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Effects of Grazing Abandoned Grassland on Herbage Production and Utilization, and Sheep Preference and Performance

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Large areas of farmland are abandoned in Norway, which for various reasons are regarded as undesirable. Loss of farmland may have negative implications for biodiversity and ecosystem function and food production potential. The objectives of this study were to assess forage mass production and utilization, botanical composition, lamb performance, and grazing distribution pattern when reintroducing livestock grazing to an abandoned grassland. The study area was located in Central Norway, unmanaged for 12 years. Sheep grazed the area for 10 weeks in 2013 and 4 weeks in spring and autumn, respectively, in 2014 and 2015. During the summer of 2014 and 2015, the area was subjected to the following replicated treatments: (1) No grazing, (2) grazing with heifers, and (3) grazing with ewes and their offspring. The stocking rate was similar in the grazed treatments. Forage biomass production and animal intake were estimated using grazing exclosure cages and botanical composition by visual assessment. Effect on lamb performance was evaluated by live weight gain and slaughter traits in sheep subjected to three treatments: (1) Common farm procedure with summer range pasturing, (2) spring grazing period extended by 1 month on the abandoned grassland before summer range pasturing, and (3) spring and summer grazing on the abandoned grassland. Grazing distribution patterns were studied using GPS position collars on ewes. Total annual biomass production was on average 72% higher with summer grazing than without. Annual consumption and utilization was on average 218 g DM/m^2 and 70% when summer grazed, and 25 g DM/m^2 and 18% without grazing, respectively. Botanical composition did not differ between treatments. Live weight gain was higher in lambs subjected to an extended spring grazing period (255 g/d) compared to common farm practice (228 g/d) and spring and summer grazing on the abandoned grassland (203 g/d), and carcass value was 14% higher in lambs on extended spring grazing compared to common farm practice. In autumn, sheep preferred to graze areas grazed by sheep during summer. Re-introduction of grazing stimulated forage production, and extended spring grazing improved performance in lambs. This study has quantified the value of abandoned grassland as a feed resource.

Keywords: abandoned grassland, grazing, herbage production, herbage utilization, sheep performance, grazing pattern, carcass value, weight gain

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INTRODUCTION

Large areas of farmland have been abandoned during the last decade in Europe (Estel et al., 2015). In the western and northern counties of Norway, 12% (26,986 ha) of the total farmland was abandoned between 2000 and 2016 (Statistics Norway, 2018a). About 92% of this abandoned farmland was used as grassland for cutting, grazing, or combined cutting and grazing. The drivers for farmland abandonment in Europe are many and includes low income, increasing aging of farmers, and low farm size, and population density (Terres et al., 2015). In Norway, many farmers have left agriculture, farming has rationalized into larger farm units, and there is an increase in the proportion of agricultural land rented (Forbord et al., 2014). At the same time, farming has intensified with an increase in production per animal head, particularly in dairy cattle production (Steinshamn et al., 2016). High quality land is commonly preferred at the expense of more marginal, remote, and less suitable areas for intensive farming. The consequences of agricultural abandonment are many, which may both be positive and negative (van der Zanden et al., 2017). Positive effects are, for example, that abandonment may increase carbon sequestration and give room for large mammals (Navarro and Pereira, 2012). It is, however, also suggested that shrub expansion may decrease total ecosystem carbon pools (Sørensen et al., 2017). Species richness declines with increasing time after abandonment, and the area will over time be encroached by shrub and trees (Staaland et al., 1999; Pykälä et al., 2005; Wehn et al., 2017). In the Norwegian context, this is regarded as undesirable since grasslands are important cultural landscape elements and an import asset for the tourism industry (Daugstad, 2008). It is also regarded as important for food security reasons to maintain the production potential of agricultural goods, and agricultural activity is important for the rural economy in Norway as well as many parts of the EU (Terres et al., 2015).

Grassland is the main asset for sheep farmers, and availability of grasslands is decisive for performance of production on sheep farms. Common sheep husbandry practice in Norway is to keep sheep indoors during winter and free-ranging on unfenced mountain or forest land during summer before slaughter in autumn (Ross et al., 2016). Access to grassland, particularly for spring and autumn grazing, is a limiting factor in Norwegian sheep farming (Vatn, 2009). Most lambs are born indoors during spring and kept for a few weeks on cultivated grasslands close to the farm at the foot of the mother before being turned out on summer range pasture (Vatn, 2009). Grazing in spring is at the expense of the yield of winter feed. The sheep farmers therefore try to limit the period of spring and autumn grazing by leading the flock to rangeland as soon as possible in spring and to slaughter the lambs in autumn just after collection from rangeland. Lamb performance is, however, affected by their weight when turned out on range pasture, i.e., performance on rangeland improves with increasing spring weight (Steinheim et al., 2008). Thus, extending the spring grazing period on cultivated pasture prior to the free-ranging period may improve the lamb performance. To our knowledge, the effect of extending the spring grazing period on lamb performance has not been tested.

Sheep farming in Norway is generally found in marginal agricultural areas, also where the land abandonment rate is high. Grasslands that are abandoned are typically owned by landowners that have quit farming. Grassland that is abandoned, or in danger of being abandoned, is therefore a potential additional grazing resource both in spring and in autumn. Including such land in existing sheep farming systems could reduce the pressure on grassland used for silage or hay production, and thereby increase the winter feed supply. Furthermore, a general change from small to larger sheep flocks (Statistics Norway, 2018b) implies that there is a need for access to more farmland, particularly for spring and autumn grazing, for those that invest in future sheep farming.

Knowledge on how to manage such grasslands during summer, between an extended spring grazing period and before autumn grazing is needed, particularly for grasslands that are not suitable for efficient mechanical harvesting. If grasslands are only used for grazing in spring and autumn, with no cutting or grazing during summer, it is assumed that the pasture feed quality for autumn grazing is poor. This is because forage plants reach maturity and have a high proportion of leaf senescence. Grazing with sheep or cattle during summer will likely maintain the sward at a more leafy stage with higher nutritional quality than without any grazing. Grazing also leaves patches of feces and herbage with higher level of nutrients that may be attractive for herbivores (Haynes and Williams, 1993). On the other hand, sheep may also avoid areas of fecal contamination (Cooper et al., 2000).

