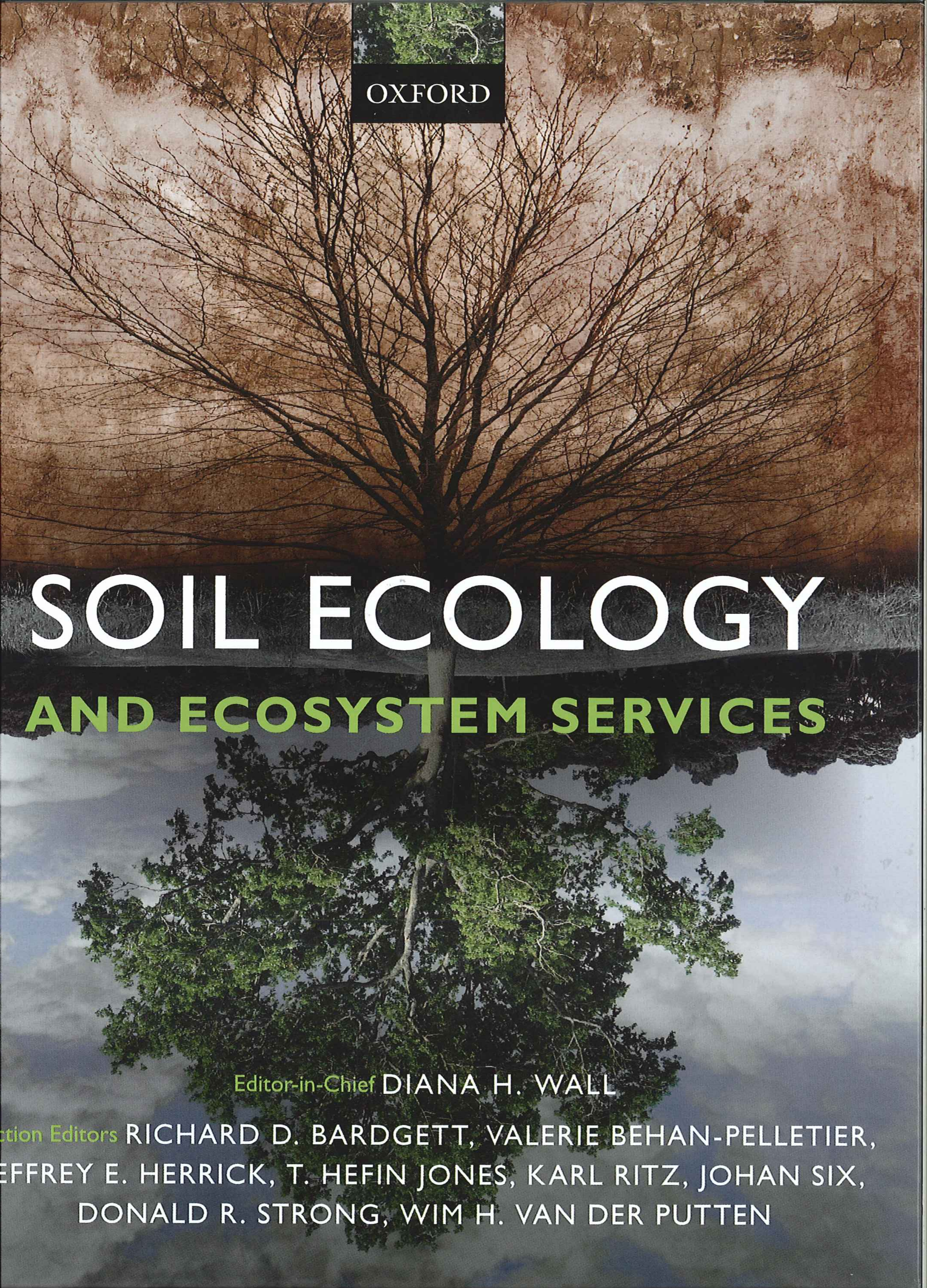

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CHAPTER 4.4

Management of Grassland Systems, Soil, and Ecosystem Services

Phil Murray, Felicity Crotty, and Nick van Eekeren

4.4.1 Introduction

Grasslands occupy almost a quarter of the land surface of the Earth (Harvey 2001) including pasture, prairie, rangelands, savannah, and steppe. The types of grasslands are varied and cover a wide range of management regimes, from intensively managed, highly productive to totally unmanaged. Globally and regionally, grasslands provide a number of key ecosystem services including support (e.g. water and nutrient cycling), provisioning (e.g. food production), regulating (e.g. climate regulation), cultural (e.g. recreational), and biocontrol (e.g. source of predatory organisms) services. Many of these services are mediated or provided by the soil biota. Grassland ecosystems tend to have a relatively stable and permanent plant cover, which in turn, provides a habitat for a large and diverse invertebrate fauna and microbes.

