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Temporal Variations in the Production—Quality and Optimal Cutting Date of Hay Meadows in the Central Pyrenees (Spain)

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Abstract: The production and forage quality of semi-natural hay meadows of *Arrenatheretalia* in the southern central Pyrenees were studied according to the time of mowing within the vegetative cycle, to determine its optimum moment. The results show important variations according to the meadows and the year. Higher productions (56% in kg DM ha^{-1}, 42% in UFL ha^{-1}) and lower qualities (−12% in CP, −11% in UFL kg DM^{-1}, −7% in PDI and −17% in RFV) were obtained in the year in which temperatures and rainfalls were the highest. It is concluded that the timing (advance or delay) concerning the maximum value of production and the quality (two years) do not have a direct relationship with the variations of accumulated rainfalls and the growing degree days. The decreases in production (18% in kg DM ha^{-1} and 25% in UFL ha^{-1} until 24 June) and quality (26% in CP, 16% in UFL kg DM^{-1}, 13% in PDI and 20% in RFV until 24 June) were also quantified from their maximum values within the traditional mowing period. The optimal time for mowing is between 20 May and 20 June, depending on the annual weather and the meadow characteristics.

Keywords: grassland; forage; feed value; mountain; management practices; accumulated temperature; growing degree days

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1. Introduction

Livestock exploitation systems are subject to discussions related to the maintenance of populations and agricultural income, technical adaptations regarding the use of endogenous resources, the intensification–extensification of livestock systems, competition between the production of plant foods for human and animal consumption, evaluation of ecosystem services, diversity maintenance, climate change, eutrophication of water, a reduction in meat consumption, and an increase in the consumption of dairy products [1–5].

Within this context, hay meadows in mountain areas have specific characteristics within livestock systems. From a vegetation perspective, they are included in the semi-natural grasslands category, due to having high diversity and low intensification [6], which, in the central Spanish Pyrenees, correspond to various associations of *Arrhenatherion elatioris* and *Triseto-Polygonion bistortae*. Council Directive 92/43/EEC (European Economic Community) considers these meadows as natural habitats of interest (6510 and 6520) and the Natura 2000 Network has established the need for their conservation and to define specific geographical areas. As they are forest substitution communities, and, in many cases, have been established on cultivated areas (until the mid-20th century), their floristic compositions depend on mowing, grazing, and fertilizing with manure. Even within relatively small surfaces—with respect to the total territory—the botanical and phytocoenological diversities are high [7–16].

In the southern central Pyrenees, meadows are used within beef cattle breeding systems with various management strategies [17,18]. The main use occurs at the end of spring/beginning of summer, via mowing, to conserve silage or hay. In addition, grazing is frequent in autumn and, in some cases, at the end of winter. Exceptionally, a second cut can be produced at the end of the summer when it is especially rainy. In general, these are surfaces that are not suitable for other agricultural uses due to their physiographic characteristics (slope, small size, and access difficulties), climate, and productivity. Consequently, they are non-competitive resources with agricultural production, for direct human consumption [5].

One relevant fact involves the reduction of mountain meadows from the 1970s to the present, both in Europe [19] and in the Pyrenees [20,21]. The reduction is linked to economic profitability in the face of competition, with more intensified forage crops and urbanization, as well as limitations imposed by physiographic and climatic characteristics of the mountains. Thus, the Common Agricultural Policy (CAP) of the European Union, through public administration, has implemented a series of measures to facilitate the competitiveness, conservation, and maintenance of diversity [22]. As of 2023, these measures will be developed within a framework of eco-schemes [23], whose objectives will be to reconcile the improvement of the use with the adaptation to the maintenance of diversity, to the reduction of energy consumption, to gas emission and to the waste reuse.

One aspect that affects mountain hay meadows involves the mowing date of the main use in the spring. The practice of mowing in semi-natural plant communities is necessary, both to obtain forage for conservation and to maintain floristic composition. The moment at which the harvest occurs determines the production and quality of the forage [24], the botanical composition [25,26], and the dynamics of other living organisms of this medium [27,28]. After the start of vegetative development at the end of winter, there is progressive increase in production and a decrease in energy, protein, and forage digestibility. Production and quality are linked to the botanical composition, climatic conditions, the characteristics of each meadow (soil, fertility, water retention capacity, etc.), and fertilization. In turn, these factors are interrelated and evolve together.

The amount and temporal distribution within the vegetative cycle of rainfall, heat, and water availability are related to production, quality, and evolution, over time. Several studies have shown that the estimation of heat through the growing degree days is related to the seasonality of production, phenology, and forage quality [29–38]. Likewise, rainfall and water availability [33,34,39–43] also impact production, quality, and temporal distribution. However, the complex relationship between these climatic factors and production/quality still needs to be clarified [40,42,44]; it is complicated by aspects related to the floristic composition of meadows and management.

From an agronomical perspective, it is of interest to know the moment when production and quality are optimal, as well as the relationship with rainfall and temperature. Likewise, it is convenient to know the effects of delayed harvesting on production and quality, the dynamics of plant species (reproduction, competition, etc.), and on the conservation of ecosystem organisms. The quantification of loss is essential, from the livestock perspective and to establish conservation measures based on delayed mowing.

The aim of this work was to analyze the variations in the production and quality of hay meadows, to decide the optimal mowing moment, the relationship with the climatic year, and the physiographic/fertilization characteristics.

2. Materials and Methods

The study area is located on the southern slope of the central Pyrenees (province of Huesca). The meadows are located on the slopes or valley bottoms of the heterogeneous substrates of moraines, slope debris, or terraces of fluvial or fluvio-lacustrine origin. These meadows are mowed at the end of spring/beginning of summer for the production of hay or silage. In summers with high rainfall, they could receive a 2nd cut at the end of August. The cows, after a stay at the summer ports, graze in the meadows between October and December. Fertilization (through manure) is applied in the winter at a rate of about 30,000 kg ha^{-1} year^{-1} and through droppings during the grazing period. In some cases, inorganic fertilizer is applied or only grazing droppings.

Eight meadows were selected with the aim of representing different physiographic, management, and botanical composition characteristics. They were located between 902 and 1615 m in altitude. In each meadow, an enclosure with exclusion for cattle was established for botanical inventory and control of production and quality. The enclosures measured 13 by 10 m and were maintained for 2 years (2019 and 2020). The enclosures had 12 plots of 4 m^2 (2 m × 2 m) corresponding to 4 mowing times, with 3 repetitions for each mowing. The plots had corridors of 1 m that separated them.

