, which compared the effect of a situation-related herbicide treatment with a 50 percent reduced rate and an untreated control. This paper is restricted to winter wheat, winter barley and winter rye.

During the first period of the field experiment (1997-2001), the reduced herbicide treatment also received a reduced mineral fertilization. This caused a very small competitive ability of the cereal crops and caused a great population development of *Apera spica-venti*. Accordingly, the yield increase after application of the reduced herbicide rate was higher compared with the situation-related treatment, though the effectiveness was 10 to 30 percent lower. During the course of the experiment, an increase in the noxious weeds in the treatment with the reduced herbicide application occurred. This consequently caused only a small yield increase compared with the situation-related treatment. The relative yield increase after herbicide application was larger if a fungicide was applied, which reduced the infestation of fungal diseases. The efficiency of nitrogen fertilization was significantly increased after the application of herbicides due to yield increases.

**Keywords:** herbicide application, nitrogen balance, yield, long-term effects

**Zusammenfassung**

*Einfluss der Unkrautbekämpfung auf die N-Effizienz im Getreidebau*

Zur Frage der Langzeitwirkung einer reduzierten Unkrautbekämpfung auf Unkrautbesatz, Erträge und N-Bilanzen liegen kaum Ergebnisse vor. Die Grundlage der hier vorgestellten Untersuchungen bilden 9-jährige Ergebnisse eines Langzeitversuches mit einer situationsbezogenen Dosierung von Herbiziden und einer im Vergleich dazu halbierten Herbizidaufwandmenge. Den Schwerpunkt der Untersuchungen stellen die Kulturarten Winterweizen, Wintergerste und Winterroggen dar.

Hierbei war von 1997-2001 die Halbierung der Herbizidmenge mit einer um 50 % reduzierten mineralischen N-Düngung verbunden. Die aus der Halbierung der N-Düngung resultierende geringere Konkurrenzkraft der Getreidebestände führte zu einer stärkeren Verunkrautung mit *Apera spica-venti*. Infolgedessen waren die herbizidbedingten Mehrerträge nach der Anwendung der halben Aufwandmenge höher als bei der situationsbezogenen Dosierung, obgleich die Wirkungsverluste im Bereich von 10-30 % lagen. Im weiteren zeitlichen Verlauf des Versuches bedingte die Wirkungsgradabnahme bei der Anwendung halbierter Herbizidaufwandmengen die Zunahme schwerer bekämpfbarer Unkräuter, was zu geringeren Mehrerträgen im Vergleich zur situationsbezogenen Dosierung führte. Bei Krankheitsbefall waren die herbizidbedingten Ertragssteigerungen in Kombination mit einer Fungizidanwendung höher als bei allei-

nigem Herbizideinsatz. Durch die Herbizidanwendung konnte die N-Effizienz infolge der höheren Erträge beträchtlich verbessert werden.

**Stichwörter:** Herbizidbehandlung, Stickstoffbilanzierung, Ertrag, Langzeiteffekte

## Introduction

The effects of different strategies of pesticides use can only be quantified in long-term experiments. This is especially true for herbicides, since various husbandry and weeding treatments cause changes in the weed population dynamics not until before several years. This includes weed density, species composition and the occurrence of noxious weeds (PALLUTT and GRÜBNER 2004). Additionally, changes in the soil organic matter content and different steady-state-situations, with consequences for the nitrogen turnover, will take a number of years to develop (KÖRSCHENS 1992, CAMPBELL *et al*. 2000, HÜLSBERGEN 2002). Once a new steady-state in the organic matter balance has been established, sound quantifications of the effect of the husbandry on the nitrogen efficiency are possible (HÜLSBERGEN 2002).

