

# Grassland renovation and consequences for nutrient management

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## ABSTRACT

Sward degradation is a serious threat to the functioning of grassland and the provision of ecosystem services. Renovation measures are frequently applied in order to restore degraded swards. However, the success is highly variable and substantial tradeoffs are often found following renovation such as among agronomic and environmental services. Starting from a general classification of renovation measures the paper investigates the processes induced by renovation that lead to a change of the vegetation and that affect carbon and nitrogen fluxes. These processes are strongly interrelated and dependent on site, climate and management condition as well as on the time scale. The more an existing and degraded sward is deliberately disturbed prior to a renovation measure, e.g. by ploughing, the larger will be the vegetation change, the potential yield and quality advantage but also the risk of soil organic carbon release and nitrogen emissions to the environment. Such effects are unlikely to maintain in the longer term. This demonstrates that the renovation of swards is always the second best solution if there is the opportunity to avoid degradation by a proper grassland utilization.

**Key words:** Carbon, Nitrogen, Reseeding, Sward improvement, Vegetation.

## Introduction

Grasslands are expected to provide multiple services among which the production of energy, protein and structural carbohydrates for feeding livestock plays a pivotal role. From a global perspective, there are natural grasslands, mainly in Asia, the Americas and Africa, and there are mostly man-made and maintained grasslands like in the temperate climates. From an agricultural point of view, grasslands are not just there, but are there for a purpose. While they are the basis of ruminant husbandry they contribute to the livelihood of around 800 million people (White *et al.*, 2000).

The way grasslands are managed and utilized follows the demands of livestock and is depending further on climate and soil conditions. Livestock density and feeding requirements vary broadly and accordingly the management intensity of grasslands is highly

variable ranging from transhumance and extensive grazing systems, mainly with goat and sheep, to intensive dairying with cattle.

Improving grasslands, and thereby livestock production, has always been a main aim of grassland utilization. Fertilization, introduction of valuable forage species and improved grazing practices are proven measures to make grasslands more productive. However, interference in a relatively stable system, which grasslands usually are, has consequences not only for soil and sward structure, but for nutrient cycling as well. An improved grassland sward might have a higher demand for nutrients and require an adapted balance. On the other hand, degradation and destruction of the soil-plant system, can result in decreased yields and in temporal or permanent losses of C and N and, consequently, affect the quality of the system and the environment. In the soil-plant system,

cycling of C and N is most important and directly links soil quality, environmental conditions, climate and the requirements of good grassland growth. Thus, this paper will focus on consequences of grassland renovation on the sward and on C and N cycling.

Grassland renovation or renewal is mainly a reaction to a decline in yield and nutritive value or damages to the sward. In general, grassland systems are rather stable compared to arable systems and they usually do not require regular maintenance efforts such as tillage and sowing. Yet, in time, sward composition and soil conditions may deteriorate through technical and weather impacts and their interaction with management, for example: wheel traffic, poaching, drought, suboptimal synchronization of N input and frequency of defoliation, under- or overgrazing. The system is then degraded. The intention of renovation is to bring grasslands back to the state of productivity which they once had. Renovation has, however, wider implications and other ecosystem services apart from production are also affected. Most of them are production related such as: maintenance of soil quality and reduction of erosion risks through soils being well covered and rooted by grasses; ensuring high surface and groundwater quality through effective nutrient use by grass swards; mitigating climate change through high carbon sequestration and low N<sub>2</sub>O emissions.