Flora inventories were carried out according to the Braun-Blanquet method [45] in the enclosure of the control plots, without considering the entire meadow. For each meadow, the altitude, soil, fertilization type, and slope parameters were characterized. The altitude is expressed in meters from the cartography of Instituto Geográfico Nacional [46]. Four soil categories were established: (1) soil with depth < 20 cm; (2) soil with depths between 20 and 60 cm, with an abundance of coarse elements that prevented the entry of the auger; (3) soil with depths greater than 60 cm, with an abundance of coarse elements that prevented the entry of the auger; (4) soil with depth greater than 60 cm. The type of fertilization was estimated from farmers' surveys; four categories were considered in addition to grazing droppings: (1) excess fertilization (>200 kg N ha^{-1}); (2) low fertilization (only grazing droppings 0 kg N ha^{-1}); (3) medium fertilization (<100 kg N ha^{-1}); (4) high fertilization (100–200 kg N ha^{-1}). The slope is expressed in degrees. These physiographic characteristics of the eight meadows are specified in Table S1 (Supplementary Material).

The climatic parameters were obtained from the climatic stations: 9446, 9789A, 9784P, 9814X, 9838A, 9838B, and 9843A of the network of the Agencia Estatal de Meteorología [47]. The accumulated rainfall and the accumulated evapotranspiration (ETo) Penman-Monteith were calculated daily since March 1. Evapotranspiration was calculated from temperature data according to CROPWAT 8.0 procedures [48]. The growing degree days were calculated since 1 February, by the sum of the daily average temperatures when they were between 0 and 18 °C. If the averages were negative, we limited them to 0 °C, and to 18 °C when they were >18 °C [49,50].

The production and quality control was carried out four time during the vegetative cycles in 2019 and 2020. The first one (cut 0) was made during the second half of April and served as an initial reference to estimate the daily production and quality values up to cut 1. Cuts 1, 2, and 3 were distributed between 20 May and 10 July. They were experimental cuts sequenced over time in that order, to study the best time to conduct the only mowing for haymaking. Production has been obtained from the green weight measured in the field in the 4 m^2 plots multiplied by the proportion of dry matter in the oven at 65 °C during a 48 h period. Quality parameters were obtained in a laboratory, from 1 kg of samples taken from the field, from the total harvested in each plot. Forage samples were frozen until processing in the laboratory. The grass was cut (5 cm from the ground) using a battery-powered hedge trimmer. A total of 192 samples were collected (8 meadows, 4 cuts per meadow, 3 repetitions, 2 years). In each enclosure, autumn grazing was simulated via mechanical mowing.

Laboratory determinations are as follows: laboratory dry matter at 105 °C for 4 h; nitrogen content (N) was determined using the Kjeldahl method and crude protein (CP) concentrations were calculated from it by multiplying (N × 6.25). Ash-free neutral detergent fiber (NDF) and acid detergent fiber (ADF) were quantified using an Ankom 200 fiber analyzer (Ankom Technol. Corp., Fairport, NY, USA), according to Van Soest et al. [51]. The net energy value of fodder UFL ("Unité fourragère lait", feed units for milk UFL (kg $DM)^{-1}$) and the metabolizable protein content PDI ("protéines digestibles dans l'intestin", digestible crude proteins in the gut, g (kg $DM)^{-1}$) have been calculated according to INRA [52]. Relative feed value (RFV) is an index that combines important nutritional factors (potential intake and digestibility) into a single number, providing a quick and effective method for evaluating feed value or quality. The RFV was calculated using the estimates of digestible dry matter (DDM%) and potential dry matter intake (DMI% of body weight) of the forage, based on the ADF and the NDF fractions [53]. The parameter UFL ha^{-1} was calculated to combine the amount of forage produced (kg DM ha^{-1}) in each meadow with its energy content (UFL (kg DM)$^{-1}$).

A non-parametric contrast treatment was carried out via the Mann–Whitney U Test for climatic, production, and quality parameters, considering the year and cutting number factors. The analysis of the relationship between production and quality and the climatic and characterization parameters of the meadow were carried out using multiple linear regression (MLR). For the selection of the dependent variables of the regression, the contrast of the production and quality parameters was carried out using Pearson's correlation. The MLR analysis was conducted for UFL ha^{-1} and UFL (kg DM)$^{-1}$ as dependent variables. Cumulative rainfall, cumulative evapotranspiration, growing degree days, altitude, soil (4 categories), fertilization (4 categories), and slope were considered as explanatory variables. For the production and quality variables, daily data obtained by linear interpolation among cuts 0, 1, 2, and 3 were used. MLR analyses were conducted for (i) UFL ha^{-1} with the daily values from 20 May to the date corresponding to the cut of the maximum value of the parameter of each meadow and year; (ii) UFL (kg DM)$^{-1}$ with the daily values from 20 May to the date corresponding to the cut of the maximum value of the parameter of each meadow and year; (iii) UFL (kg DM)$^{-1}$ with the daily values from the dates corresponding to the maximum quality values, and 24 June, when they were minimum.

Quantitative differences for the same parameters are expressed in percentages of relative increases or decreases $(X_2 - X_1)\ {X_1}^{-1}\ 100$.

Statistical analyses were performed with IBM SPSS Advanced Statistics software ver. 26 (SPSS Statistics 26.0, International Business Machines Corporation, Armonk, NY, USA).

3. Results

3.1. Flora

The floristic inventories of the meadows are attributed to *Rhinantho mediterranei-Trisetum flavescentis* of *Arrhenatherion*, with 118 species belonging to 32 families. The taxa per inventory varies between 31 and 54 (Table 1). The *Gramineae* family has the greatest coverage in most inventories (23–62%). It has 22 taxa; the most frequent and abundant are *Dactylis glomerata*, *Poa pratensis*, *Trisetum flavescens*, *Festuca arundinacea*, and *Arrhenatherum elatius*. The *Leguminosae* are represented by 10 species with high covers, between 19 and 38%. The most frequent and abundant are *Trifolium pratense*, *Trifolium repens*, *Lotus corniculatus*, *Vicia cracca*, *Medicago lupulina*, and *Lathyrus pratensis*. Other families with high representation are *Compositae* (13), *Caryophyllaceae* (7), and *Scrophulaciaceae* (7). The list of species identified in each meadow can be found in Table S1 (Supplementary Material).