In order to establish strategies for an economically successful and ecologically sound application of pesticides, a long-term field experiment was set up in 1995 at the experimental site of the Federal Biological Research Centre for Agriculture and Forestry (BBA) "Dahnsdorf" in the state of Brandenburg, Germany. In a complex field trial, the effect of a situation-related herbicide application was compared with a 50 percent reduced herbicide rate. With the experimental design chosen it was possible to quantify the long-term effects of the different application strategies on population dynamics of weeds as well as yields and the nitrogen efficiency. The nitrogen efficiency was calculated by using the indicator nitrogen balance.

## Materials und Methods

The experimental site "Dahnsdorf" is located in the German state Brandenburg. The soil is of moraine origin of the Saale glacial period, and is covered by sandy loess with great variation in depth. This is the reason for a high spatial variability of soil properties at the experimental site. The average soil characteristics were 57.9 % sand, 37.5 % silt, 4.6 % clay, 1.4 % organic matter and a pH of 5.8. According to the German classification system the soil had 48 points. The precipitation averaged 536 mm with prolonged dry periods at the end of spring and early summer. The average temperature was 8.4°C (PALLUTT 2002).

The experiment consisted of two different crop rotations:

- arable rotation: winter oilseed rape – winter wheat – winter rye – fallow (peas since 2002) – winter wheat – winter barley, with six replicates,
- fodder crop rotation: winter oilseed rape – winter barley – clover-grass-mixture – winter rye – silage maize – winter wheat, with four replicates.

The experimental design was a two-factorial split plot. The following treatments in cereals were compared:

Factor A: Intensity of pesticide application

- $a_1$ optimum = situation-related application of pesticides
- $a_2$ extensive = 50 % reduced application rates compared to $a_1$

Factor B: Type of pesticide treatments

- $b_1$ untreated control (C)
- $b_2$ herbicide (H)
- $b_3$ fungicide (F)
- $b_4$ herbicide + fungicide (HF).

Each rotational field in the experiment had the size 800 $m^2$ (25 m x 32 m). It is split according to the two levels of factor A (intensity of pesticide application). The area for factor B was 80 m², whereas the harvest area for each plot was 44 m².

The occurrence of weeds affected by the different weed control strategies was evaluated as following:

- the weed coverage of dicots was assessed approximately four to six weeks after beginning of the growing season in spring,
- the number of *Apera spica-venti* panicles was counted on an area of 0.25 m² four times in each plot four weeks before harvest.

The comparison of the effect of the weed control strategies was always calculated between the respective treatments on the same level of factor A. The yield increase caused by herbicide application was calculated either with or without fungicide application. The calculations for the nitrogen balances were performed accordingly, using the model REPRO for all approaches (HÜLSBERGEN 2002). Nitrogen content of grains was measured every year in all treatments. The results were included in the calculations of the nitrogen balances as well as average depositions of nitrogen of 30 N $ha^{-1}$ $a^{-1}$. Another special feature of the REPRO approach is the link between the nitrogen balance and changes of nitrogen and organic matter content in the soil, with consequences for the nitrogen mineralization-immobilisation-turnover (MIT). The amount of mineral fertilization applied in the experiment was between 60 and 160 kg N $ha^{-1}$ (Tab. 1). Additionally, in the second experimental period (2002-2005) different sowing rates were tested.

Due to the different nitrogen fertilizer application rates, the statistical analysis was split for the two experimental periods 1997 to 2001 and 2002 to 2005. The grain yields and nitrogen balances were compared using a t-test on a yearly basis. The development of the yield differences was calculated in a linear regression approach by using "years" as an independent variable. The slope of the functions was also checked for significance by a t-test.