The objective of this study was to assess the grazing value, i.e., forage production, feed intake, and animal performance, of abandoned grassland as spring and autumn pastures for sheep before and after the common practice of rangeland grazing during the summer. The hypothesis was that extended spring grazing on an abandoned grassland would improve lamb performance. Moreover, it was an objective to evaluate if grazing of the abandoned grassland during the summer period, with heifers or sheep, had an impact on grassland productivity and grazing value. It was assumed that only spring grazing, without summer grazing, would lead to inferior feed quality later in the season. Quantifying these aspects of reintroducing abandoned grassland into sheep farming gives both sheep farmers and landowners a knowledge basis for valuing the area in monetary terms and for decision-making.

MATERIALS AND METHODS

Experimental Site

A 22 ha grassland that has been unmanaged since 2001 was used in the study. The soil is of morainic origin with high content of organic matter (ignition loss 12.1%), with moderate pH (5.4). The phosphorous and potassium values were 7.8 and 5.8 mg/100 g, respectively, according to the extraction method of Egnér et al. (1960). The grassland is located in the municipality of Sunndal, Møre og Romsdal County (62.85°N and 8.40°E), ranging from 200 to 270 m above sea level. Before abandonment, the area was used as pasture for dairy cows. The prevailing plant species prior to onset of the experiment, assessed in the autumn 2013, included species that most likely were seeded when the grassland was used for dairy cows, such as common bent [*Agrostis capillaris* L., 37% of dry matter (DM) yield] and smooth meadow-grass (*Poa pratensis* L., 12%), and naturally occurring species such as tufted hair-grass [*Deschampsia cespitosa* (L.) P. Beauv., 18%] and meadow buttercup (*Ranunculus acris* L., 7%). Reed canary grass (*Phalaris arundinacea* L.) constituted dense stands in small patches. In 2013, the area was fenced and grazed with sheep for about 10 weeks and horses for ~2 weeks in order to reduce the amount of dead material the following spring. The experiment was run for two consecutive years, in 2014 and 2015. Except for fencing and grazing, no other management measures were taken.

The total precipitation during the growing season, from May 1 to November 1, was 564 and 520 mm in 2014 and 2015, which were 3 and 11% lower than the average of the recent 30-year period, respectively. The mean daily temperature was 13.0°C in 2014 and 11.5°C in 2015, which was warmer compared to the recent average of 10.7°C.

Experimental Design

Grazing Treatments and Measurements

Ewes with offspring grazed the entire area for ~1 month in spring (**Figure 1**, Period 1: from May 23/20 to June 20/19 in 2014/2015) and ewes with lambs for replacement for ~1 month in autumn (Period 4: from September 17/14 to October 21/14 in 2014/2015). The stocking rate of ewes was similar in both years and on average 0.4 livestock units (LU)/ha in period 1 and 0.65 LU/ha in period 4. An area of 15.3 ha of the total 22 ha was divided into three blocks with three fields, averaging 1.7 ha within each block. Three treatments were assigned randomly to the three fields within each block. The treatments were applied during the summer (Period 2): G_0, Control with no grazing; G_H, Heifers grazing; and G_S, Ewes grazing with offspring. The stocking rate was 1.8 LU/ha, in both G_H and G_S, for a duration of ~6 weeks (from June 20/19 to August 12/3 in 2014/2015). The area was left resting for about a month (Period 3: from August 12/3 to September 17/14 in 2014/2015) after grazing treatment Period 2 and before autumn sheep grazing (Period 4). The sheep and heifers were removed from the trial during Period 3. The stocking rates used were low to be sure that the animals' requirement were covered. In Period 2, the stocking rate was similar to the one used in a Norwegian model study of the costs of keeping sheep on enclosed pastures (Kjuus et al., 2003).

Temporary movable exclosure cages, made of iron nets (height 1 m, diameter 1.59 m, and area 1.99 m^2), were used to protect the herbage from grazing, enabling pasture production assessment. Five cages were allocated at random in each field. Intake was estimated by comparing herbage growth inside and outside the cage. Sickles were used to cut one 0.5 × 0.5 m square of grass to ground level outside the cage and one inside the cage at four occasions, i.e., the end of each of the four periods (**Figure 1**). Before cutting, the sward heights were measured within each square with a rising plate meter (30 cm in diameter which applied a force of 3.5 kg/m^2 at rest). Subsequent to each sampling, the exclosure cages were moved to previously grazed locations to account for the herbage growth. The herbage samples were sorted into forage species (grazed by cattle and sheep) and non-forage species, i.e., species that are avoided, such as meadow buttercup (*R. acris* L.) and marsh thistle (*Cirsium palustre* L.). Dead or senescent plant material was included in the non-forage fraction. The sorted material was force dried at 65°C for 48 h and weighed. Intake, net production and utilization of total herbage (sum of forage and non-forage species) and of forage species only were calculated according to the following equations:

$$\begin{aligned} \mathrm{HI_{gn}[gDM/m^2]} &= (\mathrm{Wu_n} - \mathrm{Wg_n}) \\ \mathrm{HP_n[gDM/m^2]} &= (\mathrm{Wu_n} - \mathrm{Wg_{n-1}}) \\ \mathrm{HPU_n[g/g]} &= \mathrm{HIg_n/HPg_n} \\ \mathrm{HGP_n[g/g]} &= \mathrm{HPg_n/HPt_n} \end{aligned}$$

where HIg_n is herbage dry matter intake, HP_n is herbage production (total and forage), HPUn is herbage intake as the proportion of the forage production, and HGP_n is forage proportion of total biomass production in period n (n = 1–4). Wu_n = dried herbage mass inside the cage, ungrazed, in g/m^2 in period n (n = 1–4); Wg_n = dried herbage mass outside the cage, grazed, in g/m^2 in period n (n = 1–4); $Wg_{n-1=}$ dried herbage mass outside the cage, grazed, in g/m^2 in the previous period n-1 (n = 1–4). Biomass production and intakes were calculated for each exclosure cage and averaged for each paddock. Annual herbage production and intake were calculated as the sum of HP and HI in the four periods, respectively.

