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Biodiversity in intensive grasslands: is a compromise possible?

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Abstract

Intensive grasslands are managed for production, while semi-natural grasslands provide biodiversity. Can we bridge the divide, given declines in biodiversity and the sustainability agenda? It is clear that very intensively managed grasslands are damaging to biodiversity, likely as much as intensive arable land. There are, however, methods to improve biodiversity on intensive grasslands. These include relatively 'light touch' approaches, e.g. small changes in management, such as decreasing cutting or grazing frequency, or reducing fertilizer use. Alternatively, field margins might be taken out of production. All these approaches have been shown to enhance plant, invertebrate and bird diversity. Adding a few plant species can enhance yields as well as biodiversity in low intensity grasslands. The most radical intervention is to restore semi-natural grasslands onto intensive grassland sites. These approaches will all likely come at a cost to production, but recent research is showing how compromises might be achievable. Increasing plant diversity, even in intensive grasslands, can benefit yield and revenues. Furthermore, considering a wider range of public benefits from grasslands, such as carbon storage, suggests mechanisms whereby farming for profit will also allow farming for biodiversity.

Keywords: management, production, restoration, semi-natural grasslands, sustainability

Introduction

There is a great divide in grassland research. Intensive grasslands (also agriculturally-improved, or production grasslands) are generally studied in terms of enhancing their agricultural production and developing efficient livestock systems. Natural and semi-natural grasslands (also conservation, or species-rich, traditional, or High Nature Value grasslands) are studied in terms of their biodiversity and wider environmental benefits (Bullock *et al.*, 2011, Bengtsson *et al.*, 2019). Individual researchers and research teams rarely cross over this divide. However, there is increasing policy interest in developing grassland systems that provide both production and environmental benefits (Pe'er *et al.*, 2019). There has been interest in the production potential of semi-natural grasslands, with the idea that increasing plant richness can boost production (Isselstein *et al.*, 2005; Bullock *et al.*, 2007, Schaub *et al.*, 2020). However, the relatively low production in non-intensive grasslands remains an issue and is the driver for the conversion of semi-natural grasslands to more productive agricultural systems (Bullock *et al.*, 2011).

It is much more rare to consider the biodiversity of intensive grasslands, or their potential to host biodiversity. There is scope for integrating at least some aspects of more traditional grazing management systems into productive agriculture to support not only productivity but also biodiversity. For example, the use of more complex legume-dominated swards to support yields under reduced fertilizer regimes. Here, we consider these issues within a wider discussion of: 1) intensive grasslands as a cause of biodiversity loss; 2) whether intensive grasslands provide any biodiversity benefit; 3) what can be done to improve biodiversity with no/little effect on production in intensive grasslands, and 4) approaches to restoring semi-natural grasslands on intensive grasslands.

Intensive grasslands as a cause of biodiversity loss

The conversion of traditional forms of agricultural grassland – semi-natural grasslands, and, occasionally natural grasslands – to intensive grasslands leads to loss of biodiversity almost by definition. While European semi-natural grasslands are among the most floristically diverse habitats in the World (Wilson *et al*., 2012), intensive grasslands are characterized by having very few plant species, several of which are often non-native cultivars. This plant biodiversity loss extends to other taxa. Reduced prey availability and more frequent cutting or grazing regimes is linked to declines in farmland bird species across Europe (Vickery *et al.*, 2001; Donald *et al.*, 2002; Strebel *et al.*, 2015). In general, semi-natural grassland hosts more bird species than intensive grassland (Barnett *et al.*, 2004; Woodhouse *et al.*, 2005). Similarly, more intensively managed grasslands have lower arthropod diversity than semi-natural grasslands, across a wide range of taxa (Attwood *et al*., 2008, Simons *et al*., 2015). This can be due to a reduction in floristic diversity, but also as a result of swards tending to be structurally homogenous and lacking many floristic structures upon which arthropods depend, e.g. flowers or seed heads (Woodcock *et al*., 2007b). Frequent cutting regimes supported by inorganic fertilizer inputs also vastly decreases arthropod abundance and diversity in these swards (Humbert *et al*., 2010). Below-ground taxa suffer as well. Changed soil characteristics in intensive grasslands, such as low organic matter and changed pH, decrease microbial biomass and growth (Malik *et al*., 2018) and earthworm species richness (Johnston, 2019).