Tab. 1: Mineral nitrogen fertilization and sowing rates in cereals in the period 1997 to 2005

*Tab. 1: Mineralische Stickstoffdüngung und Saatmengen im Getreidebau im Zeitraum von 1997-2005*

| | Period | Optimum | Extensive |
|---|---|---|---|
| N-fertilization | 1997-2001 | 120-160 kg N $ha^{-1}$ | 60-80 kg N $ha^{-1}$ |
| | 2002-2005 | 100-120 kg N $ha^{-1}$ | |
| Sowing rate | 1997-2001 | Site specific | |
| | 2002-2005 | Site specific | + 20 % |

**Results**

The results of the treatment with an application of fungicides (F) as well as the combination of herbicide and fungicide applications (HF) on weed population are not shown, since no differences were tested with respect to the chemical weed control. This is also justified because differences in weed population between the untreated control (C) and an application of fungicides (F) as well between an application of herbicides (H) and the combination of herbicides and fungicides (HF) were not observed due to the corresponding weed control.

The number of panicles of *A. spica-venti* in the first period (1997 to 2001) was lower in the optimum treatment compared with the extensive treatment of the controls (Tab. 2). In contrast, in the following period (2002 to 2005) the number of panicles was lower in the extensive treatment with the exception of winter rye. The occurrence of dicot weeds was not affected by the treatments to a large extent. In all experimental years, the occurrence of weeds in the cereal crops was low after situation-related application of herbicides. A reduced herbicide application rate only slightly increased the coverage of dicot weeds in cereals, but significantly increased the coverage of *A. spica-venti*.

In the first period (1997 to 2001) a higher yield increase in the extensive treatment was observed compared with the optimum treatment (Tab. 3). However, winter wheat responded to the optimum treatment with corresponding yield increase. A combination of herbicide and fungicide applications had only small effects on the grain yields increase caused by herbicide application. This contrasts with the results of the second experimental period 2002 to 2005. All cereal crops showed a substantial yield increase after herbicide application. This was especially true for the situation-related (optimum) herbicide treatments. The yield increase of winter wheat and winter barley after herbicide application was larger in the plots additionally treated with fungicides.

Tab. 2: Panicles of *A. spica-venti* ($m^{-2}$) and weed coverage of dicot weeds (%) in cereals in the period 1997 to 2005

*Tab. 2: Rispen von* A. spica-venti *($m^{-2}$) und Deckungsgrad dikotyler Unkräuter (%) im Getreide im Zeitraum von 1997-2005*

| Intensity of treatment | Panicles of *A. spica-venti* $m^{-2}$ | | | | Weed coverage of dicots (%) | | | |
|---|---|---|---|---|---|---|---|---|
| | Optimum | | Extensive | | Optimum | | Extensive | |
| Treatment | C | H | C | H | C | H | C | H |
| Winter wheat | | | | | | | | |
| 1997-2001 | 38.5 | 1.8 | 88.0 | 26.3 | 13.6 | 0.3 | 15.1 | 2.1 |
| 2002-2005 | 136.5 | 7.5 | 103.4 | 23.4 | 10.1 | 0.3 | 11.3 | 0.9 |
| Winter barley | | | | | | | | |
| 1997-2001 | 32.8 | 2.3 | 84.3 | 17.3 | 17.6 | 0.1 | 17.9 | 0.4 |
| 2002-2005 | 155.3 | 4.0 | 133.1 | 46.8 | 11.5 | 0.6 | 11.9 | 0.9 |
| Winter rye | | | | | | | | |
| 1997-2001 | 37.0 | 3.1 | 67.1 | 31.9 | 10.3 | 0.9 | 9.9 | 2.1 |
| 2002-2005 | 67.2 | 2.9 | 66.2 | 11.4 | 8.5 | 0.5 | 8.1 | 1.1 |

Tab. 3: Yield increase caused by herbicide application affected by the interaction of herbicide and fungicide treatments in t per ha

