INFORMATION

Long-term field experiments – museum relics or scientific challenge?

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ABSTRACT

By reference to the Eternal Rye trial in Halle, Germany, as an example, it is demonstrated that long-term trials provide indispensable information for contemporary and future land use research. These trials serve as tools for the examination of cultivation measures or the effects of climate on nutrient dynamics and mobilization, microbial biodiversity, mineral composition or soil formation processes. They are therefore essential for the evaluation of land-use strategies or climatic change and, because of that, can provide more accuracy in related political considerations.

Keywords: long-term fertilization trials; biodiversity; soil formation; nutrient dynamics; Eternal Rye trial

The soils of our planet are the basis of human existence because 98% of all food originates from terrestrial ecosystems. This fact has to be considered in relation to an annual decrease of utilizable land of about 10 million ha, due to erosion, desert formation, and the development of buildings, roads, industrial estates, etc. set against a simultaneous increase in world population which is expected to rise to at least 8.5 billion by 2020 (Powlson et al. 1997). A diminishing soil area has thus to satisfy an ever increasing population. A fundamental precept of global agricultural policies is thus to maintain significantly higher productivity using fewer resources while preserving the functioning of the soil as a living space – probably even under changed climatic conditions (global change).

Scientific research has to provide results to support decisions in agricultural and ecological policies. This requires a thorough understanding of how soils and agricultural ecosystems respond to different forms of land management and fertilization as well as to climatic factors. Such knowledge can be gained exclusively from long-term field experiments since the effects of human activity and of a change of natural conditions can be seen only gradually due to the buffering of ecosystems (Körschens 2006).

On the other hand in recent years the value of these long-term trials has been questioned. It has been argued that such experiments should be discontinued because the original questions posed have been answered and that the trials now represent museum relics of low scientific value.

The aim of this article is to discuss these questions using the Eternal Rye trial (Ewiger Roggen) in Halle, Germany, as an example.

ORIGINAL REASONS FOR THE ESTABLISHMENT OF LONG-TERM FERTILIZATION FIELD TRIALS

Almost 150 years ago, very different opinions were held about optimal nutrient supply to ensure high yields while maintaining soil fertility ("sustainable plant production").

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The view of Albrecht Daniel Thaer (1752–1828) that plants subsist on humus ("humus theory") stood in strong contrast to the "mineral theory" of Justus Liebig (1803–1873). Liebig considered a plant to be a "chemical factory" where increasing input of "raw materials" (i.e. nutrients in form of minerals) increases production (i.e. yields). A second controversy concerned the nitrogen nutrition of plants. While Liebig considered that atmospheric nitrogen provided the N source of plants, Gilbert and Lawes from Rothamsted (England) supported the idea that plants absorb nitrogen from the soil or fertilizers.

To examine these questions, long-term fertilization field trials were established in Europe to compare the effects of farmyard manure and mineral fertilizing. The first ones were in Rothamsted north of London (1843) (today under the Queen's patronage) and the Eternal Rye trial (1878), laid out by Julius Kühn in Halle (Merbach and Deubel 2007), followed in 1902 by the Static Fertilizing trial in Bad Lauchstädt (Körschens and Pfefferkorn 1998), and later (1948/49) by the Schmalfuß Long-Term Fertilizing trials in Halle (Merbach et al. 2000).

In the following section we concentrate on the Eternal Rye trial.

THE ETERNAL RYE TRIAL IN HALLE, GERMANY

Site and natural conditions

The Eternal Rye fertilization trial in Halle is located in the south of federal state Saxony-Anhalt (in German Sachsen-Anhalt, Figure 1) at the Julius-Kühn-Field, named after its founder.

Geographically, the region belongs to the eastern foreland of the Harz Mountains. The experimental side is situated on a plain (110–115 m above sea level, 51°30.8'N, 11°59.9'E), which extends east of the river Saale and Götsche valley (75 m above sea level) over the Petersberg (250 m above sea level) to the Reide lowlands in the north-eastern direction.

The Julius-Kühn-Field is located at the edge of the loess-chernozem region, which connects the chernozems of the Thüringer Becken (near by Erfurt) with those of the Magdeburger Börde (Figure 2). Accordingly the loess cover contains a relatively large amount of sand (45–80%) and has a depth of only 0.8–1.2 m (Altermann and Mautschke 1972). This so-called sandy loess accumulated during the Weichsel Ice Age on glacial till from the Saale Ice Age (Laatsch 1938), together with underlying sandy material, forms the basis of the plateau. Between the sandy loess layer and the glacial till there is a salient floor with stones.