Is the semi-natural *vs* intensive grassland a fair comparison? That is, are intensive grasslands located where traditionally there were semi-natural grasslands? Our work in Dorset, a rural county on the south coast of England suggests the situation is more complex that this simple characterisation. In the 1930s, Dorset had ca. 152,000 ha of semi-natural grassland (Hooftman and Bullock, 2012). By 2000, there was less than 11,000 ha remaining. About 58,500 ha (39%) had been converted to intensive grassland, while ca. 65,500 ha (43%) had become arable land. This loss continues; between 1990 and 2015, 15% of semi-natural grasslands in Dorset were converted to arable and 65% to intensive grassland (Ridding *et al*., 2020). Other major conversions over both time periods were to urbanisation and tree planting. Overall, conversion of this and other semi-natural habitats (heathland, broad-leaved woodland) in Dorset to intensive agriculture massively increased agricultural production, from an estimated £33M p.a. in the 1930s to £219M in 2000 (using prices for the year 2000) (Jiang *et al*., 2013). The improved grassland contributed most to this, with an increased agricultural production over the whole of Dorset worth an extra £141M p.a. From a biodiversity point of view, any conversion of these species-rich habitats is a loss. In Dorset we found that plant species richness decreased from a mean of ca. 393 species per 2×2 km grid cell in the 1930s to 289 species in 2000 (Jiang *et al*., 2013). But it is worth asking the question whether conversion to intensive grassland is the 'worst' that can happen to semi-natural habitats in terms of biodiversity.

Do intensive grasslands provide any biodiversity benefit?

Improved grasslands are not a wildlife desert. They generally have very low plant diversity, but they can provide habitat and resources for other taxa including invertebrates and birds. In England, Barnett *et al*. (2004) found twice the number of birds on improved than semi-natural grasslands, although this was due to large numbers of corvids and gulls. Species including snipe *Gallinago gallinago*, blackbird *Turdus merula,* and redwing *Turdus iliacus* were more common on semi-natural grassland. Jackdaw *Corvus monedula*, rook *Corvus frugilegus*, carrion crow *Corvus corone*, and starling *Sturnus vulgaris* were found more on intensive grassland, possibly because manure addition had led to an increase in invertebrate food quantity. Rutgers *et al.* (2016) found a higher abundance and no difference in diversity of earthworms in European intensive grasslands compared with semi-natural grasslands.

Intensive grasslands may, in some cases, be better for biodiversity compared to alternative agricultural land uses. Across Europe, Tsiafouli *et al.* (2015) found that species richness of earthworms, Collembolans, and oribatid mites was lower in arable systems than in intensive grasslands, as did Rutgers *et al.* (2016) for earthworms across Europe. A global meta-analysis by Attwood *et al.* (2008) showed that intensive grass has higher overall and decomposer arthropod species richness than cropped systems. But it should not be assumed that intensive grassland will always be the best intensive form of agriculture for biodiversity. For example, in a study across four European countries, farmed areas with flowering crops enhanced species richness of wild bees, in contrast to livestock systems (Le Feon *et al*., 2010). The meta-analysis by Attwood *et al.* (2008) showed no difference between intensive grasslands and arable lands in arthropod predator species richness. Furthermore, *Miscanthus* bioenergy crops increased earthworm diversity compared to intensive grasslands (McCalmont *et al*., 2017).

What can be done to improve biodiversity in intensive grasslands?

European agri-environment schemes have focused mostly on improving biodiversity in arable systems and fields. Interventions mostly implement a 'land-sparing' approach; removing some land from arable production – from field margins to whole fields – to provide resources and habitat for wild species (Rey Benayas and Bullock, 2012). Improving biodiversity and associated ecosystem services on intensive grassland is less well discussed or researched. Here, we consider various approaches that have been researched. To be clear, we focus on management of intensive grasslands and exclude management of semi-natural grasslands.

