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The impact of rotational grazing on biomass characteristics in boreal alluvial meadows

Kadri TALI, Indrek MELTS, Katrin HEINSOO (✉)

Chair of Biodiversity and Nature Tourism, Estonian University of Life Sciences, Kreutzwaldi 5, 51007 Tartu, Estonia

✉ Corresponding author: katrin.heinsoo@emu.ee

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ABSTRACT

Northern Boreal alluvial meadows are semi-natural habitats that require extensive management. They also have lower productivity as compared to cultivated grasslands. The subsidies for keeping meadow habitats open are currently activity-based, not results-based, and farmers tend to keep stocking rates low. This is not sufficient to keep meadows in good condition. We studied the impact of rotational grazing on biomass yield and forage quality in Estonian semi-natural alluvial meadows. Two traditionally extensively grazed pastures of approximately 36 and 20 hectares were divided into rotational systems, one of which consisted of four paddocks and the other of which consisted of eight paddocks. Other parts of the same grassland were used for low-load extensive grazing and control areas. Biomass samples we collected to measure both quantitative and qualitative parameters. We revealed that, with paddocks and rotating animals, the overall biomass production per area (ca 6 t DW per ha) and metabolic energy content (>10 MJ/kg) in the forage are larger compared with the traditional extensive grazing method, enabling increased stocking rates and the more profitable management of these grasslands. Crude protein, neutral detergent fibre, hemicellulose content and relative forage value are presented. The proportion of fibres was lower, and the proportion of crude protein was larger (10...12%) in the paddocks in which rotational grazing was used at the end of the vegetation period. The impacts of rotational grazing on local biodiversity require further study. We suggest rotational grazing for boreal growing conditions to elongate the grazing period.

Keywords: alluvial meadow, biomass, forage quality, production, semi-natural grassland, sustainable intensification

INTRODUCTION

Northern Boreal alluvial meadows (Natura 2000 code 6450 (EU/92/43/EEC, 1992)) are an important semi-natural habitat for various species (e.g., amphibians and migratory birds). These meadows, located along rivers, are characterised by two main features: flooding in spring and the impact of management. Extensive management helps to keep the meadows in good condition, with flora including low-growing species with weak competitive ability levels. The vegetation in these meadows is, to a large extent, dependent on the inflow of nutrients transported by river water, it acts as a nutrient sink, provided that this vegetation is harvested on an annual basis (Eriksson, 2008). The area occupied by this habitat type has decreased significantly in Europe due to the new drainage systems and changes in agricultural practices during the last century. Still, alluvial meadows are important ecosystems for biodiversity and also provide wide-ranging functions and services for humans (Schindler et al., 2016). Moreover, the continual management of these grasslands is essential in maintaining mosaic habitats for various specialist plant species and providing open landscapes in which birds can nest or rest during migration. The benefits of these semi-natural grasslands are available only after long-term annual mowing or grazing (Huhta Rautio, 2014; Luoto et al., 2003).

In the nineteenth century, the forage gathered from such meadows was important for nearby farms (Kukk and Sammul, 2006) and this usage peaked during the second half of that century (Truus and Tõnisson, 1998). With the development of methods for cultivating sown hay crops on arable land, this kind of land use gradually ceased because it was labour-intensive and difficult to depend on. A limited number of meadows were still managed in the traditional way in the 1950s, but most of their former area had been abandoned by 2000. The area occupied by the alluvial meadows in Estonia has decreased about ten-fold, from 150,000 ha at the beginning of the twentieth century to about 15,000 ha at present (Kukk and Sammul, 2006). Since the 2000s, subsidies have been paid to the farmers to retain these diverse and valuable areas (Guyomard et al., 2020) and 9,220 ha were managed in 2020 (Keskkonnaministeerium, n.d.). As compared to several other semi-natural habitats, the alluvial meadows provide relatively high amounts (3.7...7.3 t DW per ha (Heinsoo et al., 2010)) of winter forage without any external input of fertilisers other than the nutrients in floodwater. Traditionally, the meadows were scythed, but because this harvesting method is too laborious, too expensive and, in some years, even impossible due to high waters, it is now more common to graze the drier parts of these meadows using various species of animals.

Some investigators distinguish between commercial grazing and areas managed for conservation (i.e., grazing by smaller, usually native, breeds) (McDonald et al., 2018). This distribution is not so clear in Estonia, where commercial breeds are often exploited in protected areas where possible, but the lower forage productivity of these areas is often compensated for by a lower stocking rate. Such practices are supported by a subsidy scheme in which the management of protected sites is paid for based on hectares, not the stocking rate. In semi-natural grasslands around the Baltic Sea, a low grazing load may cause the degradation and overgrowth of pastures, while overgrazing is typically reported to be the major cause of rangeland degradation in various other parts of the world (Eldridge et al., 2016; Pittarello et al., 2018; Provenza, 2003; Pulido et al., 2018; Schönbach et al., 2011). On the other hand, new subsidy schemes for European farmers have brought new challenges while defining semi-natural habitats and more attention should be paid to social-ecological aspects and improved incorporation of semi-natural habitats into viable and sustainable farming systems (Herzon et al., 2021).