The perennial nature of grasslands means that plant–soil interactions are extremely important in regulating soil processes and the ecosystem services. The vegetation cover contributes an abundant nutrient supply and also buffers the soil environment from temperature extremes. A key feature of grasslands is the high turnover of shoot and root biomass, that consequently results in the retention of a large pool of labile organic matter at the soil surface. This allows grasslands to support a relatively stable and numerous soil biota that contribute substantially to effective soil functioning, including the maintenance of fertility. In addition, unlike in cropping systems, there is often a regular substantial input of carbon and nutrients in the form of animal returns as dung and urine.

The dynamics of the carbon (C) and nitrogen (N) cycle within grasslands directly affect the quality of the plants and the soil. A large proportion of the processes in soils are mediated by the soil biota. These include the comminution and incorporation of litter into soil, the building and maintenance of structural porosity, the aggregation in soils through burrowing activities, the control of microbial communities and activities, and the improvement of plant production (Lavelle *et al.* 2006). The interactions between groups of organisms and physical and chemical processes shape the soil as a habitat and influence the nature of the soil food web with consequences for the vegetation it supports.

Plant net primary production provides food for the soil biota, whether it is through the living plant itself, the herbivory channel, or through dead plant matter (the detrital channel). In turn, the soil biota improves soil structure, water regulation and nutrient cycling, and increases root production, and water and nutrient uptake, which results in greater plant production. In this way, the quantity and quality of litter and root exudates are increased, and the cycle continues. The challenge for sustainable grassland management is to allow this cycle to function with an optimum use of inputs (nutrients and water) (Fig. 4.4.1).

The influence of management on the grass sward cannot be decoupled from its effects on soil biota. Agricultural grasslands are generally managed to maximize production of products such as milk, meat, leather, and other goods. The ability of different grassland systems to maximize production is determined by the carrying capacity of the grass-

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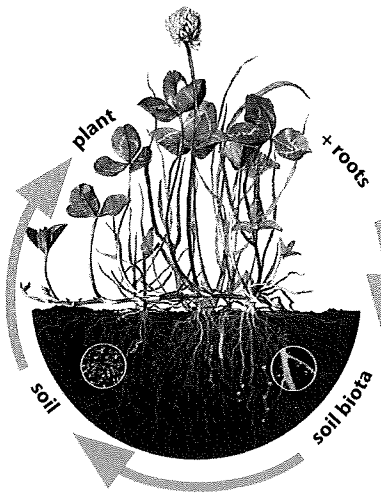

Figure 4.4.1 Cyclic interactions between above/belowground plant, roots, soil biota (root biota, decomposers, and ecosystem engineers), and soil properties (chemical and physical). (From van Eekeren *et al.* 2007.)

land (i.e. the number of animals per unit area). This, in turn, is determined by the productivity of the plant species present and the soil physical properties. How these plants are managed, and which species are present, can have a major influence on the soil biota and the ecosystem services they provide. From this we can make better use of the ecosystem services associated with soil biota and can help to limit inadvertent negative effects of management measures on soil biota and ecosystem functioning. This is described within a conceptual framework of cyclical interactions proposed by van Eekeren *et al.* (2007) (Fig. 4.4.1).