Table 1. Synthesis of the floristic composition of the meadows studied. Data expressed in % coverage.

	Meadows								Number of Species
	01	02	03	04	05	06	07	08	
Gramineae	44	55	34	23	31	53	62	47	22
Leguminosae	21	20	20	26	38	24	19	26	10
Other families	35	24	46	52	31	24	19	28	86
Number of species	44	45	41	53	35	31	35	54	118

3.2. Climatological Data

The average rainfall of the seven stations studied for the last 40 years was 1236.4 mm, with maximums in autumn and minimums in winter (Figure 1). The rainfall in the years 2019 and 2020 were 1170.7 and 1122.7 mm, respectively, with maximums in autumn in the first year and spring in the second year studied. The average annual temperature for the period 1981–2020 was 7.6 °C, 11.3 °C in 2019 and 11.5 °C in 2020. The annual distributions involved maximums in the summer; in 2019 and 2020, it was higher compared to the last 40 years, in all months.

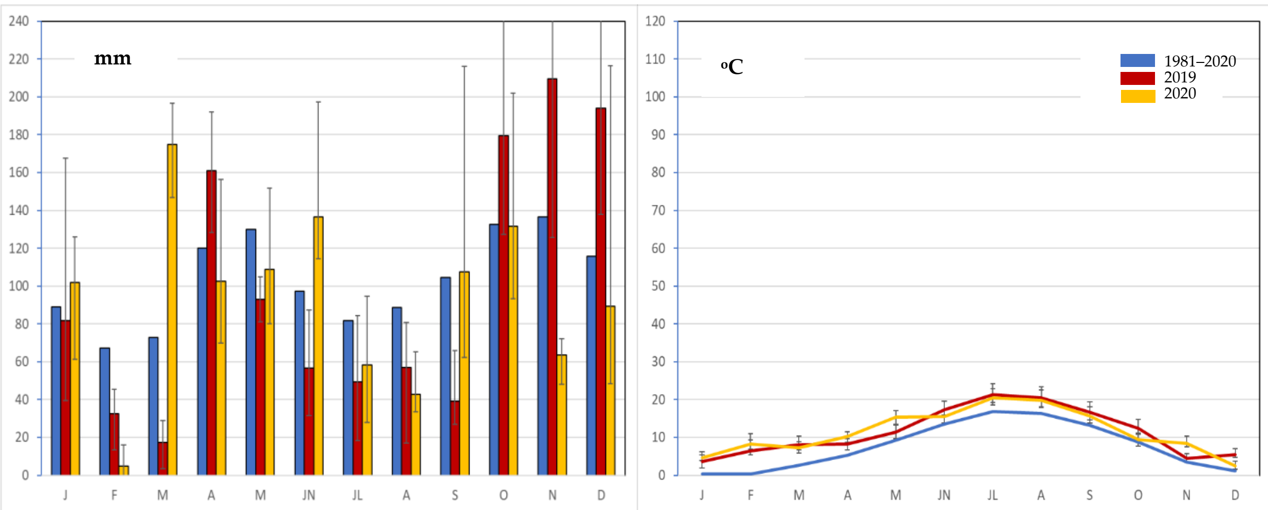

Figure 1. Average values of rainfall (**left**) and temperature (**right**) of the seven stations in the study area. Blue: the average for the period 1981–2020; red: the values for 2019; yellow: the values for 2020. Error bars represent maximum and minimum values.

Figure 1 shows that, in the 1981–2020 period, the annual rainfall histograms (left) exceeded the temperature curves (right), indicating the absence of dry months. However, in 2019 and 2020, the difference is tighter. The interannual variability of rainfall was very high. For example, in March 2019, the lowest annual value was reached, and in the following year, 2020, the highest. The intra-annual variability was also high, especially with rainfall during the autumn and winter months; depending on the location of the meteorological station, there were differences of up to 170 mm of rainfall per month (error bars, Figure 1, left). A greater availability of water in the soil for the growth of grass in 2020 was also perceived. In addition to the maximum annual rainfall in spring, well above the average, rainfall in the last three months of 2019 was also above average.

In all of the climatic stations associated with the meadows, the accumulated rainfall and growing degree days were greater in 2020 than in 2019, but in the cases of growing degree days without significant differences. The accumulated potential evapotranspiration was significatively greater in 2019. All three parameters increased significantly according to the order of the cut (Table 2).

Table 2. Average values and standard deviations of the three climatic parameters studied: cumulative rainfall, cumulative evapotranspiration ETo, and growing degree days, by year and cutting date. Sig: significance differences for $p < 0.001$; different letters in the same column indicate differences (Mann–Whitney U Test).

			Accumulated Rainfall (mm)				Accumulated ETo (mm)				Growing Degree Days (°C)			
Year	**Cut**	***n***	**Average**	**S.D.**	**Sig.**	**Sig.**	**Average**	**S.D.**	**Sig.**	**Sig.**	**Average**	**S.D.**	**Sig.**	**Sig.**
2019	1	24	274	±35			277	±24			797	±92		
	2	24	314	±38			375	±38			1090	±157		
	3	24	357	±61			503	±30			1451	±151		
	Total	72	315	±57	a		385	±98	b		1113	±301	a	
2020	1	24	396	±45			284	±29			988	±79		
	2	24	450	±47			332	±38			1141	±113		
	3	24	498	±37			383	±44			1308	±138		
	Total	72	448	±60	b		333	±55	a		1146	±172	a	
Total	1	48	335	±74		a	281	±27		a	893	±128		a
	2	48	382	±80		b	354	±43		b	1116	±138		b
	3	48	428	±87		c	443	±72		c	1379	±160		c
	Total	144	381	±89			359	±83			1129	±245		

3.3. Characteristics of the Meadows

The characteristics of the meadows varied between 902 and 1615 m of altitude, between 1 and 4 in the soil category, between 1 and 15° in slope, and between 1 and 4 in the fertilization type (Figure 2).