Heinsoo et al. (2010) have measured forage values and biomass production of several types of alluvial meadows. Biomass production varied between 0.3 and 5.0t DW t/ha based on the water gradient. A lower yield can be obtained from drier and occasionally flooded meadows with characteristic plant species: *Sesleria caerulea* (L.) *Ard.*, *Festuca ovina* L., *Nardus stricta* L. and *Agrostis capillaris* L.. Some wet meadows are dominated by *Phalaris arundinacea* L., *Deschampsia cespitosa* (L.) *P. Beauv.* and/or *Calamagrostis stricta* (*Timm*) *Tzvelev* may yield up to 7.0 t DW per ha (Melts et al., 2014). Sedges (*Carex* sp.) and rushes (*Juncus* sp.) are also important and typical herbaceous plant genera in alluvial meadows (Melts and Heinsoo, 2015), where they usually take advantage of seasonal flooding, as well as high groundwater levels and the nutrient content in the water, and in some cases, the yield can reach 10 DW t/ha^{-} (Neuenkamp et al., 2013). Unfortunately, in the case of higher yields, the nutrient content of the grass in alluvial meadows may be lower as compared to other types of semi-natural grasslands (Heinsoo et al., 2010; Melts et al., 2014). Forage quality has been under-studied in wet grasslands (Tasset et al., 2019), so we compiled the scant existing knowledge in Table 1 to provide a starting point in this regard.

In agricultural settings, plant diversity is often associated with low biomass yield and forage quality, while biodiversity experiments typically find the opposite (Schaub et al., 2020). Many factors affect the feeding value of forage, and one of the more important factors in this regard is the phenological stage of forage component species (Arzani et al., 2004; Changwony et al., 2015). Forage quality traits, such as metabolisable energy (ME), crude protein (CP), acid detergent fibre (ADF), neutral detergent fibre (NDF) and relative feed value (RFV), have been indicated to be the first priorities and most useful measures for overall ruminant-specific nutritional values by several authors (Moore and Biddingscomb, 1994; Orodho et al., 1990; Schaub et al., 2020).

Table 1. Composition of biomass in various semi-natural grasslands and forage groups

Characteristics	1	2	3	4	5	6	7	8	9	10	11	12	13
NDF (%DM)	65.4				59.7				60.6	68.2	64.5	49.9	47.0
ADF (%DM)	38.5												
Lignin (%DM)	6.7								9.9	5.3	4.9	10.3	11.3
Crude protein (%DM)	9.4	7.5	8.4	9.0	9.4	10.5	9.2	9.9	9.2	8.4	8.8	15.9	9.8
N (%DM)	1.6					1.7	1.5	1.6	1.5	1.3	1.4	2.5	1.6
Ash (%DM)					6.1				6.5	6.9	6.2	6.6	8.0
ME (MJ/kg)		8.82	9.49	9.48									

1 - Native grassland (Mikhailova et al., 2000)
2 - Alluvial *(Arrhenatherion)* meadow, traditional management by mowing in mid-June (Donath et al., 2004)
3 - Alluvial *(Cnidion)* meadow, traditional management by mowing in mid-June (Donath et al., 2004)
4 - Alluvial *(Magnocaricion)* meadow, traditional management by mowing in mid-June (Donath et al., 2004)
5 - Alluvial meadow, managed by mowing in July (Heinsoo et al., 2010)
6 - Coastal meadow, managed by grazing (Sammul et al., 2012)
7 - Alluvial *(Caricetum acutae (Vlieger et van Zinderen Bakker))* meadow, managed by mowing in July (Neuenkamp et al., 2013)
8 - Alluvial *(Filipendulo-Geranietum palustris)* meadow, managed by mowing in July (Neuenkamp et al., 2013)
9 - Alluvial meadow, managed by mowing in July (Melts and Heinsoo, 2015)
10 - grasses from different semi-natural grasslands (Melts and Heinsoo, 2015)
11 - sedges and rushes from different semi-natural grasslands in July (Melts and Heinsoo, 2015)
12 - legumes from different semi-natural grasslands in July (Melts and Heinsoo, 2015)
13 – other forbs from different semi-natural grasslands in July (Melts and Heinsoo, 2015)

