Squeeze it or leave it? An ecological-economic assessment of the impact of mower conditioners on arthropod populations in grassland

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Abstract
This study addresses the use of conditioners as a driver of arthropod loss in agricultural landscapes. Conditioners compress the freshly cut mowing material mechanically to destroy the evaporation-inhibiting wax layer of the grass material. This compression potentially increases the physical damage to several arthropod groups during the mowing process. We have combined an ecological field study on the impact of conditioners on arthropods at the plot level with an analysis of the economic rationale of applying conditioners in differently managed grasslands in the study region, in order to understand the impact of applying conditioners on the damage to arthropods at the landscape level. The use of conditioners in the mowing process significantly increased the overall percentage of damaged individuals by 18% from 52% without to 70% with conditioner use. Aphids and plant lice, beetles, thrips and mites were most severely affected by additional damage. We also found that the use of conditioners takes place on substantially more than 20% of all grasslands in the study region. Depending on the respective grassland area managed with conditioners in the future, grasslands could be losing an additional 4% to 18% of their overall arthropod numbers only due to the use of conditioners compared to a scenario without conditioners. As the damage due to the use of conditioners is presumably higher in extensively managed grasslands, and the profit of their use is higher in intensively managed grasslands, we suggest, as an implication for insect conservation, concentrating measures to disincentivise the use of conditioners on extensively managed grassland.

Keywords Technological innovation · Insect mortality · Mowing technology · Conditioner · Biodiversity loss · Insect extinction and conservation

Introduction
Agricultural intensification is a major driver of the decline of biodiversity in Europe (Kleijn et al. 2011; Emmerson et al. 2016) and other parts of the world (Landis 2017). Agricultural intensification is broadly defined as the industrialisation of agricultural practices with the aim of improving yield productivity, by increasing agricultural inputs and the rationalisation of farm and land use structures (Kleijn et al. 2009; González-Varo et al. 2013). Consequently, previous research addressing the decline of biodiversity in agricultural landscapes has focused on the increasing use of pesticides (Geiger et al. 2010, Pisa et al. 2015, Emmerson et al. 2016) and fertilisers (Kleijn et al. 2009), the establishment of large scale farms (Herzog et al. 2006), the prevalence of monocultures and landscape homogeneity (Batáry et al. 2011; Landis 2017, Birkhofer et al. 2015), simplified crop rotations (González-Varo et al. 2013) and mowing regimes (Johst et al. 2006; Drechsler et al. 2007; Wätzold et al. 2016), and a comparison of whole farming systems (Birkhofer et al. 2015; Gerling et al. 2019).

According to Herzog et al. (2006), Zanten et al. (2013) and Vogt et al. (2019) the impact of technological development of agricultural machinery may present an important additional threat to biodiversity in agricultural landscapes. Research has shown that grassland harvesting techniques do have an impact upon arthropod populations (Humbert...
et al. 2009, 2010). However, the impact of technological development has received comparatively little attention in terms of its impact on biodiversity. In addition, previous studies such as Humbert et al. (2009, 2010) do not provide an understanding of the economic drivers behind the decision to implement a specific agricultural technology. This, however, is important as its potential negative impact on the landscape scale depends not only on the mortality caused by the machinery, but also on how frequently this machinery is used by farmers in comparison to other, perhaps less harmful, machinery.

Here, we address a technological development that may be an important additional threat to arthropods in grasslands (SRU 2018), namely mower conditioners that are used to speed up the drying process of mowing material directly after the mowing process. The conditioner is usually attached to the mowing machine and compresses the freshly cut mowing material mechanically to destroy the evaporation-inhibiting wax layer of the grass material. This process is beneficial for the farmer as it reduces the field retention time of mowed material, resulting in a higher yield and energy content. However, in addition to the general mortality caused by the mowing process, conditioners may pose a further threat to arthropods as they squeeze the mowing material including the arthropods inside.

To assess the impact of mower conditioners on arthropods, we first investigated to what extent a single conditioner in the mowing and harvesting process increased damage to individuals in multiple arthropod groups, in comparison to a mowing and harvesting process without a conditioner. Arthropods are a relevant taxonomic group, as they may act as indicators of overall biodiversity (Kremen et al. 1993; Billeter et al. 2008) and are severely affected by agricultural intensification (Cardoso et al. 2020).