Changed management

As we showed above, low biodiversity and low plant species richness in intensive grasslands is linked to the intensity of management through cutting and/or grazing and fertilizer additions. So, can altered management enhance biodiversity, and what does this mean for production? A study on agriculturally-improved upland permanent pastures in Wales found that hay cutting alone or combined with aftermath grazing created more diverse plant swards with greater numbers of flowers than grazing alone, and this enhanced diversity of foliage-dwelling arthropods (Garcia and Fraser, 2019). Buckingham *et al.* (2011) showed that reducing the number of silage cuts and stopping aftermath grazing greatly increased the amount of ryegrass seed available. Use of Italian rather than perennial ryegrass also increased seed yield. In both cases, increased seed enhanced bird use of the grasslands. In general delaying mowing or grazing onset tends to benefit plants, invertebrate and birds, as shown by a Conservation Evidence review (https://www.conservationevidence.com/actions/131).

Reducing fertilizer or pesticide inputs can also enhance biodiversity in intensive grasslands. A Conservation Evidence review (https://www.conservationevidence.com/actions/139) considered 38 studies into this approach. Of these, 34 showed benefits to plant, invertebrate and bird abundance or species richness, but the others showed no, or slow effects. The aridity of intensive grassland soils is also an issue. Onrust *et al*. (2019) suggest replacing slurry- and slit injection-based management, with the use of farmyard manure to enhance surface soil moisture to benefit earthworms, and the birds that feed on them.

At larger scales, heterogeneity across grasslands has been emphasized as the best approach to benefit biodiversity. Research in England suggested that the diversity of bird species in intensive grassland landscapes through the winter would be enhanced by mosaics of fields managed as short-term leys and permanent pastures with low-intensity cattle grazing over the autumn and winter (Perkins *et al*., 2000). Also, incorporation of some arable cropping into grassland-dominating landscapes is known to benefit mobile taxa (Robinson *et al*., 2001).

While all above studies took place in intensive grasslands, the consequences for agricultural production and the farm economy in general were not covered. A few studies that looked at the farm economy reported costs associated with such modified management, which can be considerable for some production systems (e.g., Gottwald & Stein-Bachinger, 2017). It therefore remains unclear whether farmers can apply management to improve biodiversity without negative economic consequences. Indeed, many of these actions might be considered as leading to 'de-intensified' grassland (Isselstein *et al*., 2005), with positive consequences for biodiversity, but having negative impacts on production. The effect, however, depends on the intensity of the baseline grassland management. Klaus *et al.* (2013) compared conventional grasslands in Germany with those managed organically, having lower fertilizer inputs and cutting frequency, although there were no differences in grazing intensity. Vegetation biomass (mean 3 ton DM ha^{-1} for both conventional and organic grasslands) and nutrient content (used to indicate fodder quantity and quality) and soil fertility did not differ between management types, while arthropod diversity was increased by organic management. However, both grassland types can be regarded extensive in terms of their production.

Grassland margins

Similar to using field margins on arable land, field margins in intensive grassland can be used to enhance biodiversity. By contrast to arable systems, grassland field margins are not commonly used to enhance biodiversity, and can be complicated to manage. For example, livestock may need to be fenced off from these margins. Margins also represent land lost to production. While such margins have been shown to enhance production in arable systems by providing pest control, pollination and other services (Pywell *et al*., 2015), the potential for such benefits has not been studied in intensive grasslands, and demand for some (pest control) is likely to be small.

There are, however, clear biodiversity benefits. In a large project in England, 10m wide margins were created in intensive livestock farms and managed to increase sward architectural complexity through combinations of fertilizer, cattle grazing, and timing and height of cutting (Woodcock *et al*., 2007a). The absence of inorganic fertilizer, combined with a reduction in the intensity of both cutting and grazing regimes, promoted floral species richness and sward architectural complexity. Beetle abundance and species richness was higher in the extensively managed margins compared the more intensively managed margins (Woodcock *et al*., 2007a), as were these measures for a broader group of arthropods including bugs, planthoppers and spiders (Woodcock *et al*., 2009; Blake *et al*., 2011). These same treatments, along with treatments in which extra grass and herb species were sown, were assessed in terms of their ability to provide forage and structural resources for pollinators (Potts *et al*., 2009). Bumblebees were most abundant, species-rich and diverse in the sown treatments and virtually absent from the grass-based treatment. Butterflies showed similar responses, albeit also being found in the more extensively managed margins. Cattle grazing in these margins had negative effects on biodiversity, and fencing was required to exclude livestock during the flowering period.