It has been demonstrated that continuous grazing suppresses more palatable plants, and they are often unable to recover (Teague and Dowhower, 2003), so multi-paddock (MP) grazing has long been suggested by conservationists for use on semi-natural pastures, but it has not been tested in the boreal region, where the number of extensively managed cattle may be restricted due to overwintering costs, rather than pasture area. Wang et al. (2016) studied the impacts of continuous grazing and MP grazing on vegetation and livestock forage consumption on North American prairies. They revealed that, in small areas with no differences in defoliation rates across grazing methods, MP grazing did not perform any better than continuous grazing. At the scale of commercial ranches, MP grazing with improved defoliation management improved grass composition and productivity, as well as livestock consumption, especially with higher stocking rates and unfavourable initial biomass composition. The advantages of MP grazing, however, were reduced with favourable precipitation, light stocking, low levels of undesirable plants and inadequate recovery periods. It has been proven that increasing the intensity of grazing at a given stocking rate increases the amount of biomass derived from pasture due to more evenly distributed grazing (Badgery, 2017). Heitschmidt and Taylor (Heitschmidt and Taylor Jr, 1991) argued that, in a smaller paddock, grazing competition is increased, and because options are reduced, the nutritional value of animal-fed plants is declining, leading to a decline in production. These contradictions can be explained at least partly by study methods: Orr et al. (2012) showed that animals' dietary preferences change during the growing season by functional group. In fact, similar local selective overgrazing also occurs during extensive free grazing, but in that case, the animals overexploit some patches and do not graze other areas at all. If we divide 1,000 ha of pasture into four 250 ha paddocks, the animals will surely find themselves in more places that they would not have reached if they had large pastures. It is not wise to expect that MP grazing systems will definitely reduce selectivity and create a uniform lawn surface. To a greater or lesser extent, selective eating will, in any case, continue in pastures (Hunt et al., 2007).

Several local semi-natural habitat management plans (Keskkonnaministeerium, n.d.) have recommended portion-based grazing, especially during the grassland restoration period, to improve grazing quality and reduce competition with undesirable, dominant, fast-growing species. However, this method is not widespread in nature reserves because of uncertainty about its impact on rare species' dynamics and species diversity in general. Thus, under Estonian conditions, extensive free-range grazing is almost exclusively used for grazing in semi-natural areas - and so far only a few farms are available to learn alternative practices in detail. We intend to study whether the nutritional values and yield of forage could benefit from the use of various grazing schemes in Estonian alluvial meadows and thus encourage farmers to invest more heavily in semi-natural habitat management.

MATERIALS AND METHODS

Study site description

The experimental farm is in South Estonia, around the Vaidva River (Figure 1), where the predominant meadow community is *Festuco rubrae-Deschampsietum*.

According to the Estonian Environment Agency, the average annual temperature in 2018 and 2019 were 7.1 °C and 7.6 °C, respectively (long-term average of 6.0 °C). The precipitation in 2018 was 506 mm, and in 2019, precipitation was 675 mm (long-term average of 672 mm). The duration of sunshine was 2,070 hours in 2018 and 1,971 in 2019 (long-term average of 1,766 hours). The distribution of both precipitation and temperature during the vegetation period in two study years was different and these mean monthly values in the study area during the vegetation period (Keskkonnaagentuur, 2019), based on data from the nearest weather stations (Valga meteorological and Võru and hydrometric stations), are given in Table 2.