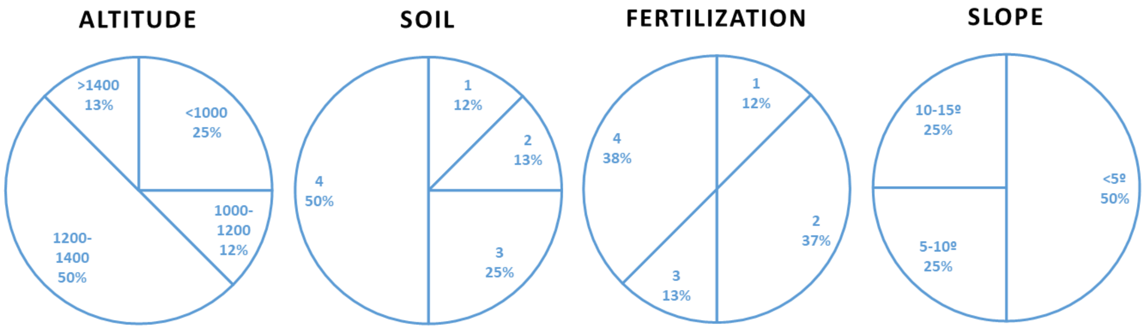

Figure 2. Proportional distributions by meadow classes, according to the altitude (m), soil (categories 1–4), fertilization (categories 1–4), and slope (°) parameters.

3.4. Production and Quality

The mass production (kg DM ha^{-1}) and energy (UFL ha^{-1}) of the eight meadows, in the three cutting dates, in the 2 years, was greater in 2020 than in 2019 for the set of three cuts, with significant differences (Table 3). Regarding the cuts, significant differences were observed only between the third and the first two.

Table 3. Average values and standard deviations of the production parameters studied: kg DM ha^{-1} and UFL ha^{-1}, by year and cutting date. Sig: significance differences for $p < 0.001$; different letters in the same column indicate differences (Mann–Whitney U Test). DM = dry matter, UFL = feed units for milk.

			kg DM ha^{-1}				UFL ha^{-1}			
Year	**Cut**	***n***	**Average**	**S.D.**	**Sig.**	**Sig.**	**Average**	**S.D.**	**Sig.**	**Sig.**
2019	1	24	2809	±1363			2779	±1347		
	2	24	3296	±1221			2916	±1177		
	3	24	2678	±1271			1982	±1009		
	Total	72	2928	±1296	a		2559	±1240	a	
2020	1	24	5046	±1018			4344	±933		
	2	24	5143	±1013			4366	±970		
	3	24	3767	±1451			2903	±1271		
	Total	72	4652	±1322	b		3871	±1259	b	
Total	1	48	3928	±1641		b	3562	±1393		b
	2	48	4220	±1450		b	3641	±1294		b
	3	48	3223	±1457		a	2442	±1227		a
	Total	144	3790	±1566			3215	±1409		

The quality values, contrary to what happened with production, were higher in 2019 than in 2020, with significant differences in UFL (kg DM)$^{-1}$ and RFV and non-significant with CP and PDI (Tables 4 and 5). From the beginning of the cycle, the quality was decreasing for the four parameters, with significant differences between cuts.

The maximum values within the cycle in kg DM ha^{-1} and in UFL ha^{-1} occurred in the first or second cut, without showing significant differences between them (Table 3). Both parameters coincided on the same date, except in two cases. Consequently, from the 0 reference cut of April, they were increasing values, and from the maximum of the first or second, they decreased until the third cut. The maximum production values were lower in 2019 than in 2020, with an increase between the annual averages of 56% in kg DM ha^{-1} and

42% in UFL ha^{-1}. The maximum production values were obtained between 21 May and 19 June (Table 6). The difference in the number of days between the two vegetative cycles for each meadow corresponding to their maximum production was negative or positive (Table 7). The accumulated rainfall and the growing degree days corresponding to the maximum production were lower in 2019 than in 2020 (Table 6, Figure 3) and in all of the meadows (Table 7). The accumulated evapotranspiration was lower in 2020 and showed negative and positive values in the two years, according to the meadows (Table 7).

Table 4. Average values and standard deviations of the quality parameters studied: crude protein CP (in g (kg DM)$^{-1}$) and feed units for milk UFL (kg DM)$^{-1}$, by year and cutting date. Sig: significance differences for $p < 0.001$; different letters in the same column indicate differences (Mann–Whitney U Test). DM = dry matter.

			CP				UFL (kg DM)$^{-1}$			
Year	**Cut**	***n***	**Average**	**S.D.**	**Sig.**	**Sig.**	**Average**	**S.D.**	**Sig.**	**Sig.**
2019	1	24	135.9	±26			0.99	±0.09		
	2	24	102.6	±23			0.88	±0.10		
	3	24	87.4	±31			0.75	±0.10		
	Total	72	108.6	±33	a		0.87	±0.14	b	
2020	1	24	106.6	±17			0.86	±0.06		
	2	24	106.5	±17			0.85	±0.06		
	3	24	98.1	±14			0.76	±0.09		
	Total	72	103.7	±16	a		0.82	±0.09	a	
Total	1	48	121.3	±26		c	0.93	±0.10		c
	2	48	104.5	±20		b	0.86	±0.09		b
	3	48	92.8	±25		a	0.75	±0.10		a
	Total	144	106.2	±26			0.85	±0.12		

Table 5. Average values and standard deviations of the quality parameters studied: digestible crude proteins in the gut PDI (in g (kg DM)$^{-1}$) and relative feed value RFV, by year and cutting date. Sig: significance differences for $p < 0.001$; different letters in the same column indicate differences (Mann–Whitney U Test). DM = dry matter.

			PDI				RFV			
Year	**Cut**	***n***	**Average**	**S.D.**	**Sig.**	**Sig.**	**Average**	**S.D.**	**Sig.**	**Sig.**
2019	1	24	86	±7			137	±24		
	2	24	77	±7			116	±22		
	3	24	70	±8			96	±14		
	Total	72	78	±10	a		116	±26	b	
2020	1	24	77	±4			111	±10		
	2	24	77	±4			107	±16		
	3	24	73	±5			96	±12		
	Total	72	76	±8	a		105	±14	a	
Total	1	48	82	±7		c	124	±23		c
	2	48	77	±6		b	111	±19		b
	3	48	71	±7		a	96	±13		a
	Total	144	77	±8			110	±22		

The maximum quality values within the cycle were decreasing from the beginning of the cycle and showed significant differences between cuts for the four parameters. The maximum quality values were higher in 2019 than in 2020 with negative increases between the annual averages of −12% in CP, −11% in UFL kg DM^{-1}, −7% in PDI, and −17% in RFV (Table 8). The amplitude of the maximum values of the meadows was also greater in the year 2019 than in 2020; the CP varied the most (Table 8). Maximum quality occurred between 20 May and 19 June. However, in 75% of the meadows it was before 22 May. Similar to production, the differences in the number of days within each vegetative cycle between the maximum qualities of the two years, were negative, null, or positive, depending on the meadows (Table 7). The accumulated rainfall and the growing degree days (Figure 4, Table 8) corresponding to the maximum quality were lower in 2019 than in 2020 and in all of the meadows (Table 7). Similar to production, the accumulated evapotranspiration was lower in 2020 and showed negative and positive values in both years, according to the meadows (Table 7).