For herbage feed quality analysis, the forage samples taken from the grazed sward outside the cages were ground to 1 mm by a UDY Cyclone Sample Mill (UDY Corporation, Fort Collins,

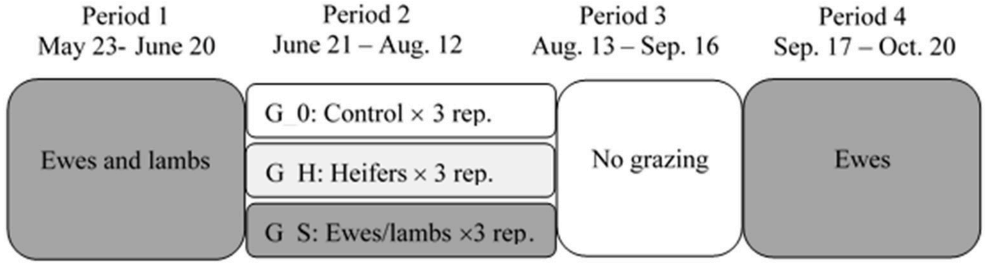

FIGURE 1 | Illustration of periods of the growing season and grazing management. In Period 2, the area was subjected to the experimental treatments G_0 Control (no grazing), G_H Heifers grazing, and G_S ewes grazing with their offspring, each replicated three times.

Colorado). Samples were analyzed at Dairy One Laboratory (Ithaca, NY) using wet chemistry analysis. The analysis included determinations of DM (AOAC 930.15), crude protein by the AOAC method (990.03), acid detergent fiber (ADF by Ankom A200 Filter Bag Technique; Ankom Technology, Macedon, NY), and neutral detergent fiber (aNDF by Ankom A200 Filter Bag Technique with amylase).

Botanical Composition

Herbage botanical composition was estimated by using the dry-weight-rank method and by estimating plant ground cover for individual species in each field in autumn (2013, 2014, and 2015). The dry-weight-rank method is based on visual evaluation of dry matter yields of the predominant plant species in a large number of squares per field (Jones and Hargreaves, 1979). Based on the scores, the proportion of individual plant species on a dry-matter basis can be calculated. In the present study ∼50 squares of 40 × 40 cm were evenly distributed over each field. The GPS-log of the observation in autumn 2013 was subsequently used so that the observations were done on the same spots in order to reduce spatial variation. In addition to the ranking of the predominant species, a list of all observed species was recorded. For the recording of ground cover of each species, four permanent plots of 1 × 1 m per field were established in autumn 2013. For items covering the ground with <11%, the cover was estimated at 1% intervals and for items with >10% ground cover, 10% intervals were used. All plant species were determined to species level except for the taxa of *Taraxacum*, *Polypodiopsida*, and *Bryophyta*. In addition to plant species, observations of open soil, stones, manure, and dead plant material were recorded.

Animal Recordings

An official ethical review process was not needed for this animal study according our institute's, The Norwegian Institute of Bioeconomy Research, guidelines and the national laws and regulations authorized by the Norwegian Food Safety Authority. The reasoning is expressed by The Norwegian Food Safety Authorities (Brumundal, Norway) as follows: "In the experiment the animals were treated according to normal husbandry practices and no practices likely to cause pain, suffering, and distress or lasting harm equivalent to, or higher than, that caused by the introduction of a needle in accordance with good veterinary practice were executed. Therefore, the Norwegian Regulation concerning the use of animals for scientific purposes (based on the EU directive 2010/63/EU) does not apply for this study." The normal husbandry practices conducted in this study were transport, weighing, and preventive treatment for parasites including catching and holding sheep. Handling was conducted by experienced workers to keep handling stress at a minimum. The sheep handlers were not certified veterinarians, but experienced sheep handlers. One of us, EB, holds the certificate for conducting animal experiments. Any sheep with signs of health problems were immediately checked by a veterinarian.

We used a commercial sheep flock of Norwegian white spæl breed with 83 (88) ewes (lambs) in 2014 and 77 (106) ewes (lambs) in 2015. The sheep farm is situated in Tingvoll municipality in Møre og Romsdal County (63.03°N and 8.15°E, 25 masl). Each year, the sheep were assigned, in a stratified random manner according to age of ewe and number of lambs born per ewe, into three treatments: S_Common, common farm procedure with short spring grazing period before summer grazing on range pasture; S_Spring, spring grazing period extended by 1 month of grazing (Period 1, **Figure 1**) on the abandoned grassland before summer range pasturing when joining the S_Common group; S_Summer, spring and summer grazing on the abandoned grassland [Period 1 and 2 (**Figure 1**), treatment "G_S" (see section Experimental design)]. In Period 3, the resting period of the experimental grassland, the animals in the S_Summer treatment were removed from the trial area and grazed an area with similar quality.

The summer range pasture, where the flock grazed free-range during the summer, is located close to the farm and is about 3,461 ha. The summer range consists of 45% forest with patches of grasses, herbs and shrubs between the trees (mainly *Betula* spp.), 48% is sub alpine vegetation with dwarf shrub heath, and 3% is bog (Ahlstrøm et al., 2014). The range is within a humid region with a quite heterogeneous topography. Calcareous rocks within the range contribute to areas of rich fens and tall herb-rich deciduous forests. Most of the forest is sub alpine birch forest dominated by blueberries (*Vaccinium myrtillus)* and in drier areas berries (*Ericaceae* spp.) in general.

Lambs were weighed at birth, at start of spring-extended pasturing (Start Period 1, **Figure 1**) after the spring-extended pasturing (Start Period 2, **Figure 1**), and in autumn (Start Period 4, **Figure 1**). Lambs were 27 (*SD* 6.7) and 25 (*SD* 4.3) days old at the start of spring-extended pasturing (period 1) in 2014 and 2015, respectively. Ewes and lambs in treatment S_Spring and treatment S_Summer were moved to the abandoned cultivated grassland by animal transport, a distance of 55 km, after recording spring weight. The animals were inspected regularly, ∼3 times per week. Ewes and lambs in treatment S_Spring were returned to the common farm summer grazing system on range pasture at the start of Period 2, **Figure 1**.

Slaughter weight, carcass conformation, carcass fatness and carcass value, in NOK, for slaughtered lambs were obtained from the abattoir. This information was obtained from 47 to 77 of the lambs in 2014 and 2015, respectively. Ewes and lambs were monitored regularly for internal parasites. All lambs were treated with tick repellent at the beginning of Period 1 (**Figure 1**).

All ewes were fitted with Global Position System (GPS) collars (Telespor AS, Tromsø, Norway). The GPS collars log and transmit position at regular intervals and the interval settings can be changed from a computer. During Period 4, the GPS tracking frequency was set to log position every 30 min.

Statistical Analysis

Botanical Composition

Herbage botanical composition estimated by the dry-weight-rank method was analyzed using the mixed procedure in SAS (SAS Institute Inc., 2011). Grazing treatment (G_0, G_H, G_S), year (2014, 2015) and their interaction were considered as fixed effects. Block (1, 2, 3) and block interaction with grazing treatment were considered as random effects.