Other studies have found similar benefits. Fencing off grassland field margins alongside watercourses enhanced densities of bugs, harvestmen, sawflies and slugs (Cole *et al*., 2012). In Ireland, Anderson *et al*. (2013) fenced off grassland field margins and found a greater diversity of a wide range of arthropods – beetles, bugs, flies, spiders and hymenopterans – in the margins compared to the intensively-managed field. These benefits increased if the margins were cultivated and sown with a wildflower and grass mixture. Birds can also benefit, and Wiggers *et al*. (2016) found that grass field margins contained more large aerial insects – which are fed on by waders – than in-field, and additional management of the grass field margin including the cessation of fertilizers and exclusion of grazers increased the number of aerial insects. Margins use a relatively small part of the field and so will have relatively limited effects on production (Pywell *et al*., 2015). But, there can be impacts on farming operations, such as the need to fence margins to prevent access by livestock (Potts *et al*., 2009).

Introducing plant species

There is increasing interest in the establishment of relatively biodiverse and productive grasslands, sometimes called herbal leys. This might offer a compromise between economically viable forage production and modest plant species richness gains using agricultural legumes and robust herbaceous species known to provide pollen and nectar resources. What evidence is there for the success of such approaches? A recent meta-analysis found that, globally, grassland net primary productivity (NPP) is higher in grasslands with legumes relative to grass-only controls (Ashworth *et al*., 2018). However, this is a poor argument for increasing plant diversity *per se*, especially as adding one legume led to 52% increase in NPP, additional legume species added only a further 6%.

More biodiversity-focused studies give more promising results. We focus here on adding plant species to intensive grassland rather than restoration of semi-natural grassland, which is covered in the next section. Hofmann and Isselstein (2005) stopped fertilizer additions in a grassland and found that over-sowing with wildflower mixtures increased dry matter yield (by 23% on average) and crude protein concentrations, although digestibility was decreased. Woodcock *et al*. (2012) sowed an intensive, species-poor grassland in central England with treatments contrasting a mix of five productive grass species, a mix comprising the same grasses with the addition of seven agriculturally bred legume species, and finally a mix comprising the same grasses and legumes with the addition of six competitive native forb species. Here, again, fertilizer additions were stopped. The increasingly plant species-rich swards had higher diversity of phytophagous beetles (Woodcock *et al*., 2012), predatory beetles and spiders (Woodcock *et al*., 2013), and bees, butterflies and hoverflies (Woodcock *et al*., 2014). The addition of only legumes had some benefit, although on their own the cover of these species (originating from agricultural seed stock) declined rapidly, so forb addition was important for maintaining biodiversity gains. In this and a parallel study in south-west England, the sowing of legumes and forbs gave higher yields of silage and increased nutrient quality of the herbage (Defra, 2013). Although the additional forb component resulted in slightly higher herbage production and quality over simply the presence of legumes, this effect was comparatively small when compared to the benefits of including legumes over a sward sown with just grasses. In addition, while the inclusion of legumes and forbs did not increase the daily rate of increase in livestock weight, they did result in swards that could be grazed for longer periods of time.

Approaches to restoring semi-natural grasslands on intensive grasslands

A radical approach to improving biodiversity in intensive grasslands is to restore them to semi-natural grassland vegetation. While there is a long history of establishing semi-natural grasslands on arable land (Pywell *et al*., 2002; Torok *et al*., 2011), there has been less work on restoring from intensive grasslands. Indeed, in general it seems easier to achieve such restoration on arable than intensive grassland sites, where the intact vegetation provides poor opportunities for introduced species to establish and survive (Kiehl *et al*., 2010). Furthermore, high soil fertility in intensive grasslands can limit success in introducing plant species (Janssens *et al*., 1998).

Studies into methods to introduce species to intensive grasslands have found similar results across Europe. In an experiment in England, severe disturbance involving turf removal followed by seed addition by sowing was the most effective and reliable means of increasing plant diversity (Pywell *et al*., 2007). Disturbance by multiple harrowing was moderately effective and was enhanced by molluscicide application to reduce seedling herbivory and by sowing the hemiparasite *Rhinanthus minor* to reduce competition from grasses. Low-level disturbance by grazing or slot-seeding was ineffective, and fertilizer addition had no effect. In Germany, introduction of seed in hay taken from semi-natural grasslands was most successful when combined with deep ploughing, but shallow tillage also gave good establishment of target species, and no soil disturbance resulted in poor establishment (Bischoff *et al*., 2018). In essence, all studies have found successful restoration on intensive grasslands requires adding seeds, for example by sowing or hay from donor sites, along with severe soil disturbance, for example by rotovating, harrowing, or ploughing, to decrease competition (Schmiede *et al*., 2012; Sullivan *et al*., 2020).