4.4.2 Plant–soil interactions

The quantity and quality of litter and root exudates (including secondary metabolites) of various herb and grass species have been shown to be major determinants of soil food web structure and soil biodiversity (Bardgett 2005). Grazing can affect soil biota through defoliation, dung and urine return, and the physical presence of animals (causing treading and excreta return in patches). These three mechanisms can again have an indirect effect on soil biota through their effect on botanical composition. The plant diversity of grasslands affects biological quality through various mechanisms: 1) the quantity and quality of resources allocated to the soil, 2) the extent to which different plant species deplete nutrients and water from soils, and 3) the modification and formation of habitats for soil biota (Wardle 2002). Wardle and Nicholson (1996) found that in grassland soils most plant species had a stimulatory effect on the microbial biomass. They showed that the biomass of saprophytic microorganisms is predominantly set by plant primary production, although it is also influenced by the number of plant species present. In a study by Proulx *et al.* (2010), plant diversity increased stability across trophic levels, at the community or ecosystem level. Scherber *et al.* (2010), however, showed that although plant diversity does impact the soil biota and their functions, the effect weakens with increasing trophic position. It is thought that the combination of diversity and rapid C flux makes the grassland soil ecosystem highly resilient. Although the soil communities appear to be relatively resilient to plant biodiversity loss, they are highly susceptible to any perturbation that affects the soil structure itself (e.g. cultivation).

According to Whipps (1990), 35–80% of the net fixed C in perennial grasses is transferred belowground. Grassland plants are able to sequester large amounts of C in the soil with an overall average sequestration rate in European grasslands of ~60 g m^{-2} $year^{-1}$ (Janssens *et al.* 2005). The vegetation type and root architecture also contribute to soil C maintenance (De Deyn *et al.* 2008; Fissore *et al.* 2008). The variable ability of some grasses to deposit C at depth, whether by root turnover or exudation, may enable a greater degree of C storage due to the differences in the processes that govern C dynamics between topsoils and subsoils (Salomé *et al.*, 2009). New developments in grass breeding for deeper roots may allow managers to take advantage of this phenomenon and raise the possibility of managing grasslands for increased subsoil sequestration (Abberton *et al.* 2008).

There is increasing evidence that there is a need for a diversity of plant functional groups that can influence soil processes e.g. legumes have been identified as key species in facilitating a number of ecosystem processes. The inclusion of legumes in grassland systems can promote C and N storage (De Deyn *et al.* 2009), and where red clover (*Trifolium pretense*) was promoted, there were associated improvements in soil structure, respiration, and increased soil organic matter content (De Deyn *et al.* 2010). Thus, it appears that the presence of key species and the properties they impart are more important than plant diversity *per se.*

Legumes can have important effects on the soil biota. For example, Elgersma and Hassink (1997) reported a greater active soil microbial biomass and measured a higher N-mineralization in grass-clover than in grass-only swards. Ryan *et al.* (2000) reported that white clover roots had a higher infection with mycorrhizal fungi than ryegrass roots, whereas in a field experiment, De Vries *et al.* (2006) measured a higher fungal and bacterial biomass in grass-only swards than in grass-clover. Mytton *et al.* (1993) found higher drainage rates in white clover than in perennial ryegrass. Moreover, in field experiments a higher biomass of earthworms was found in clover-only than in grass-only swards (van Eekeren *et al.* 2009a). Results suggest that mixed grass-clover swards combines the positive effects of clover-only on the ecosystem service of nutrient supply with the positive effects of grass-only on soil structure maintenance.

4.4.3 Ecosystem services provided by the soil biota

Grasslands provide a number of key ecosystem services, many of which are regulated by the soil biota. These include plant production, nutrient and C cycling, maintenance of soil structure, and water regulation (Brussaard *et al.* 1997). The interactions between groups of organisms and the physical and chemical processes shape the soil as a habitat. This feeds back to affect the diversity of soil biota themselves as well as impacting ecosystem processes.

4.4.3.1 Soil structure maintenance

In intensively managed grassland systems, livestock directly affect the structure of the soil in two ways, either through compaction or poaching, which occurs when soil and vegetation on poorly drained or waterlogged sites are damaged by livestock. Grazing pressure and traffic load are the main causes of soil compaction and can affect herbage composition and plant cover. This can have a deleterious impact on the soil biota; for example, Bouwman and Arts (2000) in a grassland found a shift in trophic groups of nematodes when the soil was compacted. This shift was mainly caused by an increase in herbivorous nematodes following an increase of root biomass in the topsoil.

There are a number of ways the soil biota can ameliorate compaction. Earthworms are commonly referred to as ecosystem engineers (*sensu* Jones *et al.* 1994) due to their wide ranging impacts on the soil ecosystem. In a study of upland grassland in the UK, Cole *et al.* (2006) concluded that macrofauna, particularly earthworms, have a more profound effect on soil structure than the microflora. Earthworms, in particular, affect soil structure through producing fecal casts, promoting humification, and creating pores. In a study examining a 20-year absence of earthworms and other soil invertebrates (due to pesticide treatment in perennial ryegrass pasture in the UK) (Clements *et al.* 1991) soil bulk density had increased, while there was a decrease in penetrability, soil organic matter content, initial infiltration rate, and soil moisture content. Earthworm activity in soil has also been related to improved nutrient cycling and enhanced plant productivity (Bhadauria & Saxena 2010).