The differences in production and quality among years, meadows, and cuts can be synthesized and related to the responsible variables through an MLR analysis. To represent the production, the UFL ha^{-1} were used since it has a high correlation with kg DM ha^{-1} (R = 0.969, $p < 0.001$). In quality, it was performed with UFL kg DM^{-1} because the other quality parameters present high correlations (CP: R = 0.828, PDI: R = 0.943; RFV = 0.954) and significance ($p < 0.001$). The MLR analysis was done for UFL ha^{-1} and UFL kg DM^{-1} with the daily values from 20 May to the date corresponding to the maximum of parameter of each meadow and year. The MLR was also carried out between quality in UFL kg DM^{-1} and the parameters from the maximum quality values, and on 24 June, where they were minimum. The independent variables are the accumulated rainfall, accumulated evapotranspiration, growing degree days, altitude, soil, fertilization, and slope.

Table 6. Maximum productions in the vegetative cycle and corresponding values of the accumulated rainfall (AR, mm), accumulated potential evapotranspiration (AETo, mm), growing degree days (GDD, °C) and days of the year. Minimum, maximum, and average values of the eight meadows studied and percentage increase of the averages between the two years. DM = dry matter, UFL = feed units for milk.

	2019				**2020**				
	Min	**Max**	**Average**	**S.D.**	**Min**	**Max**	**Average**	**S.D.**	**Increase (%)**
kg DM ha^{-1}	1697	4843	3415	±1028	3839	6181	5321	±861	56
UFL ha^{-1}	1563	4554	3202	±1057	3283	5662	4550	±839	42
AR (mm)	223	355	299	±42	337	517	433	±65	45
AETo (mm)	255	392	335	±42	266	335	312	±26	−7
GDD (°C)	982	1446	1150	±178	1109	1494	1309	±124	14
Days from 1 January	141	170	161	±9	146	168	159	±6	−1

Table 7. Daily and climatic differences associated with the maximum values of production (kg DM ha^{-1} and UFL ha^{-1}) and quality (CP, UFL kg DM^{-1}, PDI, and RFV) in the two years studied for each meadow. Minimum, maximum, and average values of the eight meadows studied and percentage increases between the two years. AR = accumulated rainfall, AETo = accumulated potential evapotranspiration, GDD = growing degree days.

		Production				**Quality**			
		Days	**AR (mm)**	**AETo (mm)**	**GDD (°C)**	**Days**	**AR (mm)**	**AETo (mm)**	**GDD (°C)**
Min	Units	−8	53	−61	47	−2	54	−36	115
	Increase (%)	−5	18	−16	3	−1	22	−16	11
Max	Units	6	190	22	317	16	225	64	407
	Increase (%)	4	72	7	30	11	78	26	42
Average	Units	−2	134	−24	160	5	123	9	240
	Increase (%)	−1	46	−6	15	3	48	3	27

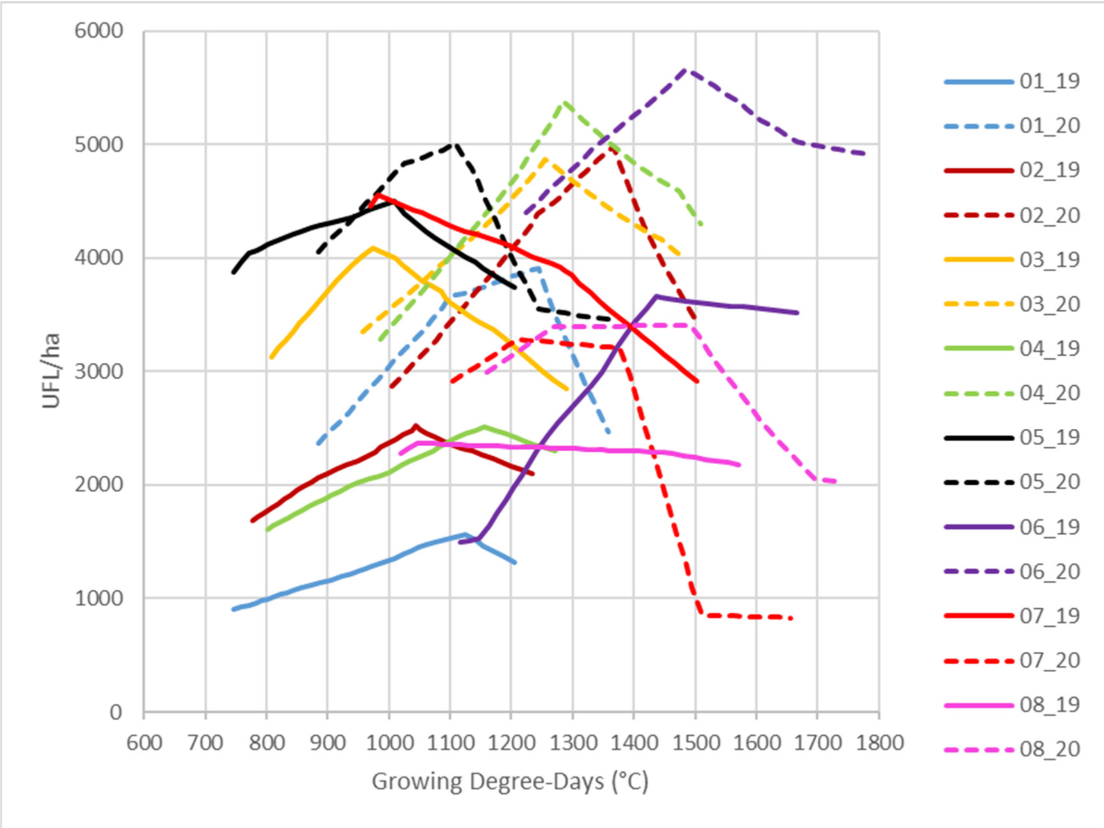

Figure 3. Relationship between UFL ha^{-1} and growing degree days of the eight meadows in the two years from 20 May to 24 June.