Using *Rhinanthus minor* or related species to reduce competition from grasses has been found to be beneficial in other projects (Pywell *et al*., 2004; Bullock & Pywell, 2005), and this could be a less extreme approach to reducing competition. But establishment of this species is erratic, leading to variable outcomes (Hellström *et al*., 2011; Mudrak *et al*., 2014), and it has not been tested across a range of countries.

Implications

It is clear that intensification of both grassland and arable systems has led to biodiversity loss (Stoate *et al*., 2009). Furthermore, because in some parts of Europe a high proportion of biomass from arable crops is being fed to animals, both grassland and arable can be regarded as parts of the same livestock production systems. In high yielding production systems, grassland and arable management is intensive. But, recent scenarios demonstrate that under a reduced share of animal protein in human diets, it is feasible to achieve reduction of either management intensity (e.g., organic management, Muller *et al.* (2017)) or the amount of land under crops and intensive grass needed for food production (Berners-Lee *et al*., 2018).

We have shown there are a number of well-demonstrated approaches to enhance biodiversity in intensive grasslands, not only for plants but also for other taxa including birds and invertebrates. These range from changing management intensity such as cutting frequency or fertilizer application, to setting small parts aside such as field margins, to adding plant species across the whole grassland from a few to many.

But, increasing biodiversity in grasslands is likely to come at a cost to production. At the extreme, production will decline greatly when restoring intensive grasslands to a semi-natural state, mirroring the large differences in production between semi-natural and intensive grasslands (Bullock *et al.*, 2011). Production aside, it is clear that semi-natural grasslands provide high levels of many ecosystem services compared to intensive grasslands (Bullock *et al.*,2011; Bengtsson *et al.*, 2019). It is therefore worth considering how to bring semi-natural, or more biodiverse, grasslands into the mainstream of agriculture. As we have pointed out, the grassland production and the grassland conservation communities tend to work separately. As a result, there is little work contrasting production in intensive grasslands to production in grasslands where biodiversity is enhanced. As it is assumed there will be a shortfall in production and so income, agri-environment schemes, which compensate farmers for income foregone, are the standard mechanism to achieve this integration of production and biodiversity conservation. Another and more forward-thinking approach would be to consider better how to utilise semi-natural grasslands for production in sustainable livestock systems, which avoid competition for arable land between human food and animal forage (Röös et al. 2016).

To this end, an increasing number of studies are demonstrating that increased plant diversity can benefit grassland production. For example, a long-term study contrasting non-fertilized, restored grasslands with seven grasses *vs* those sown with 11 grasses and 28 forbs found after eight years, that the species-rich treatment had an average 43% higher hay yield than the species-poor treatment (Bullock *et al.*, 2007). In a broader scale study, Schaub *et al.* (2020) contrasted extensive high-diversity systems and intensive low-diversity systems, considering both biomass yield and forage quality to assess revenues for milk production. Independent of management intensity, they found a positive relationship between plant diversity and potential revenues from milk production. Unsurprisingly however, revenues were lowest in the extensive systems, and highest in the most intensive systems.

As the sustainability agenda increases in importance, economic considerations other than production might become critical. For example, considering the economic benefits of both forage yield and carbon storage, Binder *et al.* (2018) calculated that even a profit-maximizing farmer would favour a diverse mix of species, with optimal richness falling between the low levels found in intensive grasslands and the high levels found in semi-natural grasslands. Finally, as well as in-field approaches, it may be possible to seek compromises between production and biodiversity by extensifying management of a proportion of grasslands in a landscape, while maintaining or even increasing intensity of management in other grasslands (Qi *et al.*, 2018). Supporting farmers with public payments for multiple public goods from grasslands, beyond their production values, remains a promising development agenda (Bengtsson et al. 2019).

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