*Tab. 3: Herbizidbedingter Mehrertrag ohne und mit Fungizidanwendung in t $ha^{-1}$*

| Intensity of treatment | Herbicide application, without fungicides | | | Herbicide and fungicide applications | | |
|---|---|---|---|---|---|---|
| | Optimum | Extensive | t-test significant | Optimum | Extensive | t-test significant |
| Winter wheat | | | | | | |
| 1997-2001 | 0.68 | 0.74 | 0*/5 years | 0.75 | 0.80 | 1*/5 years |
| 2002-2005 | 1.76 | 1.19 | 1*/4 years | 2.10 | 1.23 | 3*/4 years |
| Winter barley | | | | | | |
| 1997-2001 | 0.22 | 0.87 | 2*/5 years | 0.41 | 0.86 | 2*/5 years |
| 2002-2005 | 1.22 | 0.71 | 2*/4 years | 1.62 | 0.95 | 2*/4 years |
| Winter rye | | | | | | |
| 1997-2001 | 0.07 | 0.48 | 1*/5 years | 0.27 | 0.52 | 1*/5 years |
| 2002-2005 | 0.97 | 0.76 | 1*/4 years | 1.13 | 0.85 | 1*/4 years |

* Number of years with significant differences in the respective period, $p < 0.05$

No significant effect of herbicide application was found for the differences of yield increase in all crops except rye in the course of the two experimental periods (data not shown). During the first period from 1997 to 2001, no significant differences in yield increase over the course of time were observed for winter rye between the optimum and the extensive treatments (Fig. 1). There was, however, a tendency for larger yield increases in treatment with extensive herbicide application. This contrasts with the results from the second experimental period (2002 to 2005). While functions start approximately at the same level, the slope of the yield increase in the optimum herbicide treatment was significantly larger.

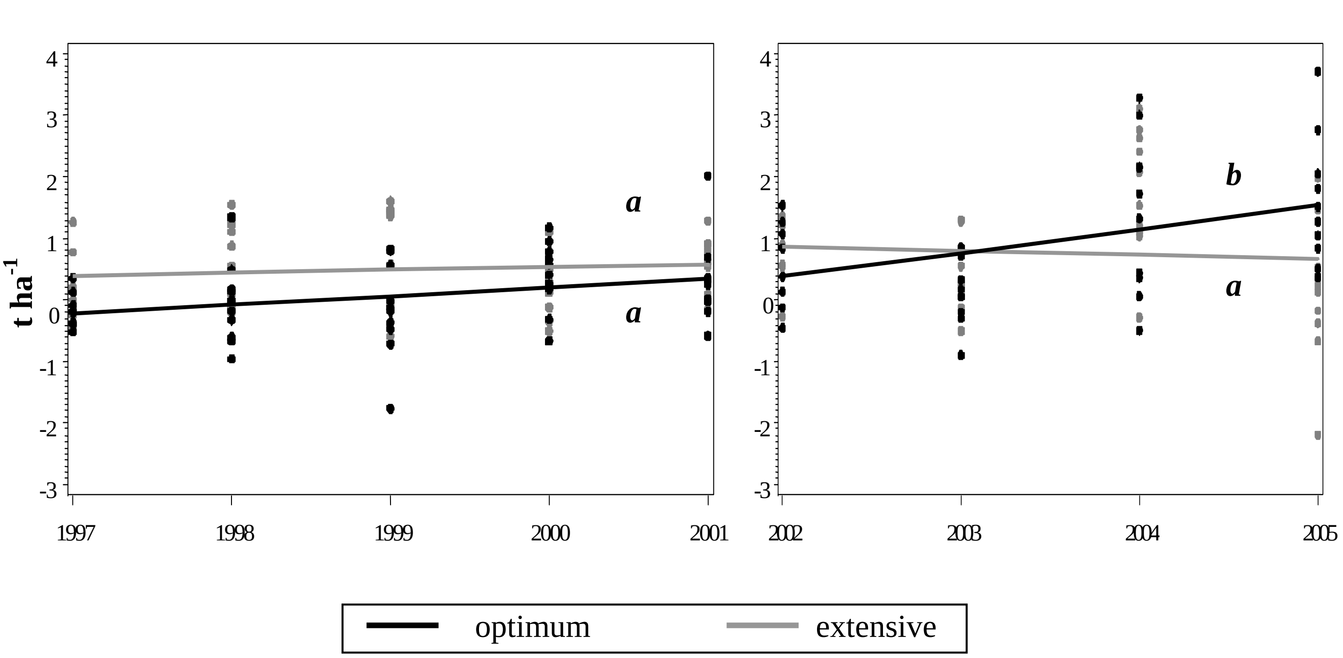


Fig. 1: Time course of yield increase in winter rye affected by herbicide application rate from 1997 to 2005; slopes of the yield increase with the same letter are not statistically different (p < 0.05).