Plant ground cover for individual species was analyzed using the mixed procedure in SAS (SAS Institute Inc., 2011). Grazing treatment (G_0, G_H, G_S), year (2014, 2015), and their interactions were considered as fixed effects. Block, square (1–4 within field) and their interactions with grazing treatment were considered as random effects. In both models, observations from the 2 years taken on the same field were treated as repeated observations. Observations from autumn 2013 were used as covariate in the statistical analysis if $P < 0.05$. Differences between least squares means were estimated with the Tukey-Kramer test.

Grassland Production

Sward height, herbage production, intake, proportion of forage biomass of total biomass produced, and proportion of forage biomass consumed of total forage biomass produced were analyzed using the mixed procedure in SAS to discern significant effects of treatments (SAS Institute Inc., 2011). Year (2014, 2015), grazing period (1–4), and grazing treatment (G_0, G_H, G_S) and their interactions were considered as fixed effects. Block and block by treatment interactions were regarded as random effects. The "Repeated" statement was used to account for correlation among measurements taken on the same plot across time (period). Year and interaction with year were for most variables not statistically significant. For variables where the residuals were not normally distributed, the data were transformed. Normal data are presented as least square mean (LSM) and transformed data are presented as the back transformed LSM. The optimal covariance structure was assessed for each parameter with attention to Schwarz's Bayesian criterion as explained by Littell et al. (2006). Tukey's *post-hoc* means test was used for comparisons of means.

Animal Performance

Lamb live weight gain, slaughter weight, carcass conformation, carcass fatness, and carcass value were analyzed using the mixed procedure in SAS (SAS Institute Inc., 2011) to discern significant effects of treatments. Treatment (S_Common, S_Spring, S_Summer), sex (1, 2), parity (1, 2, 3), and day of birth were regarded as fixed effect and year (2014, 2015) and mother were regarded as random effects. The initial model included the fixed effects treatment, sex, parity, day of birth, and their interactions, and the random effects year, mother and their interaction. There were no significant effects of the interactions of the fixed effects, so all interactions were omitted from the final analysis. The interaction of year and mother was significant and included in the model. The initial model also included year and mother by year interactions as random effects. There was no significant effect of year, and year was therefore omitted from the final analysis.

Sheep Grazing Distribution Pattern

A Chi-square Goodness-of-fit test (FREQ procedure in SAS Institute Inc. 2011) was used to compare the distribution of GPS observations of the ewes in each of the three treatments (G_0, G_H or G_S) within each spring and autumn periods and years.

RESULTS

Botanical Composition

The total number of species were 48 and 37 as assessed by the dry weight-rank method and the ground cover method, respectively (**Tables 1**, **2**). Some species disappeared while new appeared, but the total number of species declined from 2014 to 2015 as assessed by the dry weight method (**Table 1**). The species that were observed in 2013 but not in 2015 were *Alopecurus geniculatuse* L., *Poa annua* L., *Carex echinata* Murr., *Tussilago farfara* L., *Achillea millefolia* L., *Potentilla erecta* L. Raeusch, *Rumex longifolius* D.C., and *Thelypteridaceae*, while *Alopecurus pratensis* L., *Poa trivialis* L., *Taraxacum officinale* G. H. Weber ex Wigg. appeared in 2015 but not in 2013.

The botanical composition was not affected by the grazing treatments during the 2-year experiment as measured by both assessment methods (**Tables 1**, **2**). On average, the grass species that most likely have been cultivated earlier on the land (*A. capillaris*, *P. pratensis*, *F. pratensis*, *P. arundinacea*, and *P. pratense*) had a ground cover of 74% and made up 63% of the dry matter yields. Open soil, rocks and manure accounted for only small proportions of the ground cover. The yield proportion of *D. cespitosa* and *R. repens* were higher in 2015 than 2014 for G_S (**Table 1**). This was not confirmed by the ground cover assessment, but ground cover of *R. repens* was higher in 2015 than 2014 on G_0. The ground cover of dead plant material was on average 44%. In 2014, dead plant material covered a larger ($P = 0.03$) proportion of the G_S plots than G_H, but in 2015 the effect was the opposite.

Forage Production, Intake, and Utilization

The sward height was, as expected, higher in the control plot (G_0) than in the grazed plots (G_S and G_H) at the end of grazing in Period 2 (**Table 3**). The effect of grazing during Period 2 on sward height was also present at the end of Period 3, when all plots were left resting. During the spring period (Period 1), the accumulated total (HP_t), and forage (HP_g) DM yields were on average 196 and 135 g/m^2, which corresponded to a daily growth rate of 7.0 and 4.9 g DM/m^2, respectively. The sheep consumed (HI_g), on average 26 g/m^2 during this period. In the summer (Period 2), when the area was subjected to the different grazing treatments, the sheep and heifers consumed on average 160 g DM/m^2 (**Table 3**) and utilized about 67% (figures not shown) of the forage biomass. The forage production and growth rate was negative in late summer and autumn (**Table 3**). There were no effects of animal species on herbage production, consumption, and utilization. Grazing with heifers and sheep during the summer (Period 2) resulted in on an annual basis 72% more total biomass production (HP_t, 527 vs. 306 g DM/m^2), 159% more forage production (HP_g, 323 vs. 125 g DM/m^2), 9 times more forage consumed (HI_g, 218 vs. 25 g DM/m^2), and 3.2 times higher utilization of total forage produced than in the control plots (HPU, 0.70 vs. 0.22).

Summer grazing resulted in lower ($P < 0.05$) forage ADF and aNDF concentrations in the autumn (Period 4) compared to no grazing (**Table 3**). The concentration of net energy of

TABLE 1 | Effect of grazing treatment [control without grazing (G_0), grazing with heifers (G_H) or grazing with sheep (G_S)] and year on botanical composition in autumn (Period 4) of 2014 and 2015 estimated using the dry-weight-rank method (Jones and Hargreaves, 1979).