In the present paper, we investigate the issue of grassland renovation in an agronomical framework. Renovation measures are targeted to change the grassland vegetation in a way that its functioning is improved and reaches at least a level that it had before. The extent of intervention is depends on how much competition by the old sward needs to be decreased to ensure that i) the desired species

in the old sward get an advantage over the less valuable grass species, and ii) introduced new seed will be successfully established. The degree of disturbance will then directly affect the extent of changes to the soil structure and mineralization of C and N. Ploughing, for example, will completely destroy the existing soil structure and root system and, depending on water conditions and rainfall, lead to increased gaseous losses in form of CO<sub>2</sub>, N<sub>2</sub>O and leaching of NO<sub>3</sub>. Measures that disturb the soil structure and the soil-plant system less, usually lead to fewer emissions as well. The nutrient turnover processes that have been accelerated by disturbance can be slowed down and their effect mitigated by ensuring the establishment of a good sward that will immobilize N and C by building up yield, sward and root systems and soil structure. This makes grassland renovation, even in its extreme form of ploughing and reseeding, different from the transformation to arable land where the soil will be regularly disturbed by tillage and large quantities of C and N will inevitably be lost over a long period of time that can actually last decades.

The intention of the present review paper is to give a brief overview of renovation aims, measures and consequences for grassland services. We will set a framework for terms and definitions around grassland renovation. We will then provide principle considerations about the different processes that are induced and affected by renovation measures. Finally, we will analyse responses of vegetation, soil and nitrogen fluxes to renovation under practical farming conditions. Generally, the focus of the present review is on grassland in temperate climate. Yet, the conceptual framework for renovation, the classification of measures and the principles of vegetation and soil responses are certainly not restricted to temperate grassland.

## Terms and definitions

Within this review grassland renovation is seen as a target-oriented agronomic measure to bring a grassland sward (grassland system) back into a condition in which it can fully function and deliver the intended ecosystem services. In the first place, this is the quantity and quality of herbage, i.e. the agronomic performance. As grasslands are multifunctional, renovation may also be targeted at enhancing biodiversity, groundwater protection, soil conservation, climate change mitigation, or improved cultural service.

Prerequisite for renovation is a deterioration of the service. This failure in delivering the service is usually related to changes in the sward botanical composition. Vegetation cover may have gone down, light capturing is poor and so is the photosynthesis of the vegetation, weeds may have entered and occupied a relevant area of the sward. There is, however, often the situation that a grass sward is not deteriorated, but is low performing in the original status. We would not consider this as renovation but rather as improvement measure.

Terms like renovation, rejuvenation, reseeding, renewing, overseeding, ploughing-in, and break-up, among others, have all been related to interventions in the grassland sward in order to improve the conditions in some way, mainly for production. The term renovation is derived from the latin *renovare*, from *re-* 'again' and *novare*- 'make new', from *novus*, 'new'. Renovate means to make changes and repairs to (an old house, building, room, etc.) so that it is back in good condition (Merriam Webster dictionary, online 10.07.2015). Related terms like renew, restore, refresh, rejuvenate all mean: to make like new. Renew implies a restoration of what had become faded or disintegrated so

that it seems like new; restore implies a return to an original state after depletion or loss; refresh implies the supplying of something necessary to restore lost strength, animation, or power; renovate suggests a renewing by cleansing, repairing, or rebuilding; rejuvenate suggests the restoration of youthful vigor, powers, or appearance (Merriam Webster dictionary, online 10.07.2015).

We suggest to structure interventions in the grassland sward in two broad categories: (I) Improving the sward with hardly any interaction with the soil structure, retaining the old sward = (a) rejuvenation (no seed! - but improving drainage, pH, weeds, nutrient balance; avoid over- or undergrazing, reduce field tracking) and (b) oversowing. (II) Improving the sward and disturb soil to some extent. Within these two broad categories there are various transitions which are summarized in Table 1. Measures are grouped along a gradient of sward and soil disturbance. With increasing disturbance, the existing sward is more and more weakened and the competitive strength against the newly introduced seed is reduced. At the same time, the risk of temporal yield losses due to low establishment of introduced seed increases. Increasing sward and soil disturbance is usually also related to higher input costs.