To understand the impact of the use of conditioners on the damage rate in different vegetation-dwelling arthropod taxonomic groups, we carried out field experiments in managed grasslands of different land use intensities in the Aller river valley in the Heidekreis county in Lower Saxony, Germany. We sampled arthropods from strips that were cut with or without the use of a conditioner in all types of grasslands. Samples were then analysed in the laboratory to identify the damage rate in different arthropod taxonomic groups. We hypothesize that (H1) mowing with the use of conditioners considerably increases the damage rate in arthropods compared to mowing without conditioners, and that (H2) this effect is most pronounced in arthropod taxonomic groups with generally larger individuals (e.g. more in Orthopteroidea compared to Collembola).

The dissemination of conditioner use among grassland farmers was then analysed to identify the magnitude of the damage potential of conditioner use at the landscape level. We interviewed 236 farmers in Heidekreis county and carried out expert interviews with manufacturers of grassland harvesting technologies. To identify management forms for which the use of conditioners are particularly profitable, we applied profitability calculations to estimate the profit increases of farmers if they used mowing conditioners on differently managed grasslands. These calculations may also help to identify appropriate payments to compensate farmers for reduced profits if the use of conditioners is prohibited as a prerequisite to participate in future agri-environment schemes. Combining the results of ecological field sampling and the agri-economic analysis facilitates to develop holistic recommendations on the (non-)use of mowing conditioners taking into account economic and nature conservation perspectives.

Materials and methods

Study region

The Aller river valley in the Heidekreis county in Lower Saxony, Germany is characterised by pasture and meadow landscapes (Fig. 1). The area is rich in biodiversity and of relatively high nature value as it is home to a range of endangered animal and plant species, for which arthropods are an important link in the food chain (Verordnung Landkreis Heidekreis 2016). Most grassland in the region is characterised as rather extensively managed, mesophile grassland. Other areas, especially at the edge of the valley, are characterised as more intensively managed grassland (NLWKN 2020). Despite the relatively extensive management of the area, a substantial loss of biodiversity has been reported (LSG-VER 58 2016).

Grassland farming is an important sector of the agricultural economy in the county. About one-third of the county area is agricultural land, 30.5% of which is managed as grassland. 24% of local farms are considered large (> 100 hectares), 57% medium-sized, and 19% small (< 10 hectares). Large farms cultivate roughly 62%, medium-sized farms 36.5% and small farms 1.5% of the agricultural land (Statistische Ämter des Bundes und der Länder 2016). The county also follows the general trend seen elsewhere in Germany, to consolidate farms into fewer units of larger size (Grocholl and Mersch 2014). In addition, an ongoing movement towards organic farming can also be observed in the area. Around 2000, less than 3% of farmland was managed organically in the county. In 2016, this number increased to 10.5% (Statistische Ämter des Bundes und der Länder 2016).

Arthropod sampling

The sampling took place during two mowing dates at the beginning of November 2019 and in June 2020 directly
following mowing at two farms in the Aller river valley (Allerniederung). The late mowing date in 2019 resulted from an extremely dry summer period, not allowing for biomass growth and mowing before November. In total, 3 intensively and 5 extensively managed grasslands were sampled in 2019, and 6 intensively and 8 extensively managed grasslands in 2020. Intensive grassland management involved the application of 140 kg of organic fertiliser per hectare, and did not include regulations of the cutting frequency or timing. In extensive management, grasslands were not mown before June 20. In addition, no plant protection products or fertilisers were applied, and no livestock grazing was practised. The selected grasslands have similar soil types. The intensive plots are classified as intensive grassland in floodplains (GIA), the extensive plots are classified as other mesophilic grassland (GMS) and mesophilic grassland of moderately humid sites (GMF).

On each of the selected grasslands, one strip of 9 m width was mown without the use of a conditioner and a second strip of the same length was mown with the use of a conditioner for the whole length of each grassland. Four samples of freshly mown material were immediately sampled from each mown strip, and 1 kg of material was carefully packed into closed plastic bags (Fig. 2). The plastic bag content was then carefully sieved for 5 min using a beetle sieve with an 8 mm mesh size to separate plant debris from arthropods. All sieved material was directly transferred into bottles containing 75% ethanol and transported to the laboratory for identification of all arthropods. Sampling time, location, and vegetation height of the grassland prior to mowing were recorded for each sampling date and grassland. In the laboratory, the grass material remaining in the samples was sorted, arthropods were taxonomically determined to the level of the order or to suborder/family if possible. All individuals were checked for injuries during this identification procedure using a stereomicroscope (Zeiss Stemi 305) with up to 80× magnification. Individuals were counted as long as a head was present, and individuals were scored as damaged if a clear severance or squeezing of the thorax or...
abdomen was visible (Fig. 3b and d). The following 16 taxonomic arthropod groups were individually counted, observed for damage and analysed: Acari, Araneae, Auchenorrhyncha, Brachycera, Coleoptera, Collombola, Dermaptera, Gastropoda, Heteroptera, Hymenoptera (excl. Formicidae), Formicidae, Lepidoptera, Nematocera, Orthopteroidea, Sternorrhyncha and Thysanoptera (Table 6).