Table 8. Maximum quality in the vegetative cycle and corresponding values of accumulated rainfall (AR, mm), accumulated potential evapotranspiration (AETo, mm), growing degree days (GDD, °C), and days of the year. Minimum, maximum, and average values of the eight meadows studied and percentage increase of the averages between the two years. CP = crude protein, DM = dry matter, UFL = feed units for milk, PDI = digestible crude proteins in the gut, RFV = relative feed value.

	2019				**2020**				
	Min	**Max**	**Average**	**S.D.**	**Min**	**Max**	**Average**	**S.D.**	**Increase (%)**
CP (g (kg DM)$^{-1}$)	101.5	177.7	144.0	±21.9	106.1	138.5	127.1	±10.5	−12
UFL kg DM^{-1}	0.92	1.11	1.00	±0.06	0.84	0.97	0.89	±0.04	−11
PDI (g (kg DM)$^{-1}$)	78	96	88	±5	76	86	82	±3	−7
RFV	115	166	141	±17	102	129	116	±10	−17
AR (mm)	197	355	266	±46	287	513	381	±69	43
AETo (mm)	221	366	262	±43	185	332	252	±46	−4
GDD (°C)	771	1147	931	±150	884	1485	1110	±201	19
Days from 1 January	140	170	145	±10	140	156	145	±7	0

Production in UFL ha^{-1} up to the most productive cut shows a model with a high fit (R = 0.882; R^2 = 0.675; F = 135.540; $p < 0.0001$) where the variables—accumulated rainfall, growing degree days, soil, and slope—were significant ($p < 0.001$), and fertilization ($p = 0.007$). The production was conditioned in the first place by the depth of the soil (CS Beta 0.814). The climatic parameters that best fit were the accumulated rainfall since the beginning of vegetative development (CS Beta 0.639) and the growing degree days (CS Beta 0.17). For the maximum values of UFL ha^{-1}, the average increase between the two years was in the accumulated rainfall, 45%, and in the growing degree days, 14%, for an average increase of UFL ha^{-1} of 42% (Table 6). The response to the accumulated rainfall and growing degree days by meadows was positive but heterogeneous since the increases varied in the accumulated rainfall (between 18 and 72%) and in the growing degree days (between 3 and 30%), Table 7. No significative pattern was found that related the advance or delay of the dates of the maximums, as functions of the accumulated rainfall and the growing degree days.

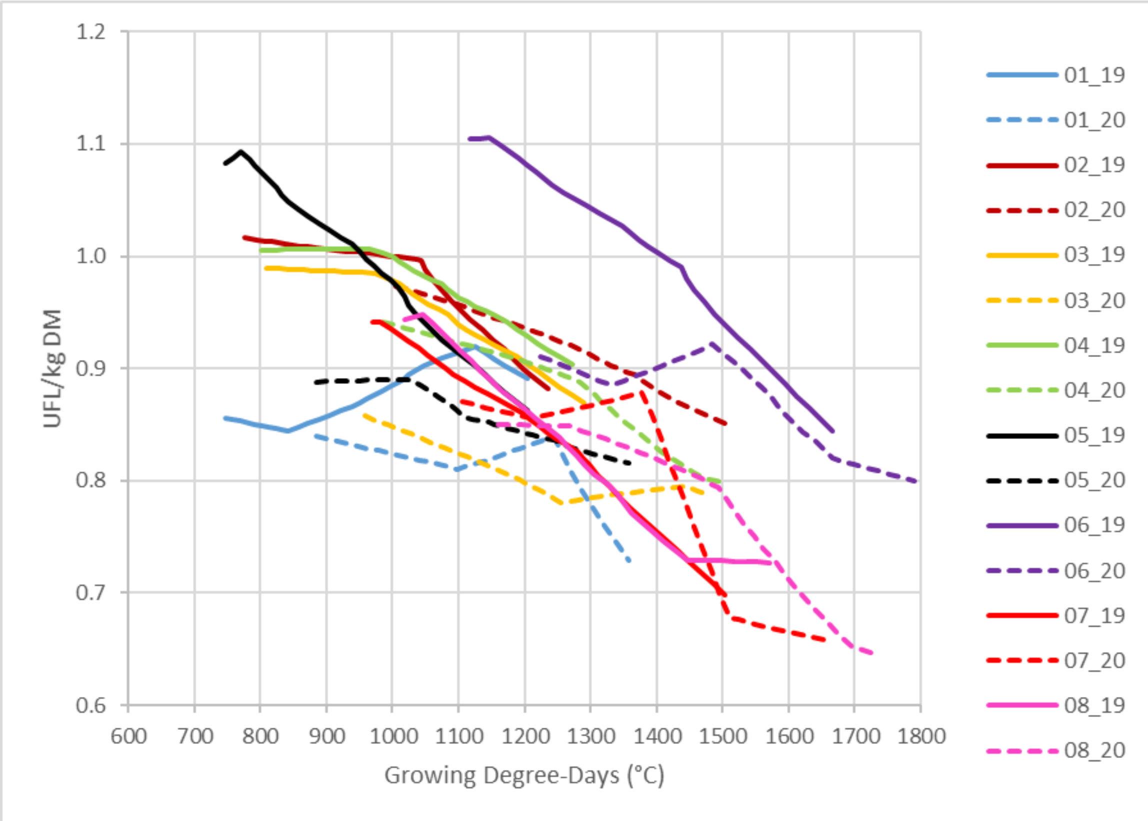

Figure 4. Relationship between UFL kg DM^{-1} and growing degree days of the eight meadows in the two years from 20 May to 24 June.

The MLR model of quality in UFL kg DM^{-1} with data up to the maximum values showed a medium fit (R = 0.713; R^2 = 0.509; F = 83.955; $p < 0.0001$) where the variables—accumulated rainfall, growing degree days, and fertilization—were significant ($p < 0.001$). The quality was negatively conditioned by the accumulated rainfall (CS Beta −0.488) and the growing degree days (CS Beta −0.214). Moreover, the positive effect of fertilization (CS Beta 0.389) on quality was noteworthy. For the maximum values of UFL kg DM^{-1}, the average increase between the two years was in the accumulated rainfall of 43% and in the growing degree days of 19% for an average decrease in UFL kg DM^{-1} of −11% (Table 8). The response to the accumulated rainfall and growing degree days by meadows was positive but heterogeneous since the increases varied in the accumulated rainfall (between 22 and 78%) and in the growing degree days (between 11 and 42%), Table 7.