4.4.3.2 Water regulation

Water regulation is closely related to soil structure maintenance. The importance of soil biota for water regulation was shown by the increased waterlogging of Scottish grassland soils where flatworm predation had significantly reduced earthworm populations (Haria *et al.* 1998). Water infiltration through macropores and stable crumb formation are two key soil processes strongly affected by earthworms. The presence of earthworms can reduce surface runoff due to the enhancement of soil porosity caused by burrowing, but there is then the possibility that this may lead to increased bypass flow and nutrient leaching.

Grass rooting depth is important for the drought resistance of grasslands. Earthworm burrows provide pathways for root penetration throughout the soil profile. In particular, the common deep-burrowing, surface-feeding earthworm species *Lumbricus terrestris* and *Aporrectodea longa* generally make vertical burrows and are able to penetrate hard pans and aid root growth.

4.4.3.3 Nutrient cycling

All groups of soil biota are involved in nutrient cycling. Bacteria and fungi contribute to this supporting service through nutrient mineralization and immobilization. In many systems plant litter is deposited on the surface of the soil where it is subsequently mineralized and incorporated. In cropped grassland systems (such as for hay or silage), the amount of litter deposited is limited because of the way the grass is cut and removed. In grazed pastures, a greater part of the herbage consumed by livestock is directly deposited on the ground through excretion of both dung and urine. This results in a more heterogeneous distribution of C and N within the pasture. In more intensively managed systems there is a greater use of liquid slurries; however, these animal returns may lead to increased N losses through leaching and volatilization. Soil organic matter content and soil biological activity can be enhanced through inorganic as well as organic fertilizers, especially when initial N levels are low. Inorganic fertilizers (containing only mineral N) feed the plant and soil micro-organisms directly and the entire soil biota indirectly by increased root biomass and exudates, and plant litter. Inorganic fertilizers, however, involve high fossil fuel energy consumption and are easily lost from the soil by nitrate leaching and denitrification. In grassland soils, organic fertilization compared to inorganic fertilization, has been shown to increase the organic C, the total N, the activity of decomposers, and the supply of nutrients via the soil food web.

Studies on the effect of specific quality aspects of organic fertilizers (higher C:N and lower mineral N:total N) on soil biota are rare. Griffiths *et al.* (1998) observed that the number of protozoa responded more quickly to the application of pig slurry than cattle slurry, and explained this by the greater proportion of readily-available C in pig slurry compared to that of cattle slurry. Van Eekeren (2009b) measured different organic fertilizers and found a higher bacterial activity and the highest amount of mineralizable N with normal manure slurry compared to inorganic fertilizers. This suggests a positive effect on the supply of nutrients and water regulation.

Nitrate leaching and denitrification are the reasons why N is predominantly lost from grassland pastures. Denitrification is a microbially mediated process involving the reduction of NO_3^- to N_2, under anaerobic conditions, the intermediaries being NO_2^-, NO, and N_2O. For denitrification to take place there needs to be a readily available supply of substrates and low oxygen concentrations. Efforts to increase denitrification through to N_2 may prove useful in reducing some of the negative impacts of excess N in soils. There are also natural nitrification inhibitors present in some grass plants; for example, the tropical pasture grass *Brachiaria* spp. inhibits *Nitrosomonas* function and therefore suppresses N_2O emissions.

4.4.3.3.1 Microorganisms

The soil microbial biomass is mostly composed of bacteria and fungi. A number of factors, such as soil moisture, pH, and substrate availability, affect the relative abundance of bacteria and fungi. Bacteria and fungi represent a large pool of N and C within the soil and increases in soil fertility can induce shifts from fungal- to bacterial-based energy channels in soil food webs (Bardgett & McAlister 1999). Intensively managed systems tend to have decreased microbial biomass and favor the bacterial-based energy channel. This has important consequences for the soil food web. Grasslands with higher N input have lower fungal to bacterial ratios, which affect the level of N leaching (De Vries *et al*. 2006).