## Grassland renovation - general considerations

### Grasslands - a stable system

Grasslands are complex ecosystems: different plants, mainly grasses, but also legumes, and herbs occur in mixed swards on a wide range of soils, water regimes and climatic conditions. This makes them distinctly different from arable land, where the intention is to plant and harvest single crops in a sequence and where the soil is ploughed or

**Table 1.** Strategies for sward renovation (adapted from Frame, 1992)

		Rejuvenation		Total reseedling		
		Partial reseedling	Surface methods			
		Retained	Partially replaced	Completely replaced	Cultivation methods	
		None	None or partial	Chemical	Physical	
Old sward		Retained	Partially replaced	Completely replaced	Completely replaced	
Destruction of old sward	None	None or partial	Chemical	Physical		
Soil cultivation	None or surface	None or minimum	or	None or surface	Tillage / Ploughed	
Herbicide	Selective	None or grass suppressants		Total sward destruction	Weed control, total sward destruction	
Methods	Improved management	Oversowing / direct drilling		Oversowing / direct drilling	Cultivation methods and drilling or broadcasting	
Seed	None	Reduced rates		Full rate	Full rate	

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Increasing disturbance of sward and soil  
 Decreasing competition from old sward  
 Increasing inputs and costs  
 Increasing risks of (temporal) yield losses

tilled regularly (Kayser, 2003). Permanent grassland, even when grazed, can be regarded as a relatively stable system with comparably greater amounts of organic matter, larger earthworm populations, a denser network of roots resulting in higher aggregate stability, more microbial biomass and a greater activity of various soil enzymes compared with arable fields (Whitehead, 1995). Soil conditions and nutrient cycling do not only differ between cut and grazed grassland, but are also dependent on fertilizer input and botanical composition of the sward. Even changing from a grass sward to a clover pasture will affect root distributions, worm population and result in changes in soil structure and chemical transport (Williams *et al.*, 2000). Grassland renovation or transformation into arable land will disturb this system and is likely to lead to larger losses of N and C.

### N and C cycling

Nutrient cycling is at the core of assessing the sustainability of forage farming systems. A comprehensive analysis and evaluation requires the consideration of a complex range of factors on different spatial and temporal scales and would involve the consideration of production conditions of imported feed stuffs (Taube *et al.*, 2014).

A number of processes are involved in the cycling of any nutrient through the soil, plant and animal components of a grassland system (Whitehead, 2000). These processes generally have the nature of conversion and/or translocation: insoluble forms turned into soluble forms in the soil, are taken up by roots, translocated and utilized by plants; followed by consumption and excretion in altered forms by animals; nutrients return to the soil through the decay and decomposition of plant residues

and animal excreta; reactions occur with inorganic and organic constituents in the soil (Whitehead, 2000). Generally, amounts of nutrients that are utilized in forage systems are much greater than the rather small amounts that leave the system with products like milk and meat (Aarts *et al.*, 1992; Whitehead, 1995; Aarts *et al.*, 2000). At the farm scale nutrient efficiency is thus depending on how well the cycling of nutrients within soil-plant-animal system is organized. Losses reduce the cost-effectiveness (profitability) of production, and as emissions from agro-ecosystems they contribute to environmental stress – pollution of atmosphere and surface and groundwater. The extent to which losses occur is to a great deal depending on management factors.

### **Carbon sequestration and greenhouse gases**

Fostering sequestration of organic carbon in soil is an important mitigation strategy to increased concentrations of carbon dioxide in the atmosphere. A number of reports agree that up to 40% of the above-ground biomass production, 1–3 t C ha<sup>-1</sup> are returned annually to the soil (Vertes *et al.*, 2007). The rate of accumulation of C in grassland soil depends on the present C and N concentration and is further influenced by variation of nutrient input, soil type, climate, and soil water budget. Soil mineralization is greatly affected by any disturbances of soil structure e.g. magnitude and frequency of tillage. Due to permanent vegetation cover and soil rest, grassland sites, permanent grassland in particular, can store relatively great amounts of organic carbon. A foremost strategy for climate protection would thus be the preservation and creation of grassland. Recent reports show that the annual rate of carbon sequestration in grassland soils is at least twice that of arable land, depending

on age, management and frequency of land or management changes (Goidts and van Wesemae, 2007, Billen *et al.*, 2009).