Statistical analysis

The abundances and damage rates of all 16 taxonomic groups were analysed in two multivariate permutational analyses of variance (PERMANOVA: type III sums of squares, permutation of residuals under a reduced model, 9999 permutations). To account for the two sampling dates (November 2019 and June 2020) and different grass conditions at times of cutting (dry or wet grass surface), the two random factors (“Date” and “Grass”) were included in the models. The factors “Management” (intensive and extensive) and “Conditioner” (with or without) were added as fixed factors and the interaction term between the two fixed factors was included in the models. Abundance data was log(x + 1) transformed for all taxa to reduce the weight of very abundant taxonomic groups in the multivariate analysis. Abundance data for all 44 sample units (21 fields with strips with and without conditioner use) was then transformed into a pairwise resemblance matrix using Bray–Curtis similarities. For the analyses of damage percentages (% of damaged individuals per total individuals), we excluded Dermaptera, Gastropoda and Lepidoptera as fewer than 50% of the sample units included these taxonomic groups. Data for the remaining 13 taxonomic groups was then transformed into a pairwise resemblance matrix using Gower similarities. This similarity measure provides pairwise resemblances between all sample units, even if an individual taxonomic group was not present in a particular sample. Gower similarity ignores missing values for the calculation of pairwise similarities. In case of a significant PERMANOVA result for a fixed factor either on the abundance- or damage-percentage, follow-up analyses were performed for the respective factor and individual taxonomic groups to calculate the effect strength according to Hedge’s g. The resulting effect strength values and the 95% confidence intervals are presented in Gardner-Altman plots for all individual taxonomic groups for which the confidence intervals did not overlap with the 0 value in effect strength. In Gardner-Altman plots, abundance data are plotted on the left axis; mean Hedge’s g is represented as a dot and horizontal line on the right axis; vertical error bars represent bootstrap 95% confidence interval together with the resampling distribution from 5000 resamples. PERMANOVA models and ordinations were created with PRIMER 7 version 7.0.13 and the PERMANOVA add-on (PRIMER-e, Quest Research Limited, Auckland, New Zealand). Hedge’s g and Gardner-Altman estimation plots were created according to Ho et al. (2019) at https://www.estimationstats.com/.

Economic assessments

The purpose of the economic assessment is to understand the economic reasons why farmers use conditioners, in order to assess the extent farmers use conditioners for different types of grassland management. We surveyed farmers in the study area using a questionnaire containing questions on the frequency, first use, and reasons for applying conditioners, as well as potential compensation payment requested for the non-use of conditioners. We also requested information regarding farm characteristics as we hypothesised this would influence the decision to use conditioners. We hypothesised that farm size, intensive versus extensive grassland management, conventional versus organic grassland farming, and the contracting of professional mowing subcontractors, influence the decision to use conditioners. These hypotheses were based on an extensive literature review and interviews with manufacturers of grassland harvesting technologies. Of 738 contacted farmers 303 responded with 236 indicating that they manage grassland. This corresponds to a response rate of 32%, which is rather high compared to other farmer surveys.
To scrutinise farmers’ responses and to obtain information beyond the case study area, we also approached the ten leading manufacturers of grassland mowing technologies in the German market to conduct semi-structured interviews by email and telephone. Under the request of confidentiality and anonymity four experts provided information about the dissemination of conditioners.