The average annual precipitation of 494 mm (1878–1995) is accompanied by a potential evaporation of 450 mm, thus preventing the formation of much ground water. Precipitation is summer dominant, with 70% of the rain during the main vegetation months. The average annual air temperature (1879–1995) was 9.2°C.

Due to human activity the region has almost no forests and is largely dominated by arable farming. Further determining elements of the site are the vicinity to cities and industrial plants, in particular the concentration of chemical industry (Chemical Triangle Leipzig-Halle-Bitterfeld), which affects the environment in various ways. For example in the vicinity of power plants up to 70 cm of fly ash was deposited during the peak times of the

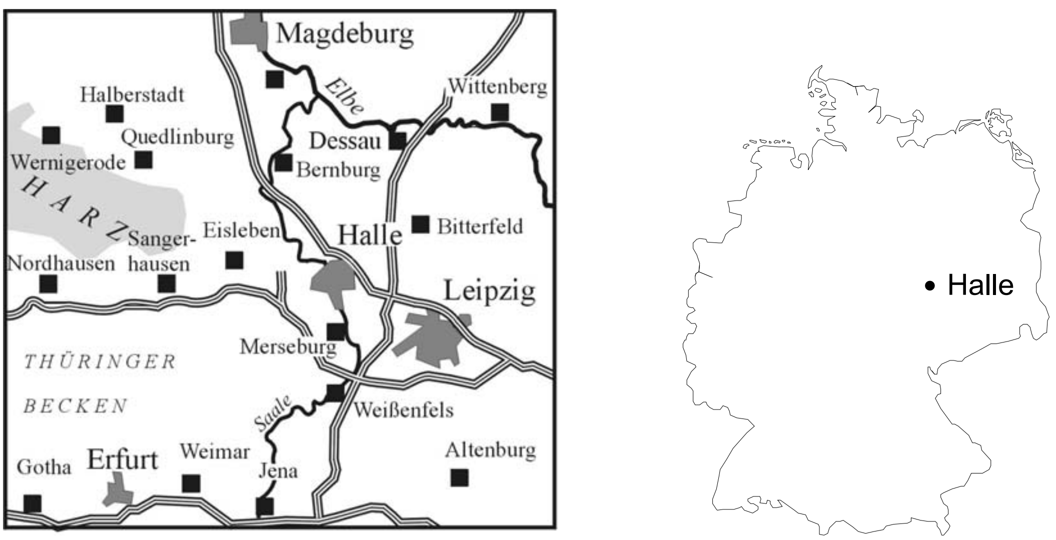

Figure 1. Map of the geographical position

Figure 2. Distribution of central German chernozems (adapted from Stremme 1936)

industrial use of brown coal in the second half of the 20th century (Enders 1995).

The soil is classified as Haplic Phaeozem (according to FAO) with an A horizon of about 60 cm. It is characterized as loamy sand in the 0–80 cm layer and as somewhat loamy sand from 80 to 100 cm. The humus content in the top horizon varies between 2.1 and 2.6%. For details see Merbach and Deubel (2007).

Aims and experimental design

The Eternal Rye trial, established as a monoculture, investigates the long-term effects of different mineral and organic fertilizers on yield and soil. It originally consisted of five, later six, plots of 1000 m^2 each. Figure 3 shows the fertilization variants tested up to 1989/90 (without replications).

The following changes took place after harvesting in 1990. The mineral N application was increased from 40 to 60 kg/ha thus aligning it with the N supply by farmyard manure (FYM I). At the same time the farmyard manure application in FYM I was changed to doses containing exactly 60 kg/ha N (approx. 12 t/ha FYM). After a single very high PK application (200 kg/ha P as triple superphosphate, and 400 kg/ha K as KCl), N treatment was replaced by a combined FYM and mineral fertilization in the amounts of the variants FYM I and NPK (120 kg/ha N).

Figure 3 demonstrates how, after the harvesting in 1961, the trial was divided into three parts. In the southern part (section C), rye monoculture was continued, in the central part it was changed to a potato-rye rotation (section B), and in the northern part to maize monoculture (section A). Fertilization remained unaltered. As a consequence, the trial programme was enriched by an additional factor since different yields and root residues, different vegetation periods and crop husbandry were likely to affect the humus content of the soil.