*Abb. 1: Entwicklung der Mehrerträge durch Herbizidanwendung in Abhängigkeit von der Aufwandmenge im Zeitraum von 1997-2005 bei Winterroggen. Anstiege der Funktionen mit gleichem Buchstaben sind statistisch nicht unterscheidbar (p < 0,05).*

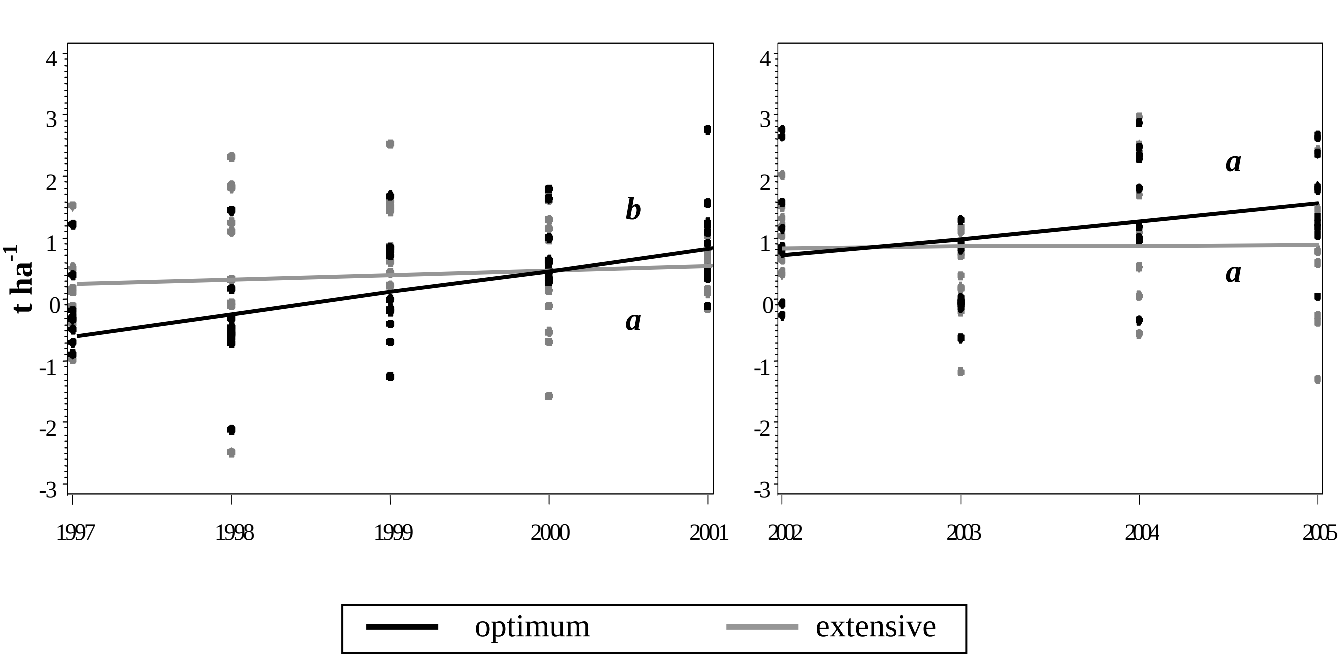


Fig. 2: Time course of yield increases in winter rye after herbicide application affected by application rate and the interaction with fungicide treatments from 1997 to 2005, slopes of the yield increase with the same letter are not statistically different (p < 0.05).