To assess the profit changes of the usage of conditioners for farmers, we calculated the difference in variable costs and the quantity and quality of grassland fodder (Mewes et al. 2015) for the use and non-use of conditioners. As a sample case, we selected the annual production of wilted silage per hectare and calculated the difference in profit for the following main types of meadow management: conventional and intensive (1), organic and intensive (2), conventional and extensive (3) and organic and extensive (4). We categorised a mowing regime as intensive if mowing was performed four times a year, and extensive if only twice. Conventional management refers to the application of mineral fertilisers four times a year, while organic management foregoes mineral fertilisation (KTBL 2020). Within these four management types, we additionally distinguish among scenarios of low and high yields, good and bad harvest weather conditions, and the usage of small and large scale mowing technology. For this we relied on secondary data from the German Association for Technology and Structures in Agriculture (Thaysen et al. 2014, Achilles et al. 2015, KTBL 2020), e.g. to specify low and high yields for the different grassland management types and small and large scale mowing technologies. In addition, we relied upon the results of our survey questionnaire and information in the literature on how to quantify and monetise differences in profit due to the usage of conditioners in the wilted silage production.

Results

Ecological assessment

A total of 21,581 arthropods were collected and examined with Acari (5540), Thysanoptera (5234), Sternorrhyncha (4398) and Heteroptera (2460) being the most abundant taxonomic groups (for more details see Tab. 5.A). Both random factors, date (F_{1,38} = 24.24, P < 0.001) and grass condition (F_{1,38} = 8.39, P < 0.001), affected the composition of arthropod communities significantly. Grassland management (F_{1,38} = 5.57, P < 0.001), but not the use of a conditioner (F_{1,38} = 0.56, P = 0.751) affected the composition of arthropod communities with no significant interaction term between both fixed factors (F_{1,38} = 0.71, P = 0.611). Extensively managed grasslands on average had 1.7 times higher arthropod abundances compared to extensively managed grasslands. Araneae and Collembola were more abundant in extensively managed grasslands (Fig. 4a and b), whilst Orthopteroidea were less abundant (Fig. 4c).

Date (F_{1,38} = 3.98, P = 0.005), but not grass condition (F_{1,38} = 2.08, P = 0.107), affected the damage percentages in arthropod communities significantly. The use of conditioners (F_{1,38} = 10.94, P < 0.001), but not the management (F_{1,38} = 1.07, P = 0.422) affected the damage percentages in arthropod communities with no significant interaction term between both factors (F_{1,38} = 0.48, P = 0.707). The use of the conditioner increased the average damage percentage across all arthropod taxonomic groups by 18% from 52 to 70% and all analysed arthropod groups were on average more damaged in samples with conditioner use. Confidence intervals of Sternorrhyncha, Coleoptera, Thysanoptera and Acari did not overlap with the zero line for effect strength (Fig. 5a–d).

Economic assessments

Dissemination rate of conditioner use

In our survey, 49 of the 236 grassland farms reported to use conditioners. This corresponds with a rate of 20.8%. 31 use conditioners all the time, whilst 18 use conditioners sometimes (depending on weather conditions and mowing volume). Due to the amount of land, larger farms tend to utilise high-tech mowing equipment, such as conditioners, more frequently in order to reduce labour and increase yield. Large scale farms with land management of over 100 hectares use conditioners at an above-average rate (30.8%), whereas small scale farms used conditioners at a below-average rate (10.9%). This leads to a higher prevalence of conditioners, as suggested by the average rate of 20.8% as large farms manage about 62% of agricultural land in the Heidekreis county (Statistisches Ämter des Bundes und der Länder 2016). Outsourcing mowing to a professional contractor also made conditioner use more likely. 41 farmers in the survey reported having hired a contractor in the past, 16 of which (39%) indicated that the contractor always uses a conditioner, and 14 (34%) sometimes uses a conditioner. In contrast, the survey found no evidence of different conditioner use on intensively and extensively managed land, or in organic and conventional grassland management.

According to the interviewed experts from the mower technology manufacturing industry, the long-term yearly average rate of mowers equipped with conditioners ranges between 15 and 20% in the German market, however this varies across mower types. Around 30% of large scale mowers, such as butterfly combinations and disc-front mowers, and around 10% of smaller scale mowers, such as rear and 3-point mowers are equipped with conditioners.

Interestingly, experts stated that, in contrast to the German average, conditioners are used more often internationally. For example, the use of trailed mowers is prevalent in
the United States of America and other European countries such as France and the Netherlands. As approximately 80 to 90% of trailed mowers are equipped with a conditioner the percentage of meadows mowed with conditioners may be as high as 70% in these countries.