	2014			2015			SEM[1]	*P*-value[2]			
	G_0	G_H	G_S	G_0	G_H	G_S		Covariate	T	Y	T×Y
n[3]	3	3	3	3	3	3					
POACEAE, %											
Agrostis capillaris L.	48.3	50.9	62.0	48.2	50.7	45.8	7.42	0.07	0.71	0.14	0.18
Deschampsia cespitosa (L.) P. Beauv.	18.1[ab]	18.9[ab]	10.0[b]	17.9[ab]	19.0[ab]	22.6[a]	3.75	0.01	0.89	0.01	0.01
Poa pratensis L.	11.8	11.1	9.1	8.7	12.5	14.7	2.49	0.01	0.56	0.63	0.41
Festuca pratensis L.	5.7	2.9	5.9	2.4	2.4	5.0	2.65	NS	0.59	0.24	0.59
Phalaris arundinacea L.	0.4	1.1	1.6	1.9	0.6	1.6	1.14	0.001	0.80	0.75	0.66
Phleum pratense L.	0.4	0.0	0.5	1.7	0.2	0.8	0.48	NS	0.27	0.14	0.34
Other Poaceae[4]	1.9	1.2	0.8	2.2	1.5	0.8	1.07	NS	0.70	0.55	0.92
DICOTYLEDONES, %											
Ranunculus acris L.	1.8	3.7	4.8	1.2	1.6	1.4	1.08	NS	0.11	0.08	0.58
Cirsium palustre (L.) Scop.	4.4	2.8	2.9	6.1	3.8	5.5	2.30	NS	0.61	0.35	0.94
Ranunculus repens L.	1.6	3.4	−1.5	2.5	4.3	1.1	0.96	0.05	0.17	0.02	0.31
Rubus idaeus L.	0.3	0.8	0.8	0.6	0.1	0.1	0.46	NS	1.00	0.29	0.42
Urtica dioica L.	0.2	0.3	0.4	1.4	0.6	0.2	0.52	NS	0.68	0.32	0.42
Other dicotyledones[5]	1.4	2.1	1.0	1.6	1.1	0.6	0.54	NS	0.35	0.46	0.58
Bryophyta and Pteridophyta[6]	2.4	1.4	1.9	2.5	3.3	−0.2	1.55	NS	0.66	0.99	0.32
Number of plant species[7]	19.1	16.3	15.5	16.6	14.3	13.0	1.41	NS	0.26	0.02	0.95

[1] Standard error of means for the interaction of treatment by year (T×Y).
[2] The observation from autumn 2013 was used as a covariate if P < 0.05. The fixed effects were treatment (T) and year (Y).
[3] The botanical composition of each replicated field was based on an evaluating of 50 squares per field.
[4] Other Poaceae in descending prevalence: Carex nigra (L.) Reichard, Juncus conglomeratus L., Festuca rubra L., Dactylis glomerata L., Carex rostrata Stokes, Holcus mollis L., Carex echinata Murray, Festuca ovina L., Poa trivialis L., Poa annua L., Juncus filiformis L., Alopecurus pratensis L., Alopecurus geniculatus L., Luzula multiflora (Ehrh.) Lej.
[5] Other Dicotyledones in descending prevalence: Stellaria graminea L., Trifolium repens L., Galeopsis bifida Boenn., Rumex acetosa L., Viola epipsila Ledeb., Stellaria media (L.) Vill., Salix spec. L., Epilobium hornemannii Reichb., Rumex longifolius DC., Betula pubescens Ehrh., Galium odoratum (L.), Tussilago farfara L., Vaccinium myrtillus L., Cerastium fontanum Baumg., Taraxacum spec. F. H. Wigg., Veronica chamaedrys L., Achillea millefolium L., Potentilla erecta (L.) Räusch.
[6] Bryophyta species were not determined. Pteridophyta in descending prevalence: Equisetum palustre L., Dryopteris expansa (C. Presl) Fraser-Jenk. & Jermy, Phegopteris connectilis (Michx.) Watt, Dryopteris filix-mas (L.) Schott, Gymnocarpium dryopteris (L.) Newman.
[7] Bryophyta, Salix spec. and Taraxacum spec. were counted with one count each.
[a,b] Values followed by different letters were statistically different (P < 0.05).

lactation tended ($P < 0.1$) to be higher in Period 4 and the CP concentration was higher ($P < 0.05$) in Period 3 on the grazed swards than in the control. The effect of period on forage feed quality differed between years, but the treatment effect was similar among the years (figures not shown).

Animal Performance

Weight gain was significantly ($P < 0.05$) higher in lambs assigned to S_Spring compared to S_Control and S_Summer (**Table 4**). Weight gain, slaughter weight, carcass confirmation, carcass fatness, and carcass value were all significantly ($p < 0.05$) higher in lambs assigned to S_Spring compared to S_Summer (**Table 4**).

Sheep Grazing Distribution Pattern

The GPS observations of ewes deviated from even distribution among treatments in all periods (**Figure 2**). There was a clear trend, particularly in the year 2014, that ewes preferred to graze where sheep grazed during the Period 2 (G_S) and to avoid the area that was not grazed (G_0).

DISCUSSION

Botanical Composition

Many of the plant species present at the onset of the current study are species that are adapted to herbivory, and the observed high proportion of *D. cespitosa* is a characteristical stage in succession after abandonment of a grassland (Jensen et al., 2001; Rosef et al., 2007). The increase in the dry weight proportion of *D. cespitosa* from 2014 to 2015 in the plots summer grazed by sheep is in accordance with another study (Krahulec et al., 2001), and may be due to sheep preference for other species than the less palatable *D. cespitosa*. The botanical assessment methods were consistent in ranking the prevailing species, being the grass species *A. capillaris*, *D. cespitosa*, and *P. pratensis*. The methods were also concurrent in that the botanical composition was not affected by grazing treatments.

The decline in number of species with year observed in the current study is in contrast with other findings. Abandonment of grazing causes a decline in plant species richness because grazing-tolerant species have a reduced ability to compete for light and space (Smith and Rushton, 1994; Wehn et al., 2017),

TABLE 2 | Effect of grazing treatment [(control without grazing (G_0), grazing with heifers (G_H) or grazing with sheep (G_S)] and year on vegetation ground cover estimated in autumn (Period 4) of 2014 and 2015 in permanent 1 × 1 m squares.