The soil microbial population represents a large store of phosphorus (P) in organic forms that is a potential source of inorganic P for crops—either directly or by replenishing the inorganic pools. There is a general understanding that some organic P will be mineralized as cells die; the rate, precise mechanisms and controlling factors have been poorly investigated. For N mineralization the role of faunal grazing as an accelerating mechanism for N release has been demonstrated (e.g. Bonkowski 2004) but this has not been demonstrated for P, although it seems logical that it should occur.

4.4.3.3.2 Symbiosis

In grassland systems symbiosis between plants and soil biota are extremely important for plant productivity, especially where essential nutrients are limited. Phosphorus is typically very immobile in soil, and the supply to roots or microbes is extremely slow. Mycorrhizal fungi form mutualistic associations with plant roots, where the fungus derives C from the host plant and forms extensive mycelial networks through the soil, absorbs P and transfers this directly to the plant. Since such hyphae are typically of the order of a few microns in diameter, they are able to explore and exploit considerably larger volumes of soil per unit C than plant roots. For example, Van der Heijden *et al*. (1998) found positive mycorrhizal effects on shoot P concentrations and shoot biomass of grasses such as *Bromus* spp. and *Festuca* spp. The filamentous structure of the mycelium provides an extensive surface area, where 1 cm^3 of soil can contain 1 km of fungal hyphae with a surface area of more than 300 cm^2. Some groups of soil biota (e.g. Collembola) potentially disrupt mycorrhizal linkages with host plants and consequently may have important impacts on herbage production (Jonas *et al*. 2007).

Legumes have long been important in grassland agriculture due to their high feeding value and their ability to form symbiotic relationships with N-fixing bacteria. In agricultural grasslands, this symbiotic association between legumes and some bacteria (including members of the orders *Rhizobiales* and *Burkholderiales*) are significant and provide around 100 kg ha^{-1} N equivalent, increasing the yields of herbage obtained without additional mineral N fertilization of the crop. Considerable effort is being focused on exploiting the potential of white clover in animal production systems which can meet the financial and environmental requirements likely to prevail. In the UK by far the most important forage legume is white clover. It is included in 75% of grassland seed mixtures. Although the presence of white clover in swards is desirable, both for its N-fixing capability and its enhanced feeding value for livestock, white clover also makes a significant contribution to the botanical composition in a maximum of 20% of UK swards. The failure of clover to thrive in pasture systems is, in part, due to the impact of pest and diseases on the seedling crop grassland production.

4.4.3.3.3 Microfauna

Nematodes and protozoa affect nutrient cycling processes indirectly through grazing on soil microbial biomass and nutrient excretion. Griffiths (1989) observed that the N content of ryegrass increased by 14% when nematodes or protozoa were added to microcosms with bacteria. Where grassland is characterized by N limitation (e.g. tallgrass prairie), herbivorous nematode densities respond positively to increased root inputs that occur following fertilization (Todd *et al*. 1999). Although plants may directly affect soil pH, their influence on soil water content may be of greater importance. Plants may change soil water status through increased evapotranspirational losses due to increased plant growth when subjected to fertilizer addition, or through climate change effects.

Not only microbivorous nematodes are involved in nutrient cycling, but also plant parasitic nematodes and herbivorous nematodes. In experiments with clover, low levels of root infestation by clover

cyst nematodes (*Heterodera trifolii*) positively influenced the rhizosphere microbial community in the soil (Yeates *et al*. 1998b). Transfer of N from legumes to companion grasses is generally caused by the death and decomposition of the root tissue which is relatively high in N. Root herbivory by nematodes, however, has been found to increase the root growth of white clover and perennial ryegrass; such herbivory of white clover roots may enhance the flux of clover N to the soil, which is subsequently recycled and taken up by the neighboring ryegrass plants (Bardgett *et al*. 1999). Similar results have also been demonstrated for larger invertebrates. For example, the larvae of the clover weevil (*Sitona* spp.) have been shown to facilitate the transfer of N from clover to companion ryegrass (Murray & Hatch 1994).