**Profit changes of conditioner use**

The economic advantage of using conditioners lies mainly in lower production costs, higher yields, and energy density of the harvested dry matter. Treating the freshly cut grass with a conditioner accelerates and eases the drying of the mowed material. In favourable weather conditions, the use of conditioners may therefore save one to two operations of tedding and turning, which lowers the variable costs for machinery input and labour costs by 12.03 to 15.23 € per hectare depending on the working width of the tedder (Eimer 1998; BLE 2015; see for details Table 3 in appendix). In unfavourable weather conditions, often tedding cannot be dispensed with due to the slow drying of mowed material (Thaysen et al. 2014). In addition, mowing with a conditioner is generally more expensive as the greater weight of the mower increases the running costs (Thaysen et al. 2014). Depending on the working widths, mower type and harvest yield, the additional mowing costs may amount to 2.21 € and 2.78 € per hectare (see for details Table 2 in the appendix).

To calculate the saving potential in the production costs of grassland fodder, the variable costs of conditioner use must be deducted from the variable costs of saved tedder use for different working widths of mower and tedder combinations per hectare. Depending on the used mowing machinery, tedder technology, and the number of saved tedding and turning operations, the potential of variable costs savings range between 9.37 € to 27.68 € per hectare during good weather conditions (see for details Table 4 in appendix). As no tedding operations can be dispensed of during bad weather conditions, this saving potential cannot be realised in this scenario.

Another advantage of using a conditioner is the potential reduction of respiration, weathering and disintegration loss, resulting in higher yields—measured in tons of dry matter (DM) per hectare—and higher energy density—measured in mega joules of net energy lactation per kilogram of dry matter (MJ NEL/kg DM). This reduction in loss primarily results from shorter field retention times of mowed material, and fewer operations of tedding and turning (Eimer 1998; Fritz 2018).

Disintegration or crumbling losses occur when cuttings fall below the turf during tedding and turning so that they are inaccessible for collection. Respiration losses are caused by the enzyme activity of still-living cells in the mowed material. To prevent respiration, the water content in the plant must fall below 38% (Gruber et al. 2015). As conditioners

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**Fig. 4** Gardner–Altman estimation plots for average log (x + 1)-transformed abundances per grassland plot and sample (N = 44) of a Araneae, b Collembola and c Orthopteroidea
In addition, the use of conditioners reduces the weather risk, as shorter windows of good weather can be exploited. Thaysen et al. (2014) estimate that for silage production, the use of conditioners reduces overall dry matter losses by around 1.5% and increases energy density by approximately 0.10 MJ NEL/kg of dry matter.

We applied the substitute value method to this data to calculate the additional costs to farmers if they abstain from using conditioners. As an alternative to the use of a conditioner they may need for instance: to increase the mowing area, or apply more fertiliser to compensate for the loss in dry matter content and reduced energy density (Thaysen et al. 2014). In line with the literature, we assume a replacement costs of 18 Ct per 10 MJ NEL/kg of dry matter.

Table 1 summarises the calculations of the profit changes of conditioner use for the main types of meadow management. We find that throughout all scenarios, the non-use of conditioners is less costly in extensively managed grassland, mainly due the fact that extensively managed meadows are less productive. Due to the slightly lower yield levels of organically managed grassland, the cost of non-use of conditioners on organic grassland is somewhat reduced.
Evaluation of the effects of conditioners on arthropods on the landscape scale and to derive recommendations for the future use of conditioners. Depending upon the grassland area managed with conditioners and at the observed average additional damage due to the use of conditioners (18%), additional arthropod losses at the landscape level are estimated to range from 4% (at 20% of grassland area managed with conditioners) to 18% (at 100% area managed with conditioners) on top of the known negative effects of modern mowers without conditioners (e.g. Noordijk et al. 2010).

Effects of intensive and extensive grassland management on arthropods (Bell et al. 2001; Cizek et al. 2012), including aspects such as mowing frequency (Johst et al. 2006, 2015; Birkhofer et al. 2015) and mowing height (Franin et al. 2020) are relatively well understood. Extensive grassland management has pronounced benefits for aboveground arthropods, whereas intensification (for example increasing the number of cuts per year) results in a homogenisation across all trophic levels (Gossner et al. 2016). Mowing at a time of lowest arthropod richness and maintaining uncut strips in meadows are two promising strategies to reduce the overall negative effects of grassland mowing on arthropod populations (for a review see New 2019). The selection of different mowing technology has been mentioned as an important strategy to conserve insect diversity (Samways et al. 2020). However, this approach has only been addressed for a few individual taxa, with only two previous studies that focus on the effect of conditioners on a single beetle species or honey bees (for a review see Humbert et al. 2009) and on butterfly caterpillars (Humbert et al. 2010). Our ecological field study, focusing on the effects of conditioners on all major vegetation inhabiting arthropod orders, suggests that the use of conditioners in the mowing process significantly increases the overall damage to arthropods from 52 to 70%. In line with previous studies, we observed that the abundance of arthropods was higher in extensively rather than in intensively managed grassland. We also observed that some of the most affected groups in our study potentially act as agricultural pests (e.g. thrips or aphids) and future studies should address the effects of mowing technology on beneficial and pest arthropods to provide more detailed conclusions.

