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Sward lifting in compacted grassland: effects on soil structure, grass rooting and productivity

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ABSTRACT

Soil compaction can impair the productivity of permanent grassland. A way to ameliorate compaction in the topsoil (0–30 cm), without destroying the sward, is soil loosening by sward lifting. To explore the potential of this form of non-inversion tillage, we applied this treatment once, either in spring or in autumn, to a moderately compacted grassland on a sandy soil and measured the effects on soil structure, grass rooting and productivity for up to two growing seasons. We also explored whether complementary overseeding with *Lolium multiflorum* Lam. would extend the duration of soil loosening effects. Our results show that sward lifting improved soil structure and rooting for at least 10–12 months, but did not result in a consistent or lasting increase in herbage yield or nitrogen (N) uptake. Loosening in spring decreased herbage yield (−27%) and N uptake (−16%) in the following growth period, but these decreases were largely compensated for (herbage yield) or more than compensated for (N uptake) by increases in the next three growth periods. The increase in N uptake in the first growing season (+13 kg N ha^{-1}) was reversed in the second season (−14 kg N ha^{-1}). Loosening in autumn increased herbage yield (+8%) and N uptake (+15%) in the first growth period (after winter), but not in the four growth periods thereafter. Cumulative yield tended to be higher (+4%), which supports the view that soil loosening should be carried out in autumn rather than in spring. The initial positive effects of loosening on herbage yield and N uptake were explained by a temporary increased soil N mineralization; initial negative effects by mechanical damage to sward and roots. Finally, complementary overseeding did not extend the duration of soil loosening effects; apparently, new root growth from the existing sward was effective enough to stabilize these effects.

1. Introduction

Soil compaction is a common problem in permanent grassland. It is caused by machine traffic (Douglas and Crawford, 1991; Frost, 1988a), livestock treading (Greenwood et al., 1997; Mulholland and Fullen, 1991) and natural soil consolidation (Carter, 1990). Soil compaction may affect root growth and activity, e.g. through physical impedance and oxygen deprivation (Cook et al., 1996; Hopkins and Patrick, 1969), and hence impair crop growth. Compaction probably affects a considerable area of grassland worldwide. In a soil compaction survey in the UK, only 30% of grassland soils were found to be in good soil structural condition; 60% in moderate condition and 10% in poor condition (Newell Price et al., 2012).

Soil compaction can be ameliorated, although prevention is more effective (Douglas, 1994). To a certain extent, compaction is reversed by natural soil processes that produce (micro) cracks (Dexter, 1991), such as soil wetting followed by drying, and soil freezing followed by thawing. This natural restoration process is further enhanced by the formation of macropores through earthworm activity and through root penetration followed by root decay (Dexter, 1991; Drewry, 2006). When, in grasslands, these processes are not sufficient to ameliorate compaction, various mechanical soil loosening methods can be applied, including slitting, spiking, sward lifting and subsoiling (Bhogal et al., 2011). Sward lifting, a form of non-inversion tillage, can be applied to ameliorate compaction in the topsoil layer (0–30 cm). Lifting and lowering of the topsoil creates a wave movement that breaks the compacted layers into smaller pieces, while leaving the sward and roots largely intact. The latter is a significant advantage over a more traditional method to ameliorate compaction, grassland renovation by ploughing and reseeding. Apart from the destruction of the existing sward, this approach is also more costly, may result in considerable losses of soil carbon, nutrients and biodiversity (Necpálová et al., 2014;

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Van Eekeren et al., 2008), and may increase nitrate leaching and greenhouse gas emissions (Drewer et al., 2017; Shepherd et al., 2001).

Sward lifting has been found to improve grassland topsoil structure, with effects persisting for up to several years (Carter and Kunelius, 1998; Drewry et al., 2000). However, soil structure improvements do not necessarily translate into higher herbage yields. In various experiments, mechanical soil loosening was found to have no effect on grass yield, which can be ascribed to experimental shortcomings (Burgess et al., 2000; Drewry et al., 2000; Harrison et al., 1994) or to a low level of soil compaction (Frost, 1988a). Sometimes also negative effects of loosening on yield are found; these have been ascribed to mechanical damage to sward and roots (Carter and Kunelius, 1998; Frost, 1988a,b).

In the Netherlands, 40% of agricultural land is used as permanent grassland, mainly for dairy farming. Although soil compaction is likely to have negative effects on the productivity of this grassland, little research has been done to assess the effects of amelioration methods. A field experiment by Van Eekeren and Ter Berg (2008) showed (short-lived) positive effects of sward lifting on soil structure, but not on herbage yield. These authors hypothesized that the effectiveness of soil loosening could be enhanced by overseeding (i.e. adding grass seeds to the existing sward), assuming that the rapidly growing roots of seedlings would be more likely to quickly occupy and stabilize the macropores created by soil loosening than the older roots of the existing sward.

The objective of the present study was to explore the potential of sward lifting, with and without overseeding, as a method to ameliorate soil compaction in Dutch grasslands. We tested this method in a compacted permanent grassland, applying it either in spring or in autumn. Effects on soil compaction, soil structure, grass rooting and productivity were measured for up to two growing seasons. We hypothesized that (i) soil loosening by sward lifting would increase herbage yield and N uptake through an improvement of soil structure and rooting conditions; and (ii) overseeding with Italian ryegrass (*Lolium multiflorum* Lam.) would extend the duration of these improvements.