*Abb. 2: Entwicklung der Mehrerträge durch Herbizidanwendung in Abhängigkeit von der Aufwandmenge und einer Fungizidbehandlung im Zeitraum von 1997-2005 bei Winterroggen. Anstiege der Funktionen mit gleichem Buchstaben sind statistisch nicht unterscheidbar (p < 0,05).*

In the treatment with fungicide application additionally to herbicides, the development of yield increase over time was larger in the optimum treatment over the period 1997 – 2001 compared with the extensive treatment (Fig. 2). There were no significant differences in the development of yield in the different treatments for the 2002 – 2005 period.

The herbicide application to winter barley and winter rye reduced the nitrogen balance to a small extent in the period 1997–2001 (Tab. 4). With exception of winter wheat, the nitrogen balance was relatively more reduced in the extensive treatment, which corresponds with the results of the effect on yields shown above. In the second period (2002 – 2005) the reduction in the nitrogen balances was more pronounced after herbicide application in all cereal crops. This was especially evident in the optimum herbicide treatments. Averaged over the different experimental years, this effect was most important in wheat and barley especially in combination with a fungicide application and occurred with a greater magnitude after situation-related (optimum) pesticide application.

Tab. 4: Decrease of nitrogen balance caused by herbicide application affected by the interaction of herbicide and fungicide treatments in kg N $ha^{-1}$

*Tab. 4: Herbizidbedingte Verringerung des N-Saldos ohne und mit Fungizidanwendung in kg N $ha^{-1}$*

| Intensity of treatment | Herbicide application, without fungicides | | | Herbicide and fungicide applications | | |
|---|---|---|---|---|---|---|
| | Optimum | Extensive | t-test significant | Optimum | Extensive | t-test significant |
| Winter wheat | | | | | | |
| 1997-2001 | 13.2 | 11.5 | 0*/5 years | 12.9 | 12.0 | 1*/5 years |
| 2002-2005 | 32.2 | 19.8 | 1*/4 years | 37.1 | 22.3 | 3*/4 years |
| Winter barley | | | | | | |
| 1997-2001 | 6.8 | 9.4 | 0*/5 years | 6.5 | 8.5 | 1*/5 years |
| 2002-2005 | 27.7 | 15.8 | 3*/4 years | 33.6 | 18.7 | 2*/4 years |
| Winter rye | | | | | | |
| 1997-2001 | 1.7 | 4.2 | 1*/5 years | 2.8 | 3.5 | 2*/5 years |
| 2002-2005 | 17.1 | 9.9 | 1*/4 years | 17.7 | 13.4 | 1*/4 years |

* Number of years with significant differences in the respective period, $p < 0.05$

## Discussion

In the first experimental period 1997 – 2001, differences in weed density and species composition between the control treatments of the extensive and the optimum treatment are caused by differences in the nitrogen fertilization (Tab. 1). The crops could not compete well with the weeds in the extensive treatments due to the low fertilizer applications compared with the optimum treatments. In the second experimental period (2002-2005), similar effects were caused by differences in sowing rates. Although the nitrogen dressing was identical in the extensive control and the optimum treatment the number of *A. spica-venti* plants was slightly lower. This has been caused by the higher seeding rate and a consequently better competition of the crops in the extensive treatment. This result is in accordance with reports by COURTNEY (1991) und MEINLSCHMIDT (1997). Also PALLUTT (2000) emphasised the importance of the competitive ability of crops for weed growth and development.

Averaged over the optimum and extensive treatment, the weed coverage of dicots was less affected. Competition was therefore not different in the treatments. Even a reduced herbicide application showed a sufficient effect on dicot weeds due to the low occurrence at the beginning of the field experiment. This was not true for the monocot weed *A. spica-venti*. A further increase in number of panicles per m² could not be controlled by a reduced herbicide application rate.