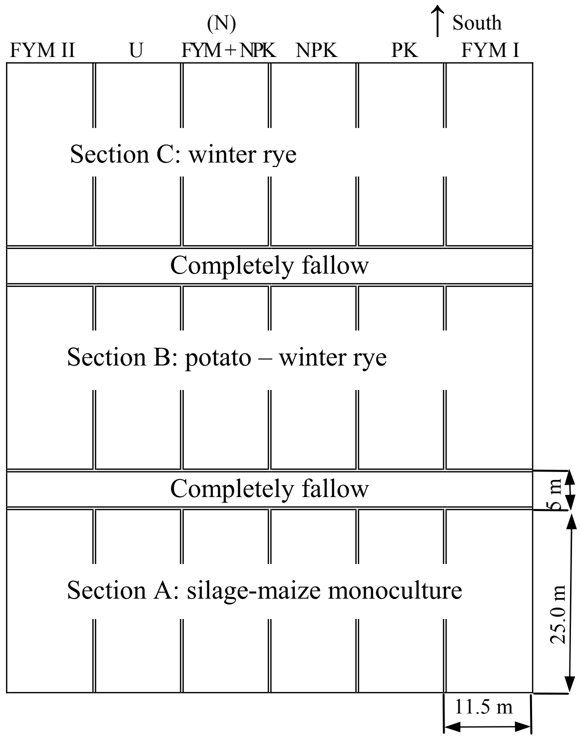

Figure 3. Lay out of the Eternal Rye trial since 1961: fertilization treatments, different rotations, and fallow paths between them

FYM II: Annual farmyard manure (FYM, 8 t/ha) 1893–1952, then unmanured; U: no fertilization; N: exclusively N fertilization (40 kg/ha N), in 1990 replaced by FYM + NPK (see text); NPK: mineral fertilization (40 kg/ha N, 24 kg/ha P, 75 kg/ha K); PK: exclusively P and K fertilization (24 kg/ha P, 75 kg/ha K); FYM I: annual FYM (12 t/ha)

1878–1948 mineral N as NH_4^+, 50% in autumn, 50% in spring; since then 15 kg/ha as ammonium sulphate in autumn, the remaining part as calcium ammonium nitrate in spring

Until 1925 mineral P as basic slag, later superphosphate/triple superphosphate

Until 1925 mineral K as kainite, since then granulated KCl

Table 1. Yields at Eternal Rye 1991–1998 (Merbach and Schmidt 2002)

Treatment	(t/ha)	(%)
FYM I (12 t/ha manure)	4.85	100
NPK	5.22	107
PK	2.91	60
Without fertilizer	1.43	49

Selected results after 130 years experiment duration

The long-term effect of different fertilizing on crop yield is shown in Table 1. Without fertilizing, yields decreased rapidly. With equivalent supply of nutrients, the same yields were realized with mineral N as well as N from organic manure. Further, plants (except legumes, not examined in this trial) absorb N from soil and fertilizer and are not able to subsist on air nitrogen.

Mineral fertilizing (NPK) and, more significantly, manure increased soil carbon contents, whereas the soil carbon contents decreased in the variant without fertilizer application (Table 2). This demonstrates the role of fertilization in humus formation. The adjustment of an "equilibrium" (constant C content) obviously took a long time (100 years, according to Table 2).

The long-term-effect of fertilization is shown in Figure 4. It is visible that an earlier supply of 8 t/ha/year manure over several decades positively affects the grain yields of winter rye. In 1993 (that is 40 years after the discontinuation of manure supply), the yields were still 20–30% higher than at the variants without fertilization. This is obviously an effect of the further mineralization of the accumulated organic soil (N) substance.

As an interim summary it should be pointed out that with equivalent nutrient supply, mineral fertilization equals farmyard manure. In respect to soil organic matter, manure is more effective. Cultivation measures affect soils and agroecosystems only in the very long term. New steady-states (input = output) have been established only after many decades. Hence, the results show the importance of long-term field trials for the evaluation of effects of fertilization and cultivation strategies and, because of that, for the provision of sound advice in policies, as for example when considering organic versus conventional farming.