2. Materials and methods

2.1. Site properties

The experiment was conducted in a permanent grassland on a compacted, undrained, fine sandy soil in the southern part of the Netherlands (51°61′N, 5°80′E). This soil was prone to waterlogging throughout the year, after periods of heavy or prolonged rainfall. The soil profile was classified as a Gleyic Podzol and had a 30–40 cm deep A-horizon overlying white sand. Soil properties of the 0–10 cm soil layer were: pH-KCl 5.1, organic matter 4.0%, total C 1.8%, total N 0.157%, P-Al 0.025% and K-HCl 0.004%. Soil properties of the 0–30 cm layer were: pH-KCl 5.0, organic matter 2.9%, total C 1.3%, total N 0.106%, P-Al 0.027% and K − HCl 0.010%. A visual assessment of soil structure and root density, right before start of the experiment, showed that the 0–10 cm soil layer had a good soil structure (high percentage of crumbs), a high root density, a high proportion of young roots and visibly active soil organisms, mainly earthworms of the species *Aporrectodea caliginosa* (see Section 2.4 for the assessment methods). The 10–30 cm soil layer had a moderate to poor soil structure, a high percentage of angular blocky elements, a high proportion of old roots, no visibly active soil organisms and a low number of macropores. The 30–40 cm soil layer showed a poor and compacted soil structure, no root presence, and a low number of visible pores. No roots or worms were found in the white sand below 40 cm depth.

The grass sward was nine years old, contained a mixture of plant species including white clover (*Trifolium repens* L.) and Italian ryegrass (*Lolium multiflorum* Lam.), and was dominated by perennial ryegrass (*Lolium perenne* L.). In previous years, the grass had been managed mostly by cutting (the first four growth periods were cut and the final growth period was grazed by young stock), which involved machine traffic for the application of liquid manure and synthetic fertilizer, and for harvesting. The 30-year average annual rainfall at the site was 804 mm, fairly equally distributed over the year (Royal Netherlands Meteorological Institute KNMI).

2.2. Experimental treatments

The field experiment was designed to assess the effects of a one-time application of soil loosening and/or overseeding on soil structure, grass rooting and productivity. Treatments were applied either in the late spring or early autumn of 2014, and effects were measured in the 2014 and 2015 growing seasons (spring treatments) or the 2015 growing season (autumn treatments). The field experiment was set up as a randomized complete block design, with time of treatment (spring or autumn) assigned to two main plots located adjacent to each other. Within each main plot, all treatments (control, soil loosening, overseeding, and soil loosening combined with overseeding) were replicated on five plots (10 × 2.7 m) in five randomized blocks. Several weeks before applying the treatments (either in spring or in autumn), the sward was sprayed with the herbicide Starane (Dow AgroSciences, Indianapolis, USA) to kill off the white clover in the sward and hence reduce potential variation associated with patchy clover distribution. The spring treatments were applied on 19 May 2014, two weeks after the first regular harvest, and the autumn treatments on 15 September 2014, six days after the fourth regular harvest. Right before applying the treatments, regrowth after the preceding harvest was cut by a flail mower to reduce potential competition between regrowth and seedlings. Overseeding was carried out before soil loosening to avoid re-compaction of the loosened soil, using a Vredo Agri Air slot-seeding machine with a working width of 2.5 m and an inter-row distance of 7.5 cm (Vredo Dodewaard BV, Dodewaard, The Netherlands), sowing Italian ryegrass (*Lolium multiflorum* Lam. cv. Mont Blanc) at 1–2 cm depth and at a rate of 25 kg ha^{-1}. Soil loosening was carried out with an Evers Agro sward lifter with five shanks, spaced 60 cm apart and fitted with hardened, 20 cm wide winged tines (Evers Agro BV, Almelo, The Netherlands). With this machine, that operated to a depth of 25 cm, the entire top layer (0–25 cm, soil and sward) was lifted 10–15 cm upwards and then lowered again.

Soil moisture content at the time of treatment application was an estimated 85% and 75% of field capacity in spring and autumn, respectively, and cumulative rainfall within 10 days after treatment was 10 and 30 mm, respectively. Thus, conditions were optimal for soil loosening (cf. Burgess et al., 2000). After treatment applications, the trafficking was controlled. Plots were trafficked lengthwise by a tractor carrying a small-scale fertilizer spreader (three to four times each growing season, wheel distance 1.5 m) and a Haldrup grass harvester (four to five times each growing season, wheel distance 0.9 m), in order to apply fertilization and determine herbage yield (see Sections 2.3, 2.5). Additionally, there was regular (light) machine traffic for grass raking, which passed over the experiment lengthwise (i.e. all plots were affected equally), four times each growing season. Traffic after treatment application, however, only had a minimal effect on re-compaction (see Sections 3.1, 4.1).

2.3. Grassland fertilization

The experiment covered four growth periods in the 2014 growing season and five growth periods in the 2015 season. In the experimental period, all N fertilizer was applied as synthetic fertilizer calcium ammonium nitrate (CAN, 27% N). In 2014, the plots with spring treatment received N fertilizer in the three growth periods following treatment at a rate of 60, 50 and 30 kg N ha^{-1}, respectively, leaving the last growth period of the season unfertilized. The plots with autumn treatment did not receive N fertilizer in the growth period following treatment, also leaving the last growth period unfertilized. In 2015, all plots (spring and autumn treatments) received N fertilizer in the first four growth