Grassland soils can store more greenhouse gases than arable land, but emissions are not necessarily smaller. In practice, there is indeed a great variability in emissions from grasslands soils, both with regard to the type of emissions (CO<sub>2</sub>, N<sub>2</sub>O, CH<sub>4</sub>) and the effect of site conditions and grassland management. The emission of CO<sub>2</sub> is directly related to the diesel consumption and the production and use of mineral N fertilizer. Grazed pastures tend to have less trafficking and a smaller CO<sub>2</sub> budget, even more so if mineral N fertilizer is reduced or replaced by white clover. The higher the N input and turnover in a grassland system is, the greater is the risk of N<sub>2</sub>O emissions.

### **Grassland break-up**

Ploughing-up grassland poses a substantial risk for increased nitrate leaching. However, there is a difference between a break-up of permanent grassland for a complete land use change to arable farming and the renovation of a grassland sward. Renovation of permanent grassland and temporal destruction of the sward would result in a more short termed potential for larger N leaching losses depending on timing of renovation and following N fertilization, which could be adapted (Seidel *et al.*, 2007; Kayser *et al.*, 2008b; Seidel *et al.*, 2009). The change to arable land is much more drastic. Immediate large N leaching losses are almost unavoidable and so are emissions of C and other greenhouse gases (Wegener, 2006; Kayser *et al.*, 2008a). Land use changes of grassland or forest to arable farming usually result in losses of soil via CO<sub>2</sub> release, while changes of arable land to grassland or forest nearly always lead to an increase in soil C (Post and Kwon, 2000; Conant *et al.*, 2001;

Guo and Gifford, 2002; Freibauer *et al.*, 2004). Pooplau *et al.*, (2011) report results from a meta-study: C losses, after conversion of grassland to arable land, amounted to roughly 41 t ha<sup>-1</sup> in 20 years while C sequestration, after a transformation of arable land to grassland, accounted for 18.4 t ha<sup>-1</sup> for the same time period. In the long-term mineralization potential is increased with increasing age of the grass sward and that requires an adjusted management with reduced N fertilization, reduced tillage and cultivation of catch crops in order to avoid excessive N and C emissions (Vertes *et al.*, 2007). In practice, this is difficult to achieve as actual mineralization processes respond to precipitation and temperature which is difficult to predict.

### Vegetation response to renovation

Degradation as well as improvement of grasslands are closely related to the vegetation cover, i.e. the plant species identity and composition. Thus, renovation at first place aims at modifying the vegetation cover, reducing bare soil, increasing desired, valuable species and decreasing weeds and less valuable species. A sward renovation should then sustain or improve yields and the herbage feeding value. Herbage intake by ruminants and herbage use efficiency would increase, and C and N cycling in the soil-plant-ruminant system accelerate. Depending on the grassland management this has the potential for a better nutrient use efficiency at the livestock level and thereby for reduced emission risks.

The way the vegetation changes after renovation is highly variable and there are several examples in the literature of both success and failure, depending on the particular site and management conditions (e.g. Pierre *et al.*, 2013). The extent of immediate change after renovation has been shown to depend on the amount of sward and top soil

disturbance prior to resowing. Fig. 1 demonstrates that the yield share of *Lolium perenne* is hardly affected by oversowing within the first year when neither the sward nor the soils are treated. On the other hand, after a complete disturbance of the sward *Lolium perenne* is dominating the vegetation while the not sown weed species *Poa trivialis* is strongly suppressed. Although oversowing without sward and soil disturbance has no or little short-term effect there is evidence that oversowing done repeatedly over years may lead to the desired vegetation change in the longer term.