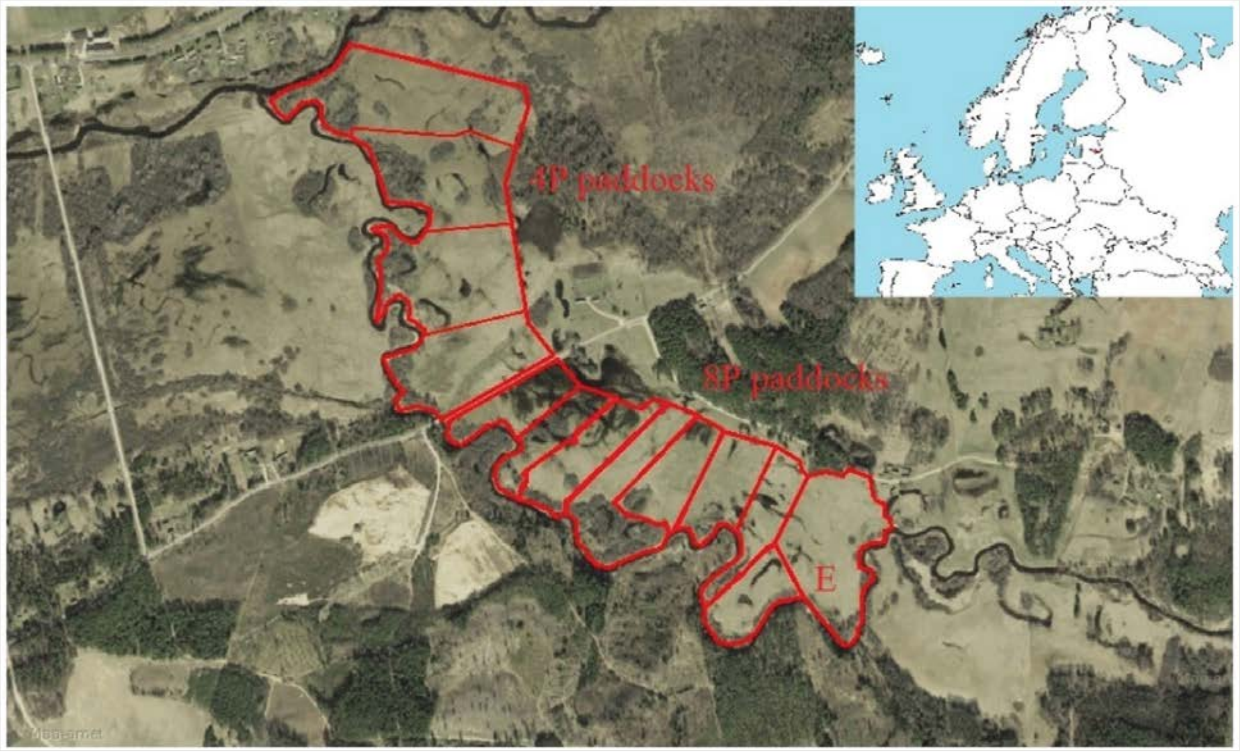

Figure 1. Location of study area and experimental scheme

Table 2. Weather parameters of the study area during the vegetation period in 2018 and 2019 (Keskkonnaagentuur/Ilm, n.d.)

Month	Total precipitation (mm)		Mean T (°C)		Total sunshine (hours)	
	2018	2019	2018	2019	2018	2019
April	37.4	1.8	7.3	7.3	183.3	311.3
May	28.6	54.3	15.3	11.3	407.8	230.7
June	83.5	57.4	15.5	18.5	288.8	329.2
July	22.7	65.2	20.3	15.9	260.2	216.5
August	102.8	51.6	18.1	16.2	245.3	250.8
September	72.4	90.3	13.8	11.3	200.7	189.3
October	53.1	94.7	6.8	7.2	100.8	62.9

Grazing and sampling schemes

Two traditionally extensively grazed pastures of approximately 36 and 20 hectares were divided into rotational systems, one of which consisted of four paddocks and the other of which consisted of eight paddocks (4P and 8P, respectively); thus, a paddock in the 4P system was 9 ha, and a paddock in the 8P system was 2.5 ha. Another 6 ha were used for traditional, extensive grazing (E) and a small patch of that pasture was separated for control sampling (C).

In two rotational paddock systems (4P and 8P), the grazing period lasted for 180 days, from May to October. All the paddocks were visited four times by the cattle. The rotation speed was approximately the same, and the stocking rate in all rotational paddocks was approximately 1 animal unit per ha. In extensively grazed pasture E, the stock rate was similar, but the grazing period was a month shorter due to the low quality of the remaining grass. In 2018, the sampling was performed in accordance with animal movement on the following dates: 14.05, 24.05, 04.06, 17.06, 10.07, 31.07, 21.08, 11.09, and 15.10 and we studied the paddocks, where the grazing was just finished or where it should start during next week according to preliminary rotation scheme. In 2019, we focused on the C and 8P areas only. This year, we separated an additional 0.1 ha area from two 8P paddocks to measure the amount of biomass consumed by the herd within a short period. These small test areas are marked as T (trampling) in the database.

For biomass sampling in each paddock, GPS-marked parallel transects perpendicular to the nearby river, with five circular plots (area = 0.05 m^2) along a transect, were used. We cut the living/green herbaceous plants rooted inside the circle manually with scissors at the ground level and stored them in paper bags. The dry weight (DW) of all samples was determined after drying in an oven for 48 h at 80 °C.

Chemical analysis

For chemical analysis, this dried biomass from five samples was mixed and milled to a size of 0.1 mm. Biomass samples were analysed for neutral detergent fibre (NDF), hemicellulose and crude protein (CP). Then, their metabolisable energy (ME), relative forage value (RFV) and dry matter intake (DMI) were calculated according to standardised AOAC methods in the Laboratory of Plant Biochemistry of the Estonian University of Life Sciences. Specifically, NDF was calculated according to the Determination of Neutral Detergent Fibre in Feed (Foss Tecator ASN3434); hemicellulose (HE) was calculated based on the Determination of Neutral Detergent Fibre in Feed (Foss Tecator ASN 3434) and the Determination of Acid Detergent Fibre in Feed (Foss Tecator ASN3436); crude protein (TP) was calculated based on Protein

(Crude) Determination in Animal Feed: Copper Catalyst Kjeldahl Method (Tecator Kjeltec system). Metabolisable energy (ME), relative forage value (RFV) and dry matter intake (DMI) were calculated via following formulas:

$$ME = 0.82*DE \text{ (digestible energy)},$$

where 1 kg DDM = 18.4596 MJ DE; RFV = (DDM) * (DMI) / 1.29 where DDM (digestible dry matter) = 88.9-(0.779*ADF) and DMI (dry matter intake) = 120/NDF. To correspond with the study questions and enable statistical analyses, the chemical analysis data were divided into three data series: spring (May), summer (June to August) and autumn (September to October). The statistical analysis of average CP content was carried out with a Ryan-Einot-Gabriel-Welsch Multiple Range test (REGWQ) in SAS 9.4. software.