To explain the behavior of the quality of UFL kg DM^{-1} after the maximum values and until 24 June, the MLR model shows a good fit (R = 0.927; R^2 = 0.859; F = 326.172; $p < 0.0001$) where the variables—accumulated rainfall, accumulated evapotranspiration, growing degree days, altitude, soil, and slope—were significant ($p < 0.001$). The quality was conditioned in the first place in a positive way by the altitude (CS Beta 0.725) and the soil (CS Beta 0.169) and in a negative way by the accumulated rainfall (CS Beta −0.424), the accumulated evapotranspiration (CS Beta −0.148), the growing degree days (CS Beta −0.329), and the slope (CS Beta −0.320). Consequently, meadows that are located at higher altitudes have deeper soils and lower slopes, have a smaller decrease in quality after their maximum values.

The production and quality decreases from the moment when the maximum values were reached, and on 24 June, and between this date and 10 July, could be quantified by the means of the daily decreases in the different parameters (Table 9). The decreases were more pronounced for all parameters in the first period, except for the PDI.

Table 9. Minimum, maximum, and average daily decreases and a percentage decrease in production and quality from the maximum average values of two years. DM = dry matter, UFL = feed units for milk, CP = crude protein, PDI = digestible crude proteins in the gut, RFV = relative feed value.

Daily decrease from the maximum values to 24 June						
	kg DM ha^{-1}	**UFL ha^{-1}**	**CP (g (kg DM)$^{-1}$)**	**UFL kg DM^{-1}**	**PDI (g (kg DM)$^{-1}$)**	**RFV**
Min	9	16	0.0302	0.0020	0.1514	0.1185
Max	177	206	0.1971	0.0116	0.7355	1.9851
Average	61	68	0.1217	0.0052	0.3752	0.9016
Variation (%)	18	25	26	16	13	20
Daily decrease from 24 June to 10 July						
	kg DM ha^{-1}	**UFL ha^{-1}**	**CP (g (kg DM)$^{-1}$)**	**UFL kg DM^{-1}**	**PDI (g (kg DM)$^{-1}$)**	**RFV**
Min	2	3	0.0025	0.0004	0.0727	−0.2393
Max	116	97	0.2361	0.0134	0.9932	2.0765
Average	36	39	0.0855	0.0059	0.4473	0.7836
Variation (%)	31	41	36	26	21	30

4. Discussion

The results show the variability of forage production and quality between the meadows, between years, and between the cutting dates within the year, as well as the relationship with the climatic parameters and characteristics of the meadows.

4.1. Variability between Meadows

The floristic diversity of the meadows of the central Pyrenees is high, as numerous studies have shown [7–14,16,54,55]. Although our inventories can be attributed to the *Rhinantho mediterranei-Trisetum flavescentis* association of *Arrhenatherion*, there are quite a few species that are only in one or two inventories, and some that show proximity to *Triseto-Polygonion bistortae* and *Bromion erecti.* The experimental plots in the meadows have a balanced flora between grasses (23–62%) and legumes (19–26%), with proportions between 0.83 and 3.33, and a high number of species (118). There are different floristic compositions and relative abundant conditions, not only the production and quality of each meadow, but also the response over time of the species to interannual and intra-annual variations in climatic factors [24,30]. Moreover, in meadows of the southern central Pyrenees, it has been observed that production is inversely related to floristic richness (and quality is directly related) [56]. On the other hand, the limited number of inventories (concerning the design of this work), the common presence of the most abundant species, and the high number of unique species, do not take the species into consideration, regarding the relationship with the climate and environment parameters.

Meadows can be considered different from production and quality parameter perspectives. Consequently, they represent part of the variabilities of the mowing meadows of the southern central Pyrenees. At the same time, the selection supposes a limitation, due to the difficulty in confirming the relationship of the variables with several common cases. The production and quality values are consistent with those reported by Maestro et al. [57] and Reiné et al. [56] in meadows of the southern central Pyrenees. On the contrary, the lack of works that have considered the variations between cuts on different dates does not allow comparison within the same annual cycle.

The characteristics of the soil, the slope, and fertilization are decisive in explaining the production and quality variations between the meadows. The MLR, up to the maximum production values in UFL ha^{-1}, indicates to a greater extent the depth of the soil, and with less importance, the slope and fertilization as the non-climatic environmental parameters that explain the differences between meadows. Regarding quality, with MLR—up to the maximum values in UFL kg DM^{-1}—only fertilization presented a significant effect among the non-climatic variables. Therefore, no relationship was found among quality and altitude, soil depth, and slope. In this sense, several authors provided results that related edaphic and fertility factors with Pyrenean meadow production [12,14,57–60]. Consequently, meadows with low production and quality values are susceptible to improvements through manure fertilization proportional to the potential determined by soil depth and slope.

4.2. Variability between Years

The variability between years of production, of the same meadows, produces a dysfunction between the annual availability of hay and its quality, and the food needs of the animals on the farm.

In this case, the interannual variations of the production and average quality of the cuts of the maximum values are relevant (increases of 56% in kg DM ha^{-1}, 42% in UFL ha^{-1}, −12% in CP, −11% in UFL kg DM^{-1}, −7% in PDI, and −17% in RFV). For both production and quality, the MLR highlights its relationship with the accumulated rainfall and the growing degree days. For both parameters, the effect is positive with respect to production and negative for quality. In addition, the amplitudes of the maximum values of the meadows were also greater in the year 2019 than in 2020, especially with the CP. It is difficult to discern between the effects of the accumulated rainfall and the growing degree days with only two years of follow-up. It is also not easy to compare interannual variations with works from other geographical areas due to differences in climate, floristic compositions, meadow management, and the low number of contrasted years. When comparing meadows in different years, regarding quality, Andueza et al. [29], Perotti et al. [38], and Andueza et al. [37] found an inverse relationship between temperature and quality; on the contrary, Michaud et al. [33] did not detect a relationship with dMO (determinant of the UFL kg DM^{-1} and PDI). Regarding rainfall, Meisser et al. [34] pointed out its inverse relationship with quality, except for CP, which did not vary as in our case. On the contrary, Andueza et al. [29] obtained a lower quality in the year with a lower rainfall. In relation to production variations, Michaud et al. [33] also pointed out the positive effects of the growing degree days, although not of the water balance. However, in our case, we observed that there was a water deficit in the year with lower rainfall and temperature. Lastly, Maestro et al. [57], regarding the meadows of the southern central Pyrenees, did not find differences in production or quality when comparing the same meadows in two consecutive years, although they did not indicate whether there were climatic differences.