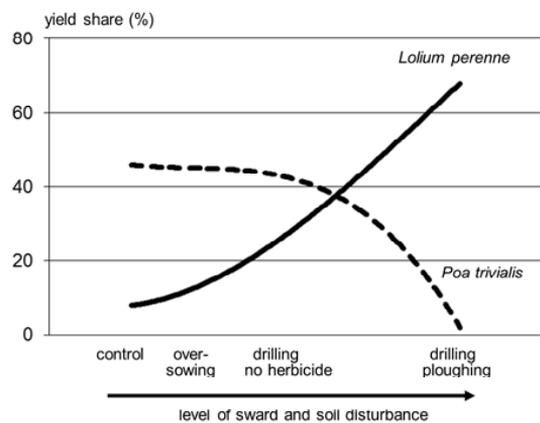


Fig. 1. Example of short-term vegetation response: The effect of various renovation measures on the yield share of the highly valuable forage grass species *Lolium perenne* and the less valuable (secondary) grass species *Poa trivialis* in the year after renovation (after Opitz von Boberfeld and Scherhag, 1980).

There is no guarantee that a strong immediate response after renovation will last. There has been extensive experimentation throughout Europe during the second half of the last century investigating long-term effects of renovation. It has been shown that depending on the seed mixture and the way and intensity of grassland management, the vegetation composition may develop highly dynamically for some years and eventually reverts to a stage where it had been before

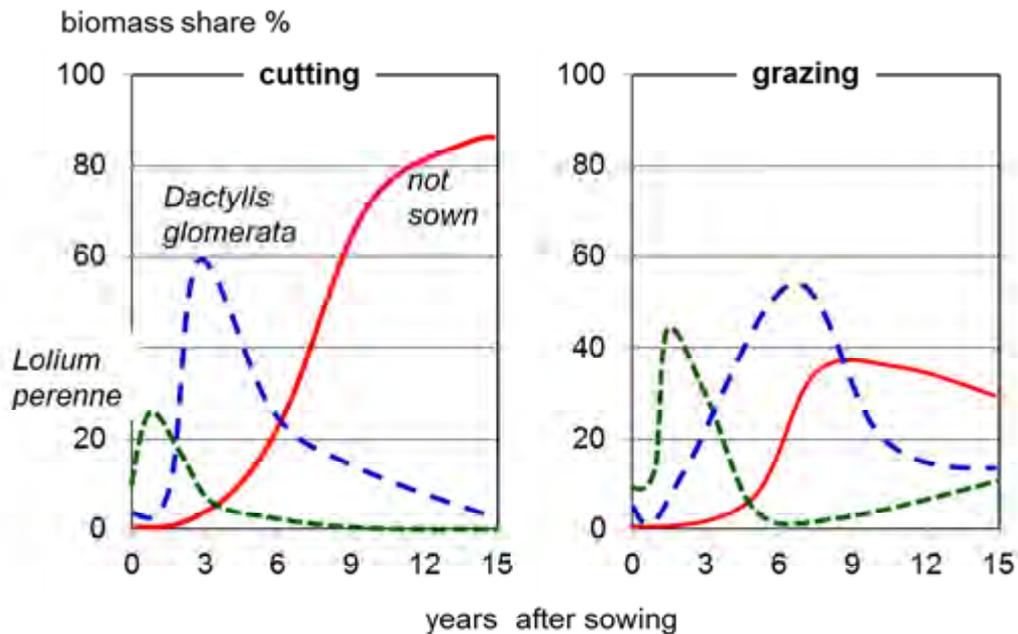


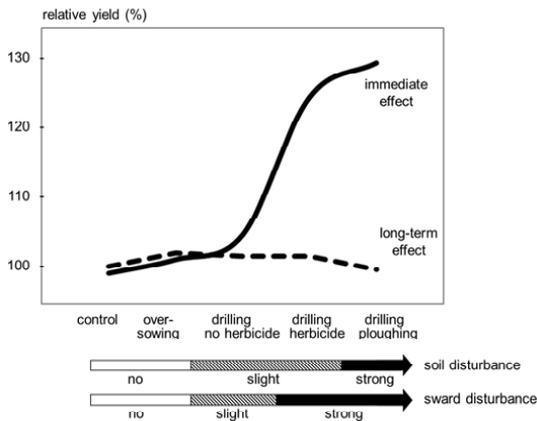
Fig. 2. Example of long-term vegetation response: The effect of grazing management of a resown grass sward on the yield share of the sown species *Lolium perenne* and *Dactylis glomerata* and on the bulk of not sown species (after Brünnner, 1967)