4.4.3.3.4 Macrofauna

Macrofauna affect nutrient cycling processes directly, through fragmentation and the transport of organic and mineral particles, and indirectly through regulating microbial communities and stimulating microbial activity. The role of the soil fauna in decomposition has received considerable attention over the last three decades, but is still not adequately defined. The animals in the soil may exert a major influence on the decomposition through interactions with the microflora. The available data on faunal contribution to N mineralization indicate a larger role than their metabolic rate would suggest. This may be due to their low production efficiency, and low N to C requirement. This means that excess N is returned to the soil in excreta in forms that are readily available to the microbial biomass. Subsequently, this biomass provides substrate for the microbivorous fauna, particularly protozoans and nematodes, resulting in the rapid turnover of a small but important pool.

In grassland, earthworms contribute significantly to organic matter fragmentation through breaking down the sod. Hoogerkamp *et al*. (1983) observed that the introduction of earthworms to grasslands in reclaimed polders resulted in the development of dark-colored top soil within 3 years after introduction. In an experiment by Clements *et al*. (1991), the most apparent effect of a pesticide treatment that excluded earthworms was the accumulation of litter. Next to fragmentation, the transport and mixing of organic and mineral particles is an important function of earthworms. In a glasshouse study with perennial ryegrass and rock phosphate, the presence of earthworms resulted in a higher yield, not only through the better mixing of rock phosphate by earthworm activity but also due to increased availability of P in worm casts (Mackay *et al*. 1982).

4.4.3.4 Herbage production

For farmers, grass production (quantity and quality) is the ultimate ecosystem service, in which the maintenance of soil structure, water regulation, and particularly nutrient supply play prominent roles. The section on nutrient supply provides several examples of positive effects of soil biota on root growth, shoot N and P content, and yield. It appears that the positive effects of soil biota on grass production under field circumstances are most obvious for earthworms, particularly when earthworms are introduced to soils where they were previously absent (Hoogerkamp *et al*. 1983).

Soil biota can, however, adversely impact grass production. Many of the invertebrates found in the soil are phytophagous and there are only limited data on the effects they may have on the growth and development of pasture plants. Such plants can cope well with aboveground herbivory, through traits such as placement of meristems near the ground and/or the ability to hold nutrient reserves in organs such as stolons and roots, that enable rapid regrowth following foliar herbivory. They may, however, be less well adapted to belowground pressures; and plant responses to belowground herbivory can be variable and will depend on the ability of the plant to compensate for the functions lost.

Root herbivores are known to have many effects on their host plants, for example, they damage and consume plant roots, sever roots segments, and increase the turnover rate of root tissue. A general loss of root material may be a particular handicap to plant performance in terms of nutrient and water absorbing capacity, but damage to more specialized structures, such as the root nodules of legumes represents both a direct loss of plant material and an impairment of the N-fixing capability. Belowground herbivory may also affect the plant composition through the selective suppression of dominant plant species (De Deyn *et al.* 2003).

4.4.4 Impact of management intensity of grassland systems

Many managed grasslands are established with a limited number of species. For example, a mixture predominantly of *Lolium perenne* and *Trifolium repens* is used in the UK. As pastures age, they tend to become more botanically diverse and less productive. If there is a desire to restore productivity, there are a number of options including fertilization or lime ($CaCO_3$) addition.

In intensively managed pastures, such as those commonly found in dairy systems, the carrying capacity is high. These systems are comprised of fast growing, highly nutritious forage species with a high N fertilizer input providing a large amount of animal feed. This results in a significant return of nutrients to the soil in feces and urine. These systems are managed so that plant diversity is low and that the litter that is returned to the soil has a high N and low C content, and that there is a high rate of root turnover. These traits, in turn, lead to the development of bacterial based food webs with a fast turnover of organic matter and nutrient mineralization, and with a low C sequestration. In intensive grassland systems, the importance of soil organisms has often been ignored, as physical manipulation of the soil and nutrient supply are increasingly provided by human inputs rather than by natural processes (Brussaard *et al.* 1997). At the other end of the scale, in semi-natural systems, plant species diversity tends to be high, with slower growing and less productive species and with poorer feeding value. In these systems the use of N fertilizers is low and there is a smaller carrying capacity. There is also a smaller amount of natural return of animal waste. The plants in these grasslands tend to have a low N and high C content, and their litter returns reflect this. The soils in these systems tend to have soil food webs dominated by fungi and micro-arthropods such as mites and Collembola (Wardle *et al.* 2004). With densities in lowland grassland reaching over 200,000 m^2, they have a large impact on decomposition processes. Despite this, decomposition tends to be slower and leads to high C sequestration.