At least at this point the question is put whether the continuation of the long-term fertilization trials would make sense or, moreover, could be justified. The original questions would be answered by now and so the purpose of the trials disposed. At the outmost, it would be possible to preserve one or another of these trials as museum pieces in the history of science – which is very often at the same moment doubted for financial reasons.

NECESSITY OF CONTINUATION OF LONG-TERM TRIALS

Of course, a trial like the Eternal Rye is valuable for the history of science and culture and contributes by its very existence to the international reputation of the agricultural sciences (in this case in Halle). But in addition – and this will be proved with a few examples from the Eternal Rye trial – long-term trials are essential for research and teaching.

They serve as objects of teaching and demonstration for students and the public

That includes, among others:

(i) demonstration of symptoms of nutrient deficiency and surplus under field conditions and of effects of

Table 2. Changes in soil C contents (%) at Eternal Rye in Halle (section C = rye, 0–20 cm depth, modified from Merbach and Schmidt 2002)

Year	Duration of trial	FYM I	NPK	U
1878	0	1.24	1.24	1.24
1929	50	1.64	1.24	1.15
1954	75	1.68	1.26	1.12
1984/1987	108	1.73	1.41	1.29
1993/1996	118	1.73	1.33	1.13

U – no fertilization

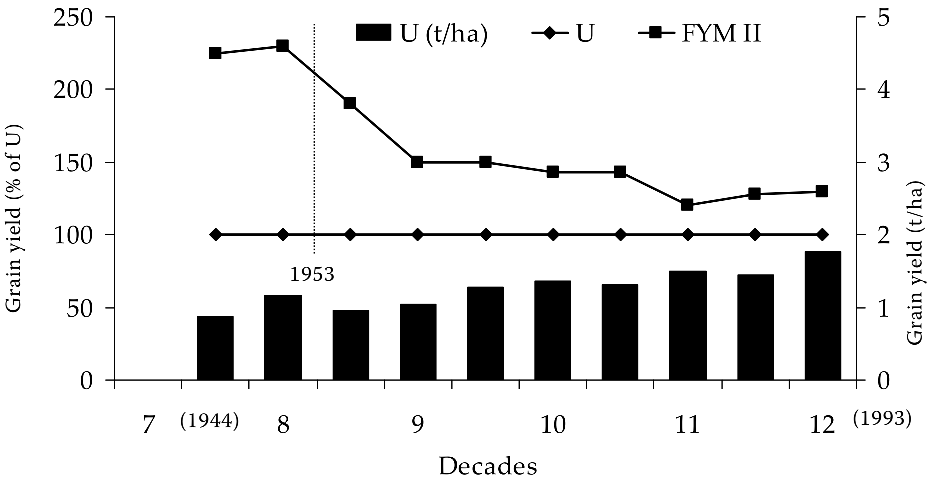

Figure 4. Average relative grain yields (86% dm) of the treatments U and FYM II before and after the cessation of manure fertilization, Eternal Rye (Schliephake et al. 1999, modified)

different fertilization for use in student education as well as for national and international visitors;

(ii) supply of analysis substances for laboratory practice, evaluation of methods for soil and plant analysis, experimental basis for diploma and doctoral theses and postdoctoral studies.

They are basic for examination and quantification of cultivation-based changes in agroecosystems

This can be realised, for example, by changing fertilization or crop rotation after the adjustment of an equilibrium (input equals output) and by measuring the subsequent effects on soil or the agroecosystem.

For example, the introduction of potato as "humus reducing crop" and (less significant) of corn in 1961 into the then existing pure rye culture resulted in a decrease of soil C contents at all fertilization variants (Table 3).

Table 3. Changes of humus C contents in soil (%) 45 years after switching from rye to corn or to rye/potato (modified by Merbach and Schmidt 2002)

Variant of fertilization	Potatoe/ rye	Corn monoculture
FYM I	1.73→1.53	1.73→1.63
U	1.29→1.07	1.29→1.11
NPK	1.33→1.17	1.33→1.24

U – no fertilization

Further, the transformation of the pure N treatment (without PK supply) to a NPK + manure treatment in 1990 resulted as expected in a rapid yield increase (+12% within one year), but C and N contents still continue to change.