	2014			2015			SEM[1]	*P*-value[2]			
	G_0	G_H	G_S	G_0	G_H	G_S		Covariate	T	Y	T×Y
n[3]	3	3	3	3	3	3					
POACEAE, %											
Agrostis capillaris L.	59.4	75.8	66.9	68.3	66.0	65.7	7.56	<0.001	0.60	0.97	0.12
Deschampsia cespitosa (L.) P. Beauv.	9.6	10.3	11.7	9.2	9.2	9.9	2.67	<0.001	0.95	0.94	0.50
Poa pratensis L.	12.7	5.7	6.4	11.8	8.2	8.5	4.26	<0.001	0.97	0.95	0.17
Holcus mollis L.	7.9	4.0	6.2	4.0	4.0	4.0	2.92	<0.001	0.73	0.15	0.13
Festuca pratensis L.	1.2	1.6	0.4	0.8	0.6	1.1	0.62	0.08	0.87	0.005	0.87
Other poaceae[4]	0.3	0.2	1.5	1.0	1.0	0.8	0.38	0.006	0.74	0.005	0.28
DICOTYLEDONS, %											
Ranunculus acris L.	1.7	1.6	1.1	2.0	2.1	1.3	0.52	0.41	0.76	0.57	0.32
Ranunculus repens L.	0.7[b]	1.4[b]	2.6[ab]	6.6[a]	3.8[ab]	1.6[b]	1.10	<0.001	0.19	<0.001	0.21
Cirsium palustre (L.) Scop.	1.5	1.2	1.4	2.2	0.9	1.5	0.59	<0.001	0.71	0.83	0.22
Other dicotyledons[5]	2.4	2.3	3.5	1.9	2.3	2.7	0.68	0.001	0.58	0.86	0.31
Bryophyta and *Pteridophyta*[6]	7.7	6.7	3.5	7.9	8.4	7.2	1.57	<0.001	0.42	0.61	0.11
Number of species[7]	7.0	6.8	7.3	7.7	7.9	7.7	0.45	<0.001	0.46	0.14	0.72
OTHER STRUCTURES, %											
Open soil	0.0	0.2	0.0	0.0	0.2	0.2	0.10	0.72	0.28	0.49	0.62
Stones	0.0	0.2	0.1	0.0	0.1	0.0	0.08	0.01	0.85	1.00	0.24
Dead plant material	47.5[ab]	27.1[bc]	64.2[a]	58.3[a]	47.5[ab]	17.1[c]	4.88	0.09	0.03	<0.001	0.17

[1] *Standard error of means for the interaction of treatment by year (T×Y).*
[2] *The observation from autumn 2013 was used as a covariate if $P < 0.05$. The fixed effects were treatment (T) and year (Y).*
[3] *The botanical composition of each replicated field was based on an evaluating of 4 squares per field.*
[4] *Other Poaceae in descending prevalence: Poa trivialis L., Phalaris arundinacea L., Phleum pratense L., Festuca rubra L., Carex nigra (L.) Reichard, Juncus conglomeratus L., Festuca ovina L., Luzula multiflora (Ehrh.) Lej., Dactylis glomerata L.*
[5] *Other dicotyledons in descending prevalence: Stellaria graminea L., Viola epipsila Ledeb., Trifolium repens L., Rubus idaeus L., Stellaria media (L.) Vill., Galeopsis bifida Boenn., Taraxacum spec. F. H. Wigg., Epilobium hornemannii Reichb., Urtica dioica L., Potentilla erecta (L.) Räusch., Veronica chamaedrys L., Cerastium fontanum Baumg., Betula pubescens Ehrh., Veronica officinalis L., Trientalis europaea L., Rumex acetosa L.*
[6] *Bryophyta and Monilophyta species were not determined.*
[7] *Bryophyta and Taraxacum spec. were counted with one count each.*
[a,b,c] *Values followed by different letters were statistically different ($P < 0.05$).*

and reintroducing grazing usually increases the number of plant species (Pavlu et al., 2007). However, the effect of grazing on species richness depends on factors like grazing intensity and the time of year grazing is conducted (Bullock et al., 2001; Pavlu et al., 2007). Most of the species found in 2013 but not in 2015, and the new ones appearing during the same time, are species associated with grassland. They contributed, however, very little to the total biomass, and the observed changes may have been caused by grazing, difference in weather conditions, and their interaction. Discrepancy in the number of species observed between the two assessment methods, is likely due to the fact that with the dry weight-rank method 50 observations were taken per field at each assessment, covering an area 8m^2, while with the ground cover method four observations on fixed squares were done with a total area of 4 m^2.

Grazing the entire area with sheep in spring and autumn, short grazing period during summer and variation of plant communities between fields likely contributed to veil potential differences between treatments. The duration of the experiment may also have been too short for revealing any difference among treatments. In addition, the amount of time since the area was abandoned, and not grazed by livestock, may have been too short for substantial change in the plant community.

Forage Production, Intake and Utilization

The positive effect of summer grazing on the primary productivity in the current study is in line with other studies with light or moderate grazing (McNaughton, 1979; Patton et al., 2007). Grazing may both enhance and reduce subsequent growth rate of plants, depending on many factors like availability of leaf area, meristems, nutrients, and frequency and intensity of grazing (Noy-Meir, 1993).

McNaughton (1979) summarizes mechanism that stimulate or compensate plant productivity with grazing, of which the following were likely important in our study: "increased photosynthetic rates in residual tissue, reallocation of carbohydrates from other plant parts, removal of older tissues, increased light intensities upon more active underlying tissues, reduction of the rate of leaf senescence, and nutrient recycling from dung and urine."

The observed negative growth rate in late summer and autumn is likely due to photoperiodic (short-day) depression of

TABLE 3 | Effect of grazing treatment, Control without grazing (G_0), grazing with heifers (G_H) or grazing with sheep (G_S), during the summer period on total (HPt) and forage (HPg) dry matter (DM) production (g/m^2 and g/m^2 and day), estimated DM intake of forage (HIg) DM (g/m^2 and g/m^2 and day), forage proportion of total biomass produced (HGP, g/g), the proportion of consumed biomass of forage biomass produced (HPU, g/g) and feed quality (n = 6).