Most grasslands are somewhere in between these two extremes. This is illustrated by a study by Rutgers *et al.* (2008) in the Netherlands (Table 4.4.1): agricultural land use represented the most fertile soil conditions while heathland and mixed forest represented the most infertile conditions. Bacterial biomass, and the abundance of nematodes and earthworms (bold-faced numbers in Table 4.4.1), are higher in agricultural and semi-natural grassland, whereas fungi and especially micro-arthropods are more abundant in heathland and mixed forests.

Studies have reported changes in the composition of soil biota on sites with an arable cropping history followed by the establishment of perennial pasture or abandonment of cultivation. Yeates *et al.* (1998a) found that earthworm populations increased when a perennial pasture was established on sites formerly under arable cropping. In a long-term study comparing a ley-arable crop rotation with permanent grassland, most soil biota were found to recover quickly from declines during the arable phase of the crop rotation, reaching overall abundance and activity levels in the ley phase comparable to those observed in permanent grassland. The physiological diversity of the bacteria community and the anecic earthworm abundance were, however, significantly reduced in the ley-arable crop rotation compared to permanent grassland. This may impair the ecosystem services of the supply of nutrients and water regulation. The combination of no disturbance and a stable supply of resource in permanent grassland probably keep these ecosystem services at a high level (van Eekeren *et al.* 2010).

4.4.5 Trade-offs between ecosystem services

In general the effect of management intensity on soil biota and ecosystem services are not independent of one other. For agriculture, the problem is typically posed as trade-off between provisioning services—for example, production of agricultural goods such as food, fiber, or bioenergy—and regulating services such as water purification, soil conservation, or C sequestration. The potential for a

Table 4.4.1 Soil biota in sandy soils with different land uses in the Netherlands (Rutgers *et al.* 2008). Bold numbers indicate higher values for biotic groups in certain ecosystems

Land use	Unit (no. of locations)	Arable farms (34)	Dairy farms (87)	Semi-natural grassland (10)	Heathland (10)	Mixed forest (20)
Soil chemical parameters						
SOM[b]	g kg dry soil^{-1}	75	64	93	73	57
C:N[b]		20	14	18	34	25
pH-KCl[b]		5.2	5.2	4.5	3.2	3.2
P-Al[b]	mg P_2O_5 100g soil^{-1}	56	54	27	2	3
P-total[b]	mg P_2O_5 100g soil^{-1}	105	149	144	41	19
Soil biological parameters						
Earthworm number[a]	n m^{-2}	38	**187**	**133**	0	9
Earthworm taxa[a]	N	2.0	4.6	6.8	0	0.7
Enchytraeid number[a]	n 10^3 m^{-2}	22	24	13	14	21
Enchytraeid taxa[a]	N	8.1	8.2	14	6.2	4.7
Micro-athropod number[a]	n 10^3 m^{-2}	23	46	101	**157**	**150**
Micro-athropod taxa[a]	n m^{-2}	22	26	24	22	59
Nematode number[b]	n 100g soil^{-1}	3717	**4926**	**5054**	2053	730
Nematode taxa[b]	N	27	32	36	22	25
Bacterial biomass[b]	µg C g dry soil^{-1}	88	146	204	75	47
Bacterial activity[b]	Thy incorp.	67	66	17	4	2
Bacterial diversity	N DNA bands	68	51	—	—	25
Fungal biomass[b]	µg C g dry soil^{-1}	—	22	24	**53**	—
CLPP, ES50[b, c]	µg dry soil	1415	637	324	9293	39712
CLPP slope[b, d]		0.55	0.57	0.35	0.41	0.60

[a] Data for dairy farm land use were collected in grassland only.
[b] Data for dairy farm land use were collected in grassland as well as the arable land of the same dairy farms.
[c] CLPP ES50: the amount of soil extract needed to convert 50% of all substrates in ECO plates. This is a measure for the physiological activity of the bacterial community. A low ES50 indicates a high activity.
[d] CLPP slope: a measure of the physiological diversity of the bacterial community. A low slope indicates a high diversity.

"win–win" management increases with an increased awareness of ecosystem services and effective methods for evaluating these services. Even for the supporting ecosystem services discussed in this chapter we see trade-offs between other ecosystem services. Improving water infiltration can require more earthworms, which are stimulated by a higher quantity and quality of resource (more production) and for water retention you need organic matter. For a better uptake of water and nutrients by grasses you need a higher density and deeper roots, but with lower fertilization there are more roots. Fine grass roots with their rhizosphere have an important positive effect on soil structure and the latter will also improve water infiltration.