They serve as tools for explaining the processes during soil formation

The Eternal Rye trial combined with the parallel Schmalfuß soil formation trial in the object Adam-Kuckhoff street (compare Merbach et al. 2000, Merbach and Deubel 2007) was the reference location for the examination of soil formation processes during the DFG (German Research Foundation) funded focus programme 1090 ("Soils as Source and Sink of CO_2 – Mechanisms and Regulation of the Stabilization of Organic Substances in Soils"). Among other factors, the implementation of plant residues into organic soil C fractions was examined. For this purpose, that part of the Eternal Rye experiment was used, in which in 1961 rye was replaced by corn. The higher natural ^{13}C abundance of corn (C_4 plant) was used to measure the implementation of corn residues into the organic soil substance. It turned out that after 40 years only 15% of the organic substance in the topsoil and approximately 3–5% in the subsoil was derived from corn. However, the comparative percentage was much higher in the soluble organic C (33%) and in soil respiration (58%) (Table 4).

This means that younger harvest residues and root residues (here from corn) are very slowly built in into the stable organic substances, and that,

Table 4. Origins of soil organic matter (SOM) 40 years after switching from rye to corn (g/m^2, percentages in brackets) (Flessa et al. 2000, Merbach and Deubel 2007)

C-fraction	Total SOM	From rye before 1961	From corn after 1961
Total C	4790 (100)	4080 (85.2)	706 (14.8)
Soluble C	1.10 (100)	0.77 (70.0)	0.53 (30.0)
CO_2-C	18.0 (100)	7.6 (42.2)	10.4 (57.8)

the mineralization of the "inert", older organic substances (here from rye) takes place at an even more slower rate. According to the latest results of Wiesenberg et al. (2004) the complete substitution of rye originated C by (silage) corn originated C in alkanes and fatty acids in soil organic matter would take approximately 50–60 years and of the complete organic soil substance approximately 250 years (Figure 5).

They can be used as tools for examining the effects of different fertilization on the microbial biodiversity of soils

This usage was examined by GSF Oberschleißheim (Germany) within the DFG (German Research Foundation) funded focus programme as mentioned above (Selesi et al. 2005). It was tested how the NPK and manure variants affect the diversity of C autotrophic bacteria, whereas the variant without fertilization was used as reference. Genes of the large subunit of RUBISCO (that is, the enzyme of the CO_2 assimilation of C_3 types) were used as functional "marker". The DNA (desoxyribonucleic acid) extracted from soil was amplified, the PCR products were cloned, the clones were screened by restriction fragment length polymorphism or their DNA sequences, respectively (Selesi et al. 2005). In contrast to the widespread view that fertilization decreases biodiversity, it was shown that the diversity indices (data not shown) as well as the number of sequences per clone (Figure 6) had been increased by fertilization.

They make it possible to evaluate the effects of long-term different intensity of fertilization on nutrient dynamics and mineral composition of the soil

Both the potassium fertilization trial (Schmalfuß) and the Eternal Rye trial show that a long-term K deficiency not only negatively affects the soluble and exchangeable K^+ because of the K removal through harvest, but also the potassium fixed in clay minerals. In this place, NH_4^+ can be deposited in the interlayers of clay minerals (Table 5), which might lead to decreased N fertilization efficiency. Simultaneously, the contents of illite decreased in favour of smectite of possible detriment to soil structure (Leinweber and Reuter 1989). A surplus of potassium leads to a larger amount of fixed K and decreases the fixation of ammonium (Table 5).

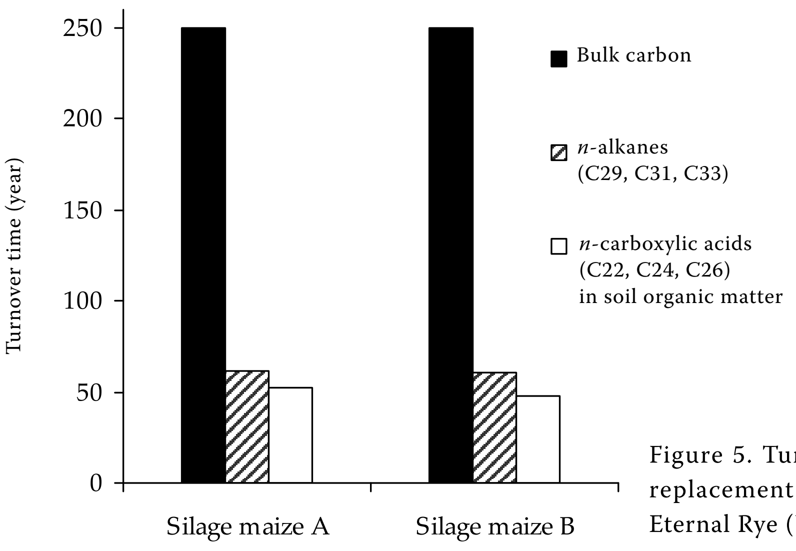

Figure 5. Turnover time calculations of a complete replacement of rye-derived C by corn-derived C at Eternal Rye (Wiesenberg et al. 2004, shortened)