Productivity modelling

Due to periodic grazing at the study sites, it was impossible to measure the annual biomass production of the herb layer directly, and therefore, modelling was necessary. For 2018, we calculated the biomass production (Prod) in rotational systems cumulatively as the sum of the biomass increase between the two measurements plus 0.5 of the previously measured biomasses if grazing has been performed on the plot between the two measurements:

$$Prod = \sum m_n - m_{n-1} + 0.5 m_{n-1},$$

where m_n is the measurement number. In 2019, we measured the difference in biomass yield in T areas of two paddocks in detail before and after grazing according to the meadow management plan. The farmers' target was to harvest half of the biomass in the form of animals. In this year, we assumed that the biomass loss of the particular paddock was equal to our measured value of T after the grazing animals returned to area T. That was a clear signal for the farmer to move them to the next paddock. The control area remained the same as in the previous year. For this year's model, the biomass productivity in the 8P system was calculated:

$$Prod = \sum m_n - m_{n-1} + /(m_{tb} - m_{ta})/m_{tb})m_{n-1},$$

where m_n is the measurement number and m_{tb} and m_{ta} are the biomass yields in area T of this particular paddock before and after the cattle visit, respectively. The occasionally negative production of biomass in our 2019 productivity model was considered to reflect the dieback of some species, mainly *Carex*, during the second half of the growing period and was therefore replaced with zero.

RESULTS

Biomass quality

In 2018, the crude protein levels were over 18% in spring and less than 10% in autumn. The drop was significant in all treatments (Figure 2).

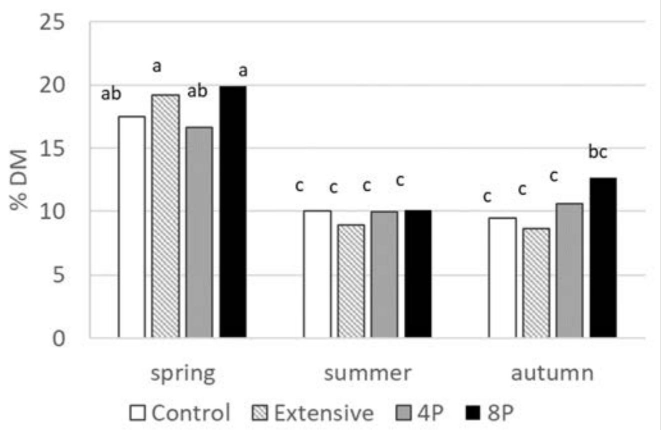

Figure 2. The average content of crude protein in various types of paddocks during the vegetation period of 2018 (4P – rotational grazing in 4 paddocks, 8P – rotational grazing in 8 paddocks. The different letters indicate statistically significant differences according to the SAS GLM REGWQ)

There is some evidence that CP is larger in the smaller paddocks (8P) than in the larger paddocks, but this result could not be statistically confirmed. For example, in September, CP in the 4P system was 9.9, as compared to 11.7, on average, for the three 8P paddocks.

Comparing the indicators of the two grazing patterns, rotational grazing versus extensive or no grazing, revealed clear differences (Figure 3). The proportion of fibres (NDF and hemicellulose) was lower and the proportion of crude protein was larger in the paddocks in which rotational grazing was used at the end of the vegetation period.