The impact on soil structure is different, in that the intensively managed pastures are often regularly ploughed and reseeded. This will help maintain structure. As the pastures age there is likely to be increased treading and machinery movements that will increase compaction. As the degree of management reduces further, and the stocking densities reduce further, there is less compaction pressure. The biota which are the ecosystem engineers (e.g. earthworms, termites, etc.) can often overcome the management pressures depending on the climate and soils.

In production-orientated grassland systems the goal is to produce as much product as possible, whether this is herbage, milk, or meat, and the management practices employed by the farmer are to achieve this. High productivity is, however, almost always at the expense of other ecosystem services. If high levels of inorganic fertilizer are used, then there is the potential for increased losses in diffuse ground pollution or gaseous emissions. The stocking rate is usually higher on the more productive swards due to the increased availability of forage. This may have a significant influence on microbial communities in grassland soils because of the returns from grazing animals. If animals are housed for longer periods, then there is the problem of how to best utilize the manure and slurries that may cause potential pollution and also impacts the soil biota.

In more extensive systems, the effects are reduced, but at the expense of production. In an experiment where there was a cessation of fertilizer input, De Deyn *et al.* (2010) found that plant species diversity increased as did the rate of soil C and N accumulation. There was, however, a concomitant reduction in plant biomass both above- and belowground. The increasing use of N impacts the relative abundance of fungi and bacteria in the soil, with implications for nutrient cycling and C storage.

4.4.6 Conclusions

The wide range of management practices in grasslands impacts ecosystem services at different temporal and spatial scales. In many temperate grasslands the level of management intensity is governed by two factors, carrying capacity and fertilizer usage. The two are almost always inextricably linked.

The functional relationships between the intensity of grassland management and ecosystem services are complex and, by definition, interactive and additive. Production per unit area declines as the intensity of management decreases, from highly fertilized and stocked to unfertilized and loosely grazed and unfertilized. The effect of the management intensity is different and often conflicting for the other ecosystem services discussed in this chapter. To improve water infiltration you need more earthworms, which are stimulated by a higher quantity and quality of resource (more production). For water retention you need organic matter. For improved uptake of water and nutrients by grass you need a higher density of roots at a greater depth. With lower fertilization, however, there are more roots. Fine grass roots and consequently the rhizosphere around them, have an important positive effect on soil structure. The latter will also improve water infiltration. The impact on soil structure is different, in that the intensively managed pastures are often regularly ploughed and reseeded which will help maintain structure. As the pastures age, there is likely to be increased treading and machinery movements which will increase compaction. As the degree of management reduces further and the stocking densities reduce further there is less compaction pressure and the biota, the ecosystem engineers (e.g. earthworms, termites, etc.), can often overcome the management pressures, although there are exceptions.

There are few studies where N has been added to bare soil and it is therefore difficult to differentiate the direct effects of fertilizer addition from those indirect ones manifested through the plants, for example, plant derived nutrients and litter inputs. There has been relatively little consideration given to how plant-mediated changes in soil abiotic conditions influence soil communities. While it is important to determine the direct effects of nutrient addition and plants on soil communities, it is perhaps more important to take a more holistic approach. We need to consider how increased plant growth may influence the soil physical environment and how such environmental changes may in turn affect the soil biota. For example, Murray *et al.* (2006) describe how fertilizer addition to upland grassland resulted in increased plant growth, with concomitant increase in evapotranspiration, which in turn created a drier soil environment that impacted the soil communities.

The introduction of a legume appears to play a more important role in how soil biota function, rather than any change in the composition of the C that is derived from that plant. The introduction of such species may potentially reduce the overall productivity of the sward, but does promote other ecosystem services including soil structure, water retention, biodiversity, and C and N storage. Therefore we can ask whether we should sacrifice a degree of production to enhance delivery of the ecosystem services (which can be more difficult to price). The trade-offs required are dependent on the goals of the land managers, and it may be that the same goals do not apply for each individual field, farm, or region. In all these scenarios there are optima which may be achieved, usually at an intermediate level. It is therefore our contention that a moderate management intensity will deliver the best use of the supporting ecosystem services discussed, while at the same time having the least compromise on actual grassland production.

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