renovation. Fig. 2 shows an example for this. The sown and highly competitive grasses *Lolium perenne* and *Dactylis glomerata* dominated the resown swards for up to seven years and were then replaced by a not sown vegetation. Only when the swards were grazed, in contrast to cutting, the sown species managed to survive in the sward for longer. From an agronomic point of view such a dynamic vegetation development is not intended as weed species may rapidly invade and deteriorate the sward status which would then require another renovation. The challenge of renovation is to anticipate the site and management conditions that are likely to cause dynamic vegetation changes and to compose the seed mixtures accordingly.

### Renovation and related C fluxes

Two aspects of C fluxes will be considered

in this chapter, one is herbage yield and the other is soil organic carbon content. As has been stated above, the major agronomic aim of renovation is to sustain and improve herbage production, i.e. fixing carbon in harvestable herbage yields. In conjunction with studies on the vegetation response to grassland renovation, extensive research has been undertaken on the yield response to renovation (e.g. Hopkins *et al.*, 1985; Hopkins *et al.*, 1990; Keating and O'Kiely, 2000; Schils *et al.*, 2002; Velthof *et al.*, 2010; Shalloo *et al.*, 2011). As with the vegetation response, the immediate yield response is strongly dependent on the amount of sward and soil disturbance prior to resowing. The higher the degree of disturbance and, thus, the stronger the vegetation change, the higher is the potential yield benefit of renovation. This is illustrated in Fig. 3, which is a schematic representation based on a range



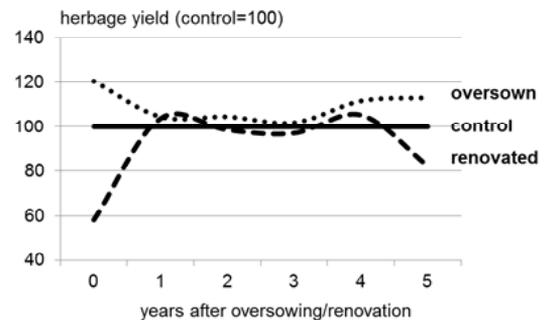
**Fig. 3.** The effect of a range of grassland renovation measures with an increasing soil and grass sward disturbance prior to sowing on the immediate (first two years after renovation) and the long-term (thereafter) herbage yield of temperate grasslands (schematic representation)

of experiments throughout Central and Western Europe. Within the first two years after renovation, the yield advantage of the renovated compared to the untreated permanent (control) sward may amount up to 30%. However, there are also experiments showing either no yield effect or even a short-term yield depression after renovation, the latter being due to production losses in the year of sward disturbance and resewing (see also Figures 4 and 6). Irrespective of the short-term effect, to our knowledge there is no data available that gives evidence for a longer lasting (> three years) yield benefit of resown swards in temperate climate. However, it has been found that the benefits for herbage quality may last longer than the positive effect on herbage yield (Schilset *al.*, 2002, Hopkins *et al.*, 1990).

The potential benefit of oversewing without disturbing the existing grass sward is shown in Fig. 4. There was no yield drop in the sowing year and yield was slightly superior to the control sward in the medium-term. Whether

such agronomic advantage does occur or not is strongly dependent on the successful establishment of seed from the of introduced forage species.