	[1]Period (P)	Treatment (T)				*P*-value		
		G_0	G_H	G_S	SEM	P	T	P×T
Sward height (cm)	1	10.5	11.3	10.5	0.87	<0.001	0.014	<0.001
	2	18.8[a]	7.8[b]	8.7[b]	1.14			
	3	14.6[a]	11.3[b]	12.2[b]	1.54			
	4	7.5	6.5	7.3	0.98			
HPt (g DM/m^2)	1	144	247	197	16.7	<0.001	0.013	0.364
	2	198	222	266	17.8			
	3	−53	43	11	58.7			
	4	17	14	53	48.0			
	Annual	306[b]	526[a]	527[a]	48.4	–	0.010	–
Daily HPt (g DM/m^2 d)	1	5.1	8.8	7.0	0.60	<0.001	0.070	0.589
	2	4.1	4.6	5.5	0.37			
	3	−1.2	1.1	0.4	1.44			
	4	0.6	0.4	1.8	1.74			
HPg (g DM/m^2)	1	100	171	143	15.0	<0.001	0.009	0.461
	2	191	187	220	17.6			
	3	−119[b]	−3[a]	−31[a]	52.1			
	4	−47	−35	−4	34.1			
	Annual	125[b]	320[a]	327[a]	41.8	–	0.023	–
Daily HPg (g DM/m^2 d)	1	3.6	6.1	5.1	0.53	<0.001	0.007	0.252
	2	4.0	3.9	4.6	0.36			
	3	−3.1[b]	−0.2[a]	−0.8[a]	1.30			
	4	−1.6	−1.2	−0.2	1.23			
HIg (g DM/m^2)	1	18	45	31	6.4	0.002	0.002	0.029
	2	6[b]	165[a]	153[a]	25.0			
	3	–	–	–				
	4	1	27	16	25.4			
	Annual	25[b]	236[a]	200[a]	40.8	–	0.002	–
HGP = HPg/HPt (g/g)	Annual	0.40	0.60	0.62	0.076	–	0.104	–
HPU = HIg/HPg (g/g)	Annual	0.22[b]	0.75[a]	0.65[a]	0.112	–	0.032	–
NEL (MJ/kg DM)[2]	1	5.04	5.05	5.12	0.058	<0.001	0.089	0.111
	2	4.49	4.54	4.60	0.075			
	3	4.80	4.97	4.94	0.068			
	4	4.65	5.03	5.06	0.083			
CP (g/kg DM)[3]	1	145	145	143	4.2	<0.001	0.020	0.069
	2	108	119	130	7.1			
	3	133[b]	163[a]	168[a]	7.4			
	4	121	134	141	5.9			
aNDF (g/kg DM)[4]	1	561	560	552	6.6	<0.001	0.042	0.190
	2	634	630	620	9.4			
	3	597	575	576	7.4			
	4	612[a]	565[b]	561[b]	11.3			
ADF (g/kg DM)[5]	1	315	305	298	7.4	<0.001	0.033	0.014
	2	366	357	353	7.4			
	3	352	335	335	7.4			
	4	346[a]	311[b]	318[b]	7.4			

[1] *Period 1, 2, 3, and 4 is spring, summer, late summer and autumn in **Figure 1**. Period is not included in the statistical model for the annual sums.*
[2] *NEL is net energy of lactation.*
[3] *CP is crude protein.*
[4] *aNDF is ash free neutral detergent fiber.*
[5] *ADF is acid detergent fiber.*
[a,b,c] *Values followed by different letters within rows were statistically different (P < 0.05).*

TABLE 4 | Effect of spring grazing treatment on lamb live weight gain, slaughter weight, carcass conformation, fatness and value (LSMeans with standard error of mean in brackets).

	Treatment[1]			P-value
	S_Common	S_Spring	S_Summer	
LIVE WEIGHT GAIN (G/DAY)				
n	75	54	64	
Birth—start Period 1[2]	288 (12.0)[a]	278 (13.1)[a]	280 (12.8)[a]	0.795
Start period1—Slaughter date[3]	228 (6.1)[a]	255 (6.6)[b]	203 (6.5)[c]	0.001
Period 1[4]		327 (10.8)[a]	321 (10.6)[a]	0.674
Start Period 2—Slaughter date[5]		229 (8.6)[a]	164 (8.6)[b]	0.001
SLAUGHTER PARAMETERS				
n	48	33	43	
Slaughter weight (kg)[6]	14.3 (0.45)[ab]	15.7 (0.52)[a]	13.2 (0.48)[b]	0.002
Carcass conformation[7]	5.80 (0.228)[a]	6.24 (0.264)[a]	5.06 (0.243)[b]	0.003
Carcass fatness[8]	1.68 (0.102)[ab]	1.87 (0.117)[a]	1.50 (0.108)[b]	0.059
Carcass value (NOK)	614 (28.2)[ab]	700 (32.6)[a]	542 (30.0)[b]	0.002

[1]*S_Common;, common farm procedure with short spring grazing period before summer grazing on range pasture; S_ Spring; ∼4 weeks extended spring grazing period on the abandoned grassland before summer grazing on range pasture as in S_Common; S_Summer; grazing on the abandoned grassland all summer).*
[2]*Live weight gain from birth to start Period 1 (See **Figure 1**).*
[3]*Live weight gain from start Period 1 to autumn.*
[4]*Live weight gain during Period 1, ∼4 weeks extended spring grazing period (See **Figure 1**). Lambs in S_Common on Rangeland were not weighed.*
[5]*Live weight gain from end of Period 1 to autumn (Period 2 and 3). Lambs in S_Common on Rangeland were not weighed.*
[6]*Slaughter weight.*
[7]*EUROP system: P– = 1, P = 2, P+ = 3, O– = 4, O = 5, O+ = 6, R– = 7, R = 8, R+ = 9.*
[8]*EUROP system: 1– = 1, 1 = 2, 1+ = 3, 2– = 4, 2 = 5, 2+ = 6, 3– = 7, 3 = 8. … 5+ =15.*
[a,b,c]*Values followed by different letters were statistically different (P < 0.05).*

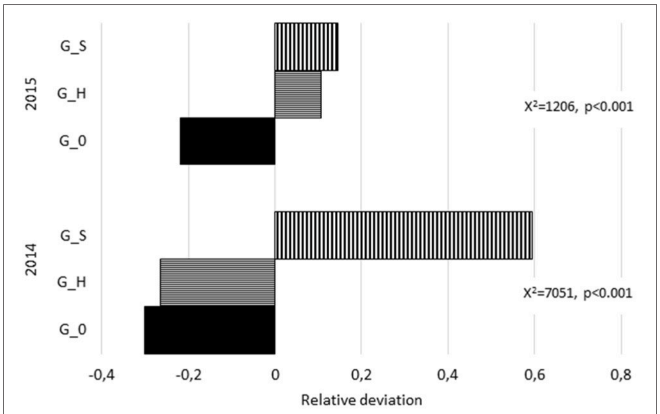

FIGURE 2 | Relative deviation of the GPS observations of ewes from hypothesized (i.e., random) GPS distribution in autumn (Period 4) after the summer grazing in 2014 and 2015, respectively, in each of the three summer grazing treatments [G_0 Control (no grazing), G_H Heifers grazing, and G_S ewes grazing with their offspring]. In Period 4, the ewes could graze the entire area freely. Relative deviation is calculated as the difference between the observed and hypothesized percentage (33%) divided by the hypothesized percentage. Positive deviation indicates preferred area by the sheep while negative deviation indicates avoided area. The distributions are compared by a X^2 Goodness-of-fit test.

growth, in order to cold-harden the plants. This is common in plants originating from higher latitudes (Hay, 1990).