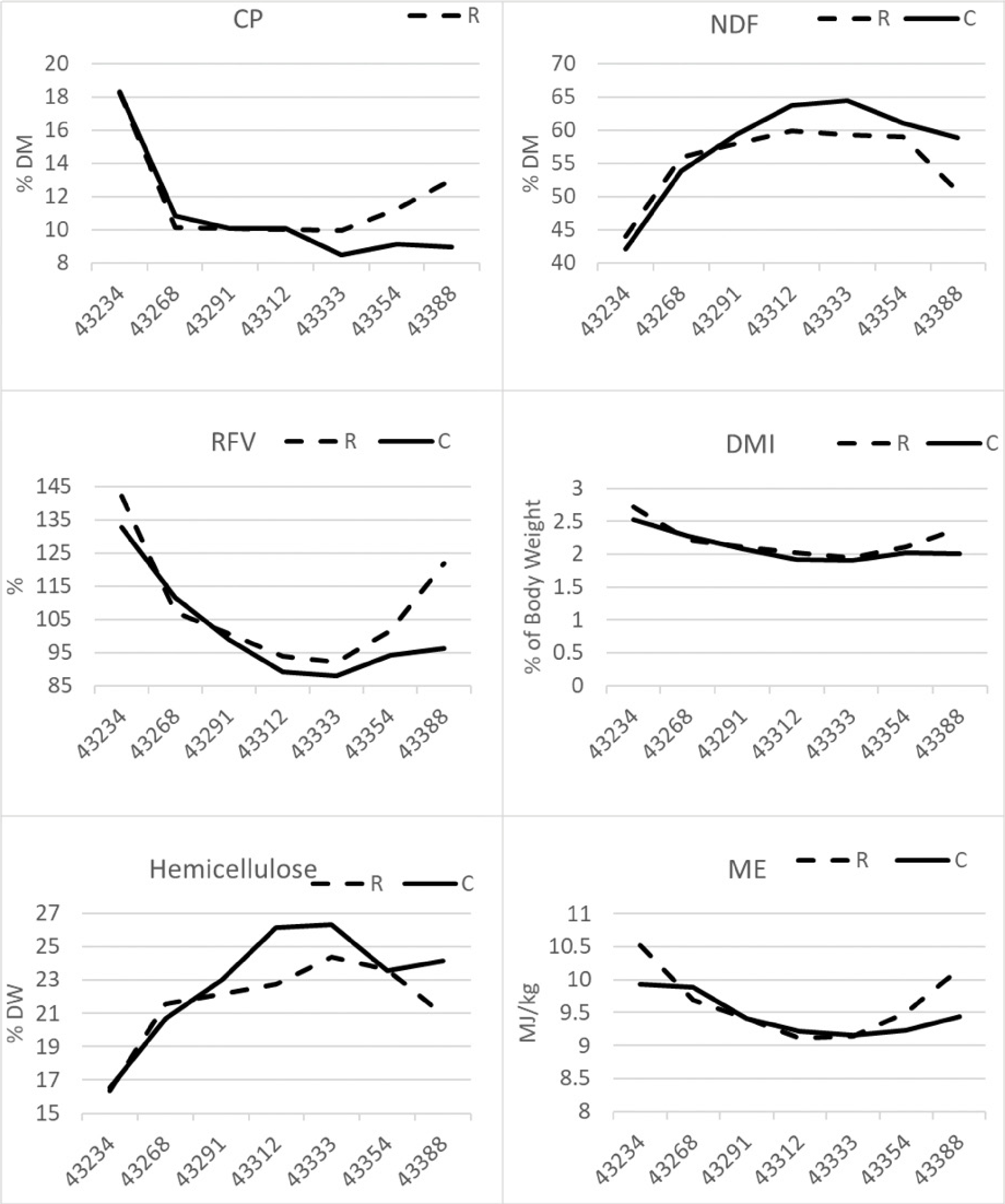

Figure 3. Dynamics of various quality indicators in herbaceous biomass during the grazing period in 2018 (R – an average of 4P and 8P data; C&E – an average of extensively managed and controlled area data)

Biomass quantity

Ungrazed plots of our study area yielded 4.04 DW t/ha of biomass in June, dropping to 3.1 DW t/ha in September. The annual cumulative biomass yields of most rotational paddocks we studied were higher than this value (Figure 4).

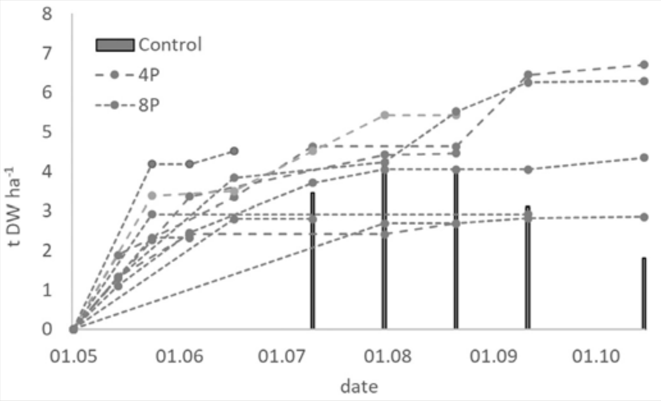

Figure 4. Cumulative biomass yield in various studied rotational paddocks as compared to the production of control patches in 2018

The modelling of biomass production in 8P sites according to locally grazed biomass loss revealed that a high short-term stocking rate in T areas did not have any severe impact on biomass production and that the annual yield in these plots was higher than that of the control area. According to the model we used, the average biomass production in rotational paddocks was 40% higher than that of the control patches (Figure 5).