Renovating grass swards is accompanied by changes in soil organic carbon. The more the permanent sward is destroyed prior to reseeding the higher is the short-term mineralization of organic carbon. Apart from the disturbance level, the amount of mineralization of organic carbon is also dependent on the soil type, the hydrology of the soil and the age of the old sward. After a single renovation event with ploughing up of grassland and immediate resewing, Necpalova *et al.* (2014) found a considerable decrease in soil organic carbon (20% reduction) within a few months. Even after 25 years of grassland utilization following renovation the soil organic carbon did not fully recover (Fig. 5). Other recent experiments on sandy soils did not confirm the findings of Necpalova *et al.* (2014). Turning an existing sward by ploughing and reseeding it with a grass mixture did not lead to a reduction of soil organic carbon in the top soil layer compared to an untreated control sward (Linsler *et al.*, 2013). These results demonstrate the need to



**Fig. 4.** Medium-term effect of grassland improvement measures on the herbage yield, control=no sward treatment, oversown: oversewing without sward disturbance, renovated=complete mechanical sward disturbance plus resewing (after Elsässer *et al.*, 2015)

consider the wider environmental conditions of a grass sward when evaluating the potential carbon losses to atmosphere after the renovation of grasslands.

### Renovation and emission risks

When grassland is renovated the sink and source balance of nutrients, in particular C and N, will be altered. Sward improvement without destruction can have favourable effects not only on yield and nutrient uptake by the sward, but on C and N accumulation in the soil as well.

We have to distinguish between immediate emission risks after renovation and long-term risks (Fig. 6). Both increase with the frequency of renovation and with the degree of soil disturbance and interact with management and soil conditions. There is still a lack of systematic research on the topic. Nutrient emissions occur as gaseous losses and leaching. Emissions of CO<sub>2</sub> are related to soil mineralization, N<sub>2</sub>O mainly to enhanced N turnover and fertilization with the risk of indirect N<sub>2</sub>O emissions that are related to larger NO<sub>3</sub>-N leaching losses. Only techniques with no or minimal destruction of the old sward seem to be positive where emissions are concerned. Velthof *et al.* (2010) found that renovation increased N<sub>2</sub>O emissions by a factor of 1.8–3.0 relative to the reference grassland. It has also been reported that a non-destructive renovation measure that combines killing of the sward by herbicide and direct seeding can lead to enhanced mineralization and related gaseous losses (Velthof *et al.*, 2010; MacDonald *et al.*, 2011). In contrast, recent investigations by Buchen *et al.* (2015) found no significant differences in N<sub>2</sub>O emissions after renovation by sward killing-direct seeding and sward killing-ploughing. However, on an organic soil N<sub>2</sub>O losses were somewhat larger after

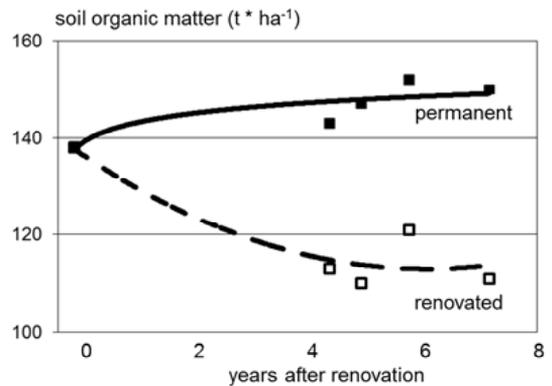


Fig. 5. Soil organic carbon (0–30cm) under permanent and renovated grassland during seven years following renovation. The site was an intensively managed permanent grassland with average herbage yields of 14 t dm per year. For renovation the paddock was ploughed and reseeded with a perennial ryegrass white clover mixture. Differences between treatments were significant at  $P = 0.005$  (after Necpalova *et al.*, 2014).