The improved nutritive value of the forage by grazing is in line with findings in other studies (Pontes et al., 2007; Schönbach et al., 2012). Grazing reduces the number of stems and tissues that reach mature stage, and the age of tissue is generally lower than under no grazing (Schönbach et al., 2012).

Sheep Grazing Distribution Pattern

As the swards in the plots that were grazed during the summer had shorter plant height with higher nutritional quality at the end of Period 3, it was expected that ewes in the autumn (Period 4) preferred to graze more in these plots than in the control plots. Sheep are more generalist than specialist herbivores as they do not change foraging behavior and become more specialist when food is abundant (Arnold, 1987). As long as forage availability is sufficient, we would not expect difference in grazing distribution pattern. However, herbivores generally select short, leafy swards that contain relatively high concentrations of nutrients (McNaughton, 1984). Sheep avoid grazing areas infected by intestinal parasites (Cooper et al., 2000), and their feces aversion outweighs their attraction toward high forage quality sward (Hutchings et al., 1999). We have no record of parasite infection status of the studied grassland, but as it had not been used for a long period of time the parasitic pressure was expected to be low. However, the difference between the 2 years, with higher preference for the area grazed by sheep in autumn of the first than the second year, may be due to increased parasitic pressure.

Animal Performance

The higher weight gain, slaughter weight, carcass confirmation, carcass fatness, and carcass value observed in lambs kept for an extended 1 month period on spring pastures (S_Spring) are likely due to both animal and pasture related factors. As weight gain correlates with slaughter characteristics this is as expected (Sents et al., 1982). Animal factors such as age, weight, and condition of lambs when turned out on summer range pasture is known to affect performance of lambs (Warren and Mysterud, 1995; Dwyer, 2009).

The common farm practice in Norway is to keep the spring pasturing period as short as possible, turning ewes and lambs as early as possible on summer range pastures. Extending the spring grazing period implies that lambs are older and heavier when turned out on summer range pastures, explaining their better weight gain in this study. Further, spring pastures are commonly cultivated grasslands close to the farm building and at lower altitudes than range summer pastures. In spring, grass growth starts earlier at lower altitudes. Extending the spring grazing period on lowland, cultivated pastures may have provided access to high quantities of easy available, high quality grass for a longer period in spring explaining the improved performance in lambs. However, during the summer the forage quality of the enclosed pasture declines. Keeping ewes and lambs on the same enclosed cultivated grasslands for the entire grazing season (S_summer) gave the lowest average weight gain in lambs of all treatment groups. This can be explained by the forage maturation hypothesis (Albon and Langvatn, 1992), i.e., the forage quality declines with the maturity but the rate depends on altitude. Sheep on rangeland may move to higher altitude and have access to plants in a young stage of development for a longer period of time than those kept on enclosed pastures in the lowland.

The study farm was situated in the county of Møre and Romsdal, which is considered to have medium quality rangeland pastures with an average lamb weight gain of 252 g/day compared to national average of 261 g/day in 2015 according to the Norwegian Sheep Recording System (Ringdal et al., 2016). This indicates that there is genetic potential for increased weight gain. The observed weight gains in our study of 255g/day in the treatment with the highest (S_spring) and 228 g/day in the group with the poorest weight gain (S_summer) further shows that including abandoned cultivated grasslands has the potential to exploit the genetic potential for weight gain in lambs in this region.

Ensuring animal health and welfare in farming systems receives increased attention and new policies and legislations are implemented (Main and Mullan, 2017). Grazing unfenced mountain and forest rangelands provides an opportunity for the animals to perform natural behaviors, and therefore has the potential to provide a high level of animal welfare. Sheep on rangeland are, however, also associated with risk factors such as undetected disease and predators causing suffering as well as lamb losses. Providing ewes and lambs with an extended spring grazing period, and thus a farming system where older and heavier lambs are released on range pasture, has the potential to improve performance, condition, and thus animal welfare in sheep farming (Warren and Mysterud, 1995; Dwyer, 2009). There is abundant range summer pastures available for domestic herbivores in Norway (Rekdal, 2013), and the Norwegian authorities state that food production should be increased and that livestock production should be based on domestic feed resources (Landbruks- og matdepartementet., 2016). Our results suggest that access to abandoned cultivated grasslands, commonly located close to arable farmland, may allow sheep farmers to increase flock size and ensure healthy, robust lambs for rangeland pasturing. This will also increase the stocking rate on rangeland areas, and thus to increased food production on abundantly available feed resources.

Abandoned farmland, or land in danger of being abandoned in Norway, is owned by landowners that for various reason have quit farming. The areas are often marginal, steep sloping with high content of stones in the soil, and difficult or impossible to till with tractors. Putting a value on such land is often difficult, and even if the Norwegian legislation states that landowners are obliged to maintain farmland, it is not necessarily done for marginal land, as it is less attractive to rent. However, it is likely that social and juridical factors as much as technical and management factors account for why these areas are not rented out to active farmers (Flemsæter et al., 2011; Sang et al., 2014). Social and juridical constraints were beyond the objectives of the current study, but our findings may serve as a basis for sheep farmers and landowners to value the land in monetary terms.

CONCLUSIONS

The global need for food with an increasing world population and a national responsibility to ensure food security implies that available feed resources should be used for food production. By showing that marginal and abandoned grassland has a value, we provide both the landowner and the potential farmer of the land with information that may be important for decision-making and rental agreements. The abandoned grassland used in this study showed that the productivity and forage quality improved when it was grazed, and that the performance of lambs improved when using it for extending the spring grazing period. Including such grassland in existing sheep farming therefore shows potential for improving animal welfare, performance, and economy.

DATA AVAILABILITY

The datasets generated and analyzed during the current study are available in the Mendeley data repository doi: 10.17632/gb7822ngty.1.

AUTHOR CONTRIBUTIONS

HS, LG, UL, and EB conceptualized the study. SA: did the botanical assessment. HS analyzed the data from the herbage production. LG data from the sheep performance. HS, LG, and SA wrote the manuscript and all authors were involved in reviewing, revision and final approval of the manuscript.

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