### Discussion and conclusion

The impact of technological development of agricultural machinery, with a specific focus on the use of conditioners in agricultural grasslands, is a topic that has received little attention as a driver of arthropod loss in agricultural landscapes (but see Humbert et al. 2010). Conditioners compress the freshly cut mowing material mechanically to destroy the evaporation-inhibiting wax layer of the grass material, increasing the physical damage of several arthropod groups during the mowing process. Here we combined a study on the impact of conditioners on arthropods, with an analysis of the economic rationale of applying conditioners in differently managed grasslands to understand the magnitude of damage on arthropods on the landscape scale and to derive recommendations for the future use of conditioners. Depending upon the grassland area managed with conditioners and at the observed average additional damage due to the use of conditioners (18%), additional arthropod losses at the landscape level are estimated to range from 4% (at 20% of grassland area managed with conditioners) to 18% (at 100% area managed with conditioners) on top of the known negative effects of modern mowers without conditioners (e.g. Noordijk et al. 2010).

| Management scenarios | Unit | Low yield  | High yield |
|----------------------|------|------------|------------|
| Conventional-intensive silage production, good weather, small scale mowing machines | €/hectare/year | 48.38 | 73.33 |
| Conventional-intensive silage production, good weather, large scale mowing machines | €/hectare/year | 94.70 | 121.93 |
| Conventional-intensive silage production, bad weather, small scale mowing machines | €/hectare/year | 47.22 | 73.81 |
| Conventional-intensive silage production, bad weather, large scale mowing machines | €/hectare/year | 94.96 | 117.71 |
| Organic-intensive silage production, good weather, small scale mowing machines | €/hectare/year | 36.32 | 56.99 |
| Organic-intensive silage production, good weather, large scale mowing machines | €/hectare/year | 35.16 | 57.27 |
| Conventional-extensive silage production, good weather, small scale mowing machines | €/hectare/year | 55.03 | 70.09 |
| Conventional-extensive silage production, good weather, large scale mowing machines | €/hectare/year | 48.87 | 63.93 |
| Conventional-extensive silage production, bad weather, small scale mowing machines | €/hectare/year | 21.29 | 34.07 |
| Conventional-extensive silage production, bad weather, large scale mowing machines | €/hectare/year | 20.13 | 34.55 |
| Organic-extensive silage production, good weather, small scale mowing machines | €/hectare/year | 55.03 | 62.56 |
| Organic-extensive silage production, good weather, large scale mowing machines | €/hectare/year | 48.87 | 56.40 |
| Organic-extensive silage production, bad weather, small scale mowing machines | €/hectare/year | 21.29 | 26.54 |
| Organic-extensive silage production, bad weather, large scale mowing machines | €/hectare/year | 20.13 | 27.02 |

Own calculation, based on results of Table 4 and data from KTBL (2014, 2020) and Thaysen (2014)

*a Used example for small scale machines = Mounted mower with working width of 2.8 m + tedder with working width of 4.5 m
**b Used example for small scale machines = Mounted mower with working width of 6.2 m + tedder with working width of 8.5 m
We found that approximately 20% of mowers are equipped with a conditioner. Large scale and trailed mowers frequently integrate conditioners and are commonly applied on large scale grassland. Due to the infrequent use of trailed mowers, the use of conditioners is less common in Germany than in other European countries or North America. While profit increases for farmers are higher on intensively rather than extensively managed grassland, we do not find a difference in the use of conditioners across grassland management types.