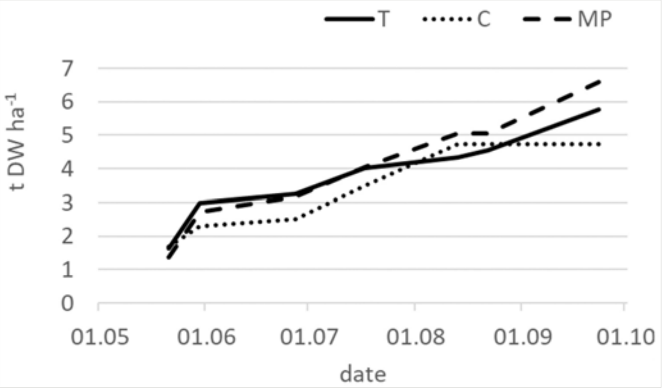

Figure 5. Average cumulative biomass yield in rotational paddocks (MP), trampling areas (T) and control patches (C) in 2019

DISCUSSION

Biomass quality

The comparison of chemical content in semi-natural grasslands has always been problematic due to their variable plant species compositions. For example, the plant species that are fond of Estonian alluvial meadows amount to about 350 species (Pärtel et al., 2007), and their proportions depend on the meadow management regime (Katrin Heinsoo et al., 2020). The chemical composition of different species or plant functional groups, however, is different (Melts and Heinsoo, 2015), and thus, a high level of variability can be expected. Therefore, the mixing of various samples and amalgamation of various data based on the study question seems reasonable. Our results from the beginning of the grazing season revealed that, in general, the chemical composition of all studied areas was similar and, therefore, the grazing system layout was appropriate for answering our study questions. In traditionally extensively managed meadows or abundant grasslands, the biomass's crude protein content is high in spring but declines quickly after midsummer (Melts and Heinsoo, 2015; Michaud et al., 2012). During the second half of the growing period in our study, the crude protein content in the plant biomass tended to be higher in rotational grazing systems providing animals with more nutrients. The lowest CP values were recorded during the midsummer period in all study areas, but in rotationally grazed paddocks, the CP levels increased afterwards, indicating that the plants there regenerated more quickly.

Several publications have revealed that grazing intensity has a large impact on meadow biomass quality (Cao et al., 2024; Jarque-Bascuñana et al., 2022; Ren et al., 2016). The rotation speed in a rotational grazing system is an important factor in ensuring the longest possible time spent in the vegetative state for most of the plants and, therefore, also the nutritional value of the biomass consumed (Badgery, 2017; Heitschmidt and Taylor Jr, 1991; McCosker, 1994). There was evidence, in our study, that the CP in the grass of the 8P system in autumn was higher than that of the 4P system. Any statistically significant differences, however, in CP values between 4P and 8P systems were not detected, likely due to the small data size. Therefore, the rotation scheme that favours the highest quality forage for cattle in local alluvial meadows remains to be determined in forthcoming years.

To study the seasonal dynamics of the biomass's chemical composition in more detail and to potential effects of site-related factors, we amalgamated the data derived from all grazed paddocks and compared this info with that gathered from extensively managed and control areas. The last generalisation was made according to the assumption that, unless forced to do otherwise, cattle eat the favourable plant species first and that the biomass we sample during the second half of the grazing season is composed of unfavourable species that have remained un-eaten for a long period. Our analysis revealed that both sugar and CP content increased in rotational grazing paddocks after the midsummer decline, while in continuous management areas (C&E), the value remained low. This change in CP proportion was most likely due to the fibre (NDF) and hemicellulose content, which, in rotationally grazed areas, began to decrease after the mid-summer peak much more rapidly than in continuously managed areas. Therefore, the RFV of rotationally grazed paddocks in autumn was comparable with that value in spring, while that of continuously managed/unmanaged areas has decreased by more than one-third. According to animal welfare scientists, it takes ME of 10.5...10.6 MJ and CP of 14...15% to ensure adult cattle's health and weight gain in local climatic conditions (Greenwood, 2021). In Natura2000 habitats, it is not allowed to provide grazing animals with additional forage during the grazing period due to nature conservation restrictions (European Commission, n.d.). Thus, to ensure a sufficient grazing load on these semi-natural meadows and also secure a good conservational state for the meadows, adequate forage quality is important, and we can recommend rotational grazing for this purpose in boreal alluvial meadows.

Biomass quantity

The biomass growth in boreal semi-natural grassland has always been much lower than that of cultivated hayfields. Among Estonian semi-natural grasslands, the alluvial meadows have the highest biomass productivity, with an average of 5.7 t DW per ha (Heinsoo et al., 2010), but this number is much lower than those reported for established cultivated Estonian grasslands, about 20 t of fresh material (moisture content approximately 50%) per year (Aamisepp and Persitski, 2017). The high variability of semi-natural alluvial meadow productivity indicates that this plant community is sensitive to various environmental factors and, therefore, special care must be taken to guarantee economically reasonable management. The biomass yield in the control area of the studied meadow was in the range we have measured in our previous studies. The seasonal dynamics of this value in 2018 revealed that the rapid biomass growth during the first half of the growing period was followed by plant senescence and die-back during the second half of the growing season. Most likely, this pattern was caused by the fact that the 2018 summer was one of the driest in years. Additional measurements taken in 2019 revealed that, with more precipitation in the first half of the growing season, followed by a colder July and August, the plant biomass growth in the control area was almost 20% greater (4.15 and 4.7 t DW per ha, respectively). This large difference reveals that it is important to avoid premature senescence and low forage quality in such areas via adaptive grazing management.