ploughing than after chemical sward destruction; in all cases N<sub>2</sub>O emissions were much reduced in the second year after renovation. From investigation on sandy soils in northern Germany, Seidel *et al.* (2007, 2009) report that type of fertilizer as well as the level of N fertilization before renovation had no significant effect on soil mineral N in autumn and N leaching during the winter following grassland renewal in spring. When grassland was renewed in late summer/autumn this resulted in larger NO<sub>3</sub>-N leaching losses during the first winter (36–64 kg N ha<sup>-1</sup>) compared to a renewal in spring (1–7 kg N ha<sup>-1</sup>). The effect leveled out in the second winter (Fig. 7). It can be concluded that losses of N via leaching and N<sub>2</sub>O emissions after renovation can probably not be avoided, but that renovation in spring instead of autumn in combination with proper tillage and timing of fertilizer application can minimize N losses (Seidel *et al.*, 2007; Seidel *et al.*, 2009; Velthof *et al.*, 2010).

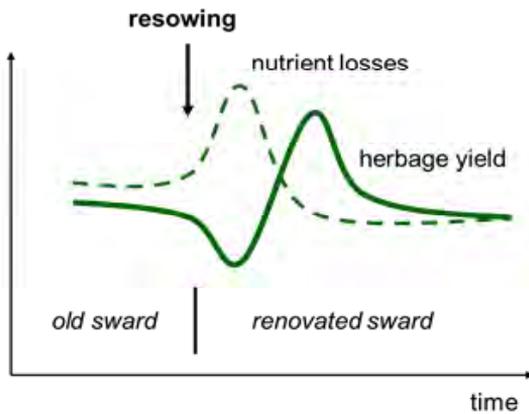


Fig. 6. Schematic representation of the effect of resowing on the dynamics of herbage yield and related nutrient losses with time (after Hatch and Hopkins, 2007, Taube and Conijn, 2007)

## Conclusions

Grassland renovation is advised when grass swards are degraded and do no longer provide the functions and services that are expected from them. It was shown that the consequences of grassland renovation are highly variable and may differ among the different services. A major reason for this is the variation of the degree of sward disturbance before sowing the new sward. Therefore, it was necessary to develop a clear classification of renovation measures. A closer look at the agronomic consequences showed that the amount of benefit in terms of higher yield and better herbage quality may vary a lot, depending on the particular conditions. The issue is becoming even more complicated when several services are considered at the same time. Trade offs have been shown to occur when grass swards are renovated, in particular among agronomic and environmental services. An improved insight into the processes induced by renovation measures and their interactions with the site and climatic conditions is needed to be able to better balance potential benefits and potential risks of renovation measures and to adopt an

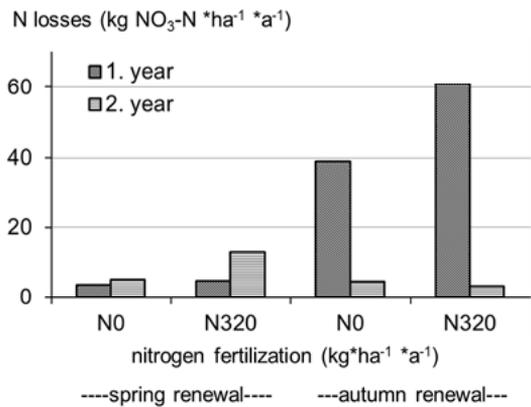


Fig. 7. Nitrate leaching losses in the first and second year after renovation (complete grass sward disturbance by a rotary cultivator followed by reseeding) on a sandy soil after either spring or autumn renewal and no or 320 kg N fertilization annually to the previous crop. Average of two experiments. The factors time of renovation and N fertilization being significant in the first year following renovation ( $P < 0.05$ ) (after Seidel *et al.*, 2009).

appropriate grassland management. As a rule, gentle measures of renovation that do not rely on sward and soil destruction, such as oversewing, pose little risks for renovation failure and environmental pollution. It seems promising to further develop such methods and make them more effective. Above all, renovation is likely to fail in the medium and longer term if the reasons that had contributed to grassland degradation such as overstocking or poor grazing management are not properly addressed after the renovation. For practical farming, managing permanent grasslands in a way that the services are sustained over time should always be given priority in order to reduce the necessity of grassland renovation.

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