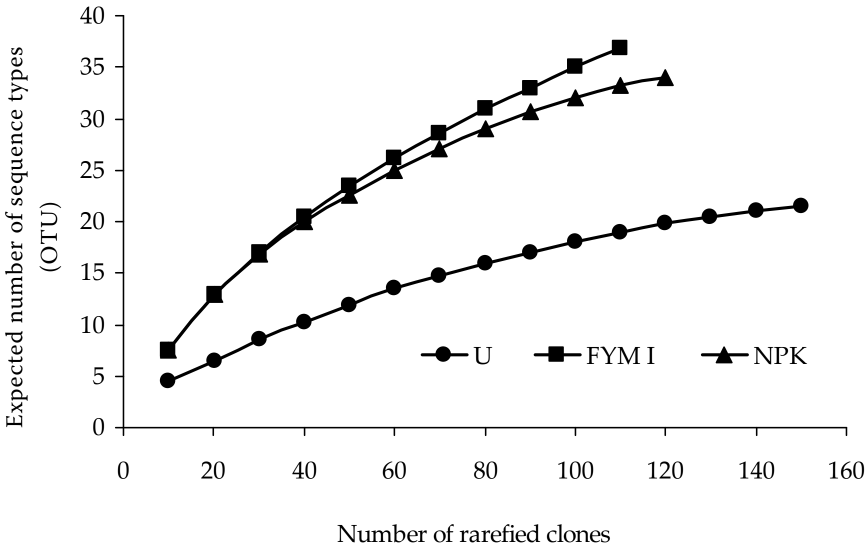

Figure 6. PCR analysis of RUBISCO forming genes (large subunit) of C autotrophic soil bacteria with different long-term fertilization, Eternal Rye (Selesi et al. 2005)

Long-term fertility trials enable the estimation of nutrient release from soil as well as nutrient mobilization by plant roots in order to include such dynamic processes in the determination of fertilization demands

Questions of nutrient dynamics were considered in many publications, especially concerning phosphorus (Gransee and Merbach 2000, Deubel et al. 2002, Gransee 2004). For example, in the P long-term fertilization trial at Julius-Kühn-Field Halle always more total P was found in the topsoil than that expected after P removal by plants. The reason for this fact is that the root incorporates P from the subsoil and, moreover, acquires sparingly soluble phosphate directly or indirectly through microbes (Deubel et al. 2000), especially under P deficiency. P deficiency enhances the release of organic acids by roots and microbes that favour P acquisition by dissolving poorly soluble phosphates. These results could be used to modify the determination of plant available soil P since the common DL (double lactate) method does not sufficiently reflect plant available P under these conditions (Gransee 2004).

The results illustrate that multi-disciplinary study of the processes in different long-term trials contributes to a better understanding and forecasting of long-term effects of cultivation changes on the substance dynamics in the soil-plant-system as well as of the processes of soil formation. This leads to a scientifically based evaluation of long-term effects of land use strategies which could contribute to more accuracy in political decisions in terms of lasting effects. Alone this fact already demonstrates the necessity of continuing the (Halle) long-term trials instead of only preserving them as a kind of scientific cultural monument. They therefore should be continued and, where necessary, cautiously modified.

Table 5. Influence of long-term different K supply on the amounts (mg K/kg soil) of fixed K^+ and of NH_4^+ and the composition of clay minerals (field C, potassium long-term fertilization trial: compare Garz et al. 2000; Eternal Rye: compare Leinweber and Reuter 1989)

Parameter	K-fertilization level		
Potassium long-term fertilization trial (kg K/ha/year)	0	125*	245
Fixed K^+	–15.3	529	+118
Fixed NH_4^+	+139	278	–114
Eternal Rye (kg K/ha/year)	0	75*	
Illite (%)	52	58	
Smectite (%)	14	6	

*K input by fertilization nearly equal to K removal by harvest

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