An important consequence of a long-term reduction in herbicide application rates is the shift of the weed population to increasingly noxious weeds. Depending on the number of noxious weeds at the start of the weed control strategy, however, it may take more than ten years until such a development occurs (PALLUTT and GRÜBNER 2004). A higher weed infestation in the cereal crops occurred in the extensive treatment from 1997 to 2001, due to less competitive ability. This was the reason for the higher yield increase after reduced herbicide application compared with an optimum application and agrees with results from PALLUTT (2000), who has reported a larger increase after herbicide treatment in crops with smaller competitive abilities.

In contrast, in the second period (2002–2005) the yield increase was larger after the optimum treatment compared with the extensive treatment. This probably was mainly due to the fact that the weed population density increased sharply in the control treatments. The results contrast the study of OERKE and STEINER (1996) who have found yield reduction of between 16 to 18 percent without herbicide application in the first experimental year. This difference might be caused by the low original weed population density at the experiment site "Dahnsdorf". Additionally, a strong increase of noxious weeds was observed after a long-term reduction in herbicide application rates especially *A. spica-venti, Matricaria* spp., and during the last years also *Centaurea cyanus.*

An additional fungicide application did not cause significantly higher yield increases after herbicide application in the first experimental years. This is in contrast to the results from the second experimental period. From 2002 to 2005, especially in winter wheat and winter barley, the yield increase after herbicide application was more pronounced in plots treated with fungicides. There are two explanations for this interaction. An early herbicide application reduces the inter-species competition between crops and weeds and thus increases the tillering and biomass of cereals. On the other hand, fungicide treated crops have a higher yield potential, remain green for a longer time during the summer and therefore benefit from less competition with weeds. Results from PALLUTT (2002) also demonstrate that *A. spica-venti* might directly benefit from a fungicide treatment. The competitive ability of the weed is increased and consequently a higher number of panicles after a fungicide treatment was found.

The development of the crop yields in the experiment clearly indicates that the effects of a reduced pesticide and, in particular, herbicide strategy require long-term experiments for surveying. It was possible to increase yield with a reduced herbicide application in crops with low competitive capacity - extensive treatment in our experiment – as shown in the first years of the field trial. However, this is a sharp contrast to the results of the second experimental period due to the problems with noxious weeds like *A. spica-venti*. It was not possible to control the noxious weeds with the reduced application rates in the second period of the experiment. Therefore, the yield increases following the situation-related herbicide application were larger. In such a complex situation, short-term experiments would give inadequate results and lead to an underestimation of the effect of reduced herbicide application strategies. The yield trends in the second experimental period indicate an advantage of the situation-related herbicide treatment compared with the reduced herbicide application rates. This effect occurred earlier if herbicide and fungicide treatments were both applied. Short-term experiments would substantially underestimate the effect of a reduced herbicide application rate. A quantification of the interaction of fungicide and herbicide treatments based on a short-term experiment is therefore not recommended.

The effects of the different herbicide and fungicide treatments on crop yields correspond with changes in the nitrogen balances. During the first experimental period, the effect of different herbicide application strategies on the nitrogen balance in cereals was negligible, apart from a small reduction in the extensive treatment due to a small yield increase. This yield effect, however, did not completely translate into differences in the nitrogen balance, because grain nitrogen content was lower in the extensive treatment. In the optimum treatment higher grain nitrogen content consequently caused a higher nitrogen uptake, though yield increases were not different. During the course of the experiment, the nitrogen balances were significantly decreased in the treatment with the situation-related herbicide application based on population dynamics and weather conditions. Similar results have been reported by HANUS and FAHNERT (1987), who observed a reduction of the nitrogen balance in wheat and barley by 40 to 80 kg N $ha^{-1}$ following a fungicide application. Based on the results presented in this study and reports by other authors it can be concluded that the application of pesticides can decrease the nitrogen balance and thus reduce the risk of nitrogen pollution in ground water.

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