Our study has shown that more research with an emphasis upon technological development of agricultural machinery is important. Based on the ecological and economic insights of our study, we suggest several policy recommendations on the (non)use of conditioners. As the ecological harm caused by the use of conditioners is higher in extensively managed grassland, and the profit increase for farmers is higher in intensively managed grassland, we suggest concentrating measures to disincentivise the use of conditioners on extensively managed grassland. In principle, this can be done in two ways: (1) by banning the use of conditioners, or (2) by compensating farmers who forgo conditioners. A ban seems problematic because extensive meadow management already often operates on the edge of profitability (Pötsch et al. 2012). Accordingly, there is a risk that a ban will push the profitability of extensive meadow management below an acceptable level. This may result in intensification or, more likely as intensification on grassland has already taken place on a large scale where this is profitable during the last decades, in the abandonment of the grassland. Both options are undesirable from a conservation point of view given the importance of extensively managed grassland for biodiversity conservation (Bengtsson et al. 2019).

We therefore propose to integrate the abdication of conditioner use in existing agri-environmental and climate programs in extensive meadow management as a further condition of participation and to increase existing compensation payments in this context. The results of our economic assessment may be helpful in determining the appropriate payment increases (compare Table 1). We do not see any particular political hurdles that may prevent the inclusion of a requirement to abstain from the use of conditioners in agri-environmental and climate programs. From an administrative point, the requirement is easy to include in a programme, it is likely to be supported by NGOs working in the field of nature conservation, and farmers are unlikely to object as they receive compensation for their reduced profits. Some agri-environmental and climate programs in Germany already have requirements on using specific mowing technology (e.g. SMEKUL 2021).

It is also important to ensure that farmers do not switch to mowing techniques which may also cause considerable ecological damage after the introduction of measures against conditioner use. For example, generally, conditioners are integrated into mowers. Without a conditioner a mower is lighter, which enables the use of mowers with larger working widths. Thus eliminating the use of a conditioner may result in the use of mowers with greater working widths. There is a risk that increasing the working widths may lead to the loss of important landscape structure elements such as hedges and bushes, which may hinder the application of mowers with large working widths. To avoid such unintended consequences, further ecological and economic research is required that jointly examines the use of different mowing technologies and the resulting ecological effects.

Appendix

See Tables 2, 3, 4, 5, 6.

### Table 2 Variable costs for conditioner use per cut and hectare

| Types of rotary mowers                      | Yield (in tons) | Diesel consumption | Machinery input costs | Total variable costs |
|---------------------------------------------|-----------------|--------------------|-----------------------|----------------------|
| Mounted, working width of 2.4 m             | 25              | 0.80€              | 1.41€                 | 2.21€                |
| Mounted, working width of 2.8 m             | 25              | 1.00€              | 1.78€                 | 2.78€                |
| Mounted front-rear combination, working width of 6.2 m | 8               | 1.00€              | 1.50€                 | 2.50€                |

Source: Thaysen et al (2014), pp. 130–132 and (KTBL 2020), supplemented by own calculation
Table 3  Variable tedder costs for different working widths per hectare

| Working widths of tedder | Working time | Labour costs | Diesel consumption | Machinery input costs | Total variable costs |
|--------------------------|--------------|--------------|--------------------|-----------------------|---------------------|
| 4/5 m                    | 0.43 h       | 6.45€        | 2.60 €             | 6.18 €                | 15.23 €             |
| 5.5 m                    | 0.35 h       | 5.25€        | 2.60 €             | 5.98 €                | 13.83 €             |
| 6.5 m                    | 0.31 h       | 5.65€        | 2.70 €             | 6.03 €                | 13.88 €             |
| 7.5 m                    | 0.28 h       | 4.2€         | 2.80 €             | 5.98 €                | 13.08 €             |
| 8.5 m                    | 0.24 h       | 3.6€         | 2.60 €             | 5.83 €                | 12.03 €             |

Source: Thaysen et al (2014), p. 169 and (KTBL 2020), supplemented by own calculations

Table 4  Saving potential in variable costs through the use of mowing conditioners per hectare during good weather conditions

| Mower and tedder combination | Variable costs of mowing conditioner use | Variable tedder costs | Saving potential in variable costs |
|------------------------------|------------------------------------------|-----------------------|-----------------------------------|
| Mounted mower with working width of 2.8 m + tedder with working width of 4.5 m | 2.78€ | 15.23€ | 12.45 € | 27.68 € |
| Mounted front-rear combination, working width of 6.2 m + tedder with working width of 8.5 m | 2.66€ | 12.03€ | 9.37 € | 21.40 € |