It is complicated to measure the impact of paddock-scale grazing on biomass production in heterogeneous meadows, as selective eating remains (Hunt et al., 2007) and, on semi-natural grassland, the disc pasture meter is disabled because of different plant lifeforms and microrelief. In 2018, we assumed that the farmer moved the cattle to another paddock if half of the biomass was eaten by animals and the correct timing was indicated based on grass height. With such modelling, we were able to demonstrate that rotational grazing increased the biomass available for the animals by about twofold. The significant benefits of adaptive grazing for biomass production were also subjectively confirmed by the farmer. In 2019, we improved our study method and measured the amount to consumed biomass in smaller areas immediately before and after the grazing. We measured the consumed forage to be between 40 and 60%, depending on the season and site characteristics. Nevertheless, this model revealed that rotational grazing increased the biomass productivity of the area by 40%. Increased plant biomass production due to rotational grazing systems has been reported by several authors in areas with longer grazing seasons (Badgery, 2017; Milchunas et al., 1998; Teague and Dowhower, 2003).

Rotational grazing and nature conservation

Rotational grazing effects are much more studied in prairies, steppes and other arid and semi-arid rangelands; the trends in boreal alluvial meadows remain to be revealed. It is important to emphasise that, in our study, the intensive trampling of animals in small paddocks (T) did not have a negative impact on local biomass productivity. For a detailed analysis, longer periods of such grazing are required, but our first results indicate that the alluvial meadows are capable of recovering quickly from short periods of high stocking rates. Such grazing practices can suppress the dominant plant species and increase the local biodiversity by creating new niches (Hofmann and Isselstein, 2004).

Therefore, time rotation that keeps grass in a prolonged vegetative state has a direct effect on the species composition. It has been demonstrated that a reasonable rotational grazing system should be favoured, instead of continuous grazing, to increase the local butterfly and bumblebee diversity (Ravetto Enri et al., 2017) and increase local floristic richness (McDonald et al., 2019). Karen Hickman and others (Hickman et al., 2004) found significantly higher native plant species diversity, species richness and growth form diversity in grazed compared to not grazed prairie and the greatest diversity was at the highest stocking rates. It is possible that dominating grasses and sedges on these meadows decline and give more room to other herbs (including legumes) thanks to higher consumption of less palatable species during rotational grazing. Changes in species composition may also have an impact on biomass quality. The grazing regime, however, plays an important role in shaping plant community structure and diversity (Kouba et al., 2021; Li et al., 2023; Wan et al., 2015). It is essential not to increase the stocking rate above a certain limit, which will cause area exhaustion for a long period (Fynn and Jackson, 2022). To increase pasture-flowering intensity, sometimes, an alternative rotational schedule may be suggested (Farruggia et al., 2012).

Under Estonian conditions, the subsidies for keeping meadow habitats open are currently activity-based, not results-based, and farmers tend to keep stocking rates low to be on the safe side and not affect animals' increase in weight. Our goal was to find an economically reasonable method via which to maintain open meadows, which are important for nature conservation, while also ensuring reasonable and ecological meat production. We were able to demonstrate that rotational grazing had certain benefits for the farmer, but the impact of such an approach on local biodiversity requires longer and more dedicated studies. These can be conducted after introducing this novel management pattern to local farmers.

CONCLUSIONS

A 2-year experiment on rotational grazing at different intensities revealed that, in general, paddock-method grazing resulted in higher plant biomass production and better forage quality in terms of crude protein content than that detected in control areas or extensively managed areas. After midsummer protein content depression, its value in rotational grazing systems increased but remained below the limits for animal welfare in continuously managed areas. In senescent grass in continuously managed/unmanaged parts of the same meadow, the hemicellulose and fibre content increased. Thus, we find that rotational grazing affords cattle a better nutritional supply as compared to traditional extensive grazing.

It is difficult to evaluate the total biomass production in meadows while they are being grazed. According to our models, the cumulative biomass production in the rotational grazing systems, approximately 6.3 t DW per ha, was significantly larger than the amount that was available for animals in the conventionally and extensively managed part of the meadow, 4.04 t DW per ha. During the second half of the grazing period, the biomass in the latter decreased rapidly due to plant senescence (e.g., *Carex*). Therefore, we suggest rotational grazing for boreal growing conditions to elongate the grazing period. That is extremely important in areas where farmers are not allowed to provide animals with extra fodder while grazing (e.g., due to Natura2000 restrictions).

There are pro and con arguments regarding the impact of rotational grazing on local biodiversity. A two-year experiment was too short to reveal the influence of rotational grazing on vegetation in detail, and therefore, long-term studies should follow to improve our knowledge about the specific factors that influence the effectiveness of rotational grazing in different contexts and develop tailored-made management strategies that can optimise the benefits of this approach for both nature conservation and livestock production.

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