Own calculation, based on data and results of Table 1 and 2

Table 5  Calculation of yearly profits of conditioner use for an intensive, 4-cut silage production on conventionally managed grassland during good weather conditions

|                | Unit   | Low yield | High yield |
|----------------|--------|-----------|------------|
| Fresh weight of harvested grass, 18% DM content | t/ha   | 38        | 56         |
| Silage yield, 35% DM content                      | t/ha   | 16.6      | 24.5       |
| Energy density                                    | MJ NEL/kg DM | 6.1      |
| Reduction in dry matter loss due to conditioner use | % points | 1.5    |
|                                                        | kg/ha   | 249       | 368        |
|                                                        | MJ NEL/ha | 1519    | 2242       |
| Substitute value of reduction in dry matter loss   | €/ha    | 27.34     | 40.35      |
| Increase in energy density due to conditioner use  | MJ NEL/kg DM | 0.10    |
|                                                        | MJ NEL/ha | 1660    | 2450       |
| Substitute value of increase in energy density of DM | €/ha    | 29.88     | 44.10      |
|                                                        | MJ NEL/ha | 1660    | 2450       |
| Variable mowing costs reduction for small scale mowers and tedders due to conditioner use<sup>a</sup> | €/ha/1 cut | 12.45   | 12.45      |
|                                                        | €/ha/4 cuts per year | 49.80 | 49.80      |
| Variable mowing costs reduction for large scale mowers due to conditioner use<sup>b</sup> | €/ha/1 cut | 9.37   | 9.37       |
|                                                        | €/ha/4 cuts per year | 37.48 | 37.48      |
| Profit of conditioner use (small scale mowers)<sup>a</sup> | €/ha/year | 107.02 | 134.25     |
| Profit of conditioner use (large scale mowers)<sup>a</sup> | €/ha/year | 94.70 | 121.93     |

Own calculation, based on results of table A.3 and data from KTBL (2014, 2020) and Thaysen et al. (2014)

<sup>a</sup>Used example for small scale machinery = Mounted mower with working width of 2.8 m + tedder with working width of 4.5 m

<sup>b</sup>Used example for small scale machinery = Mounted mower with working width of 6.2 m + tedder with working width of 8.5 m
Table 6  Total number of damaged and undamaged individuals per taxonomic group for extensively and intensively managed grasslands and with or without the use of a conditioner in all samples (N = 176)

| Taxonomic group          | Management     | Conditioner |       |       |       |       |       |       |
|--------------------------|----------------|-------------|-------|-------|-------|-------|-------|-------|
|                          | Extensive      |             |       |       |       |       |       |       |
|                          |                | Intensive   |       |       |       |       |       |       |
|                          | Damaged        | Undamaged   | Damaged | Undamaged | Damaged | Undamaged | Damaged | Undamaged |
| Acari                    | 1052           | 3008        | 342   | 1138  | 1112  | 2023  | 282   | 2123  |
| Araneae                  | 128            | 89          | 37    | 14    | 81    | 53    | 84    | 50    |
| Hemiptera (Auchenorrhyncha) | 399          | 111         | 262   | 67    | 371   | 82    | 290   | 96    |
| Diptera (Brachycera)     | 93             | 52          | 181   | 80    | 145   | 52    | 129   | 80    |
| Collembola               | 233            | 291         | 82    | 83    | 191   | 160   | 124   | 214   |
| Coleoptera               | 199            | 79          | 137   | 66    | 193   | 25    | 143   | 120   |
| Dermaptera               | 1              | 0           | 1     | 0     | 1     | 0     | 1     | 0     |
| Hymenoptera (Formicidae) | 51             | 30          | 86    | 101   | 82    | 46    | 55    | 85    |
| Gastropoda               | 1              | 0           | 0     | 0     | 0     | 0     | 1     | 0     |
| Hemiptera (Heteroptera)  | 1532           | 633         | 151   | 144   | 1077  | 444   | 606   | 333   |
| Hymenoptera (not Formicidae) | 76          | 92          | 58    | 42    | 84    | 73    | 50    | 61    |
| Lepidoptera              | 17             | 4           | 3     | 1     | 13    | 0     | 7     | 5     |
| Diptera (Nematocera)     | 43             | 39          | 24    | 31    | 38    | 33    | 29    | 37    |
| Orthoptera               | 139            | 22          | 315   | 89    | 259   | 24    | 195   | 87    |
| Hemiptera (Sternorrhyncha) | 1669          | 913         | 1392  | 424   | 1763  | 500   | 1298  | 837   |
| Thysanoptera             | 1500           | 2856        | 340   | 538   | 956   | 1176  | 884   | 2218  |

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