The interannual differences on the dates when the maximum production and quality values occurred showed that there was no definite effect because they varied from one year to another within the same meadow (Tables 6–8). On the contrary, the maximums were systematically obtained with higher values in the second year in the accumulated rainfall and growing degree days, both in production and quality. Therefore, in relation to the advance and delay of the dates, our results are apparently contrary to what was stated by Amaudruz et Meisser [35], regarding Swiss meadows, where the increase in the growing degree days advanced the optimal phenology for mowing or grazing. This discrepancy is probably related to the fact that these authors considered only temperature and that water deficits occur in the southern central Pyrenees. In our case, water deficits were observed between rainfall and evapotranspiration in 2019 but not in 2020, despite the fact that their temperatures were higher. Water deficit was also detected in meadows with 4–5 cuts per year in Switzerland, which occurred from July, but did not affect production due to the reserve of useful water in the soil [42]. Vitra et al. [44], regarding meadows with induced drought, directly related the production decrease to the decrease in rainfall. Duru et al. [39], although focused on the beginning of the vegetative activity, related plant growth to temperature and water availability in the meadows of the north central Pyrenees, as factors that advanced or delayed development, in addition to fertility. Lambert et al. [43], regarding the Belgian meadows, attributed negative developmental effects on the temperature increases in years with lower rainfall. This effect cannot be contrasted with our results since we do not have data for a year with higher temperatures and lower rainfalls.

4.3. Variability in the Vegetative Cycle

Similar to other works, our results show an increase in production and a decrease in forage quality within the cycle. In our case, the decrease in production was also detected after a certain moment. The maximum values of production (dry matter and energy) and quality (CP, UFL kg DM^{-1}, PDI, and RFV) coincided within the vegetative cycle (with some exceptions). When considering the relationship between crude protein and digestibility (therefore also UFL kg DM^{-1} and PDI) within the vegetative cycle, some studies show the same trend as ours [61,62] and others indicate that they do not maintain this relationship [26].

Within the vegetative cycle, it was observed that the maximum values of production and quality occurred at a long period between 20 May and 19 June, although, in quality, in 75% of cases it was before 22 May. From the perspective of the accumulated rainfall and the growing degree days, the maximum production and quality (Figures 3 and 4, Tables 6 and 8) showed relatively large amplitudes, with ranges that varied between years. If 25% of the later meadows are excluded, the differences (with respect to the maximum quality values) are notably reduced.

The variation ranges of the growing degree days and of the maximum production dates are of the same order or higher than those provided by Duru et al. [30] in the north central Pyrenees, Carrère et al. [31] in the French Massif Central, or Michaud et al. [33] in France. A comparison with the French Massif Central meadows [32] shows that the differences in production between meadows was greater in ours for different accumulated degrees and that the amplitudes of the production did not increase with growing degree days.

The amplitudes of the dates, accumulated rainfall, and growing degree days assumed that the characteristics of the meadows determined the mowing dates by the farmers. This allowed the distribution of the mowing work throughout the month between 20 May and 20 June.

From the maximum values of production and quality, a more or less pronounced decrease occurred during the rest of the vegetative cycle. In production, the average decrease per day until 24 June was 61 kg DM ha^{-1} day^{-1} and 68 UFL ha^{-1} day^{-1} and from 24 June to 10 July it was 36 kg DM ha^{-1} day^{-1} and 39 UFL ha^{-1} day^{-1}. Regarding quality, the decreases until 24 June were 0.12 CP day^{-1}, 0.0052 UFL kg DM^{-1} day^{-1}, 0.38 PDI day^{-1}, and 0.90 RFV day^{-1}, and from 24 June until 10 July was 0.09 CP day^{-1}, 0.0059 UFL kg DM^{-1} day^{-1}, 0.45 PDI day^{-1}, and 0.79 RFV day^{-1}. The degree of daily decrease is relevant in relation to the amplitude of the mowing period, in which the production is more or less affected [30,62]. In this sense, our results show three things. The first is that the decreases vary between meadows and between years, the second is that the most productive year has greater daily decreases, and the third is that there is no correlation between the maximum production and the correspondence decrease.

According to the MLR model of UF kg DM^{-1} quality, from the maximum values onwards, it is evident that those meadows that are at higher altitudes have deeper soils, and with less slope have a smaller decrease in quality after their maximum values. The rate of decline in digestibility and protein over time was not found to be related to the ratio of grasses to legumes [24]. In the meadows studied, legumes were in high proportions (19–38%). Likewise, being meadows with high diversity (between 31 and 54 species in the plots), trade-offs between species could occur according to their phenology and quality over time and the additive effects of the mixture [24]. On the other hand, the results by Reiné et al. [63] show that the quality (digestibility, protein, energy, and minerals) of legumes and some species of other families is higher than that of grasses in these same meadows. The three umbelliferae from our inventories (*Chaerophyllum aureum, Heracleum sphondylium,* and *Laserpitium latifolium*) show high quality values, contrary to what has been said by some authors [24,26,64,65].

We consider these declines in production and quality as relevant facts given that our surveys and some bibliographical references [18,57,66] show that a substantial part of the meadows of the Pyrenees central south are mowed in the second half of June until 15 July. The delay of the harvest dates, with respect to the maximum production and quality, may be due to the erroneous appreciation that production increases, to traditional uses, to the accumulation of work due to the transfer of animals to summer pastures, to inclement weather, to the difficult access into the small areas of meadows and to environmental guidelines recommendations [22,23].

However, there are few works regarding mowing meadows in the Pyrenees where we can compare, in a quantified way, the decrease in production throughout the annual cycle, while on the decrease in quality, there are more quantified (or not quantified) references. From the results of Bossuyt et al. [36], regarding the Swiss meadows, it could be interpreted that there is also a decrease in production at the end of the first vegetative cycle. After an increase in the amplitude of production from 600–700 °C day (or 120 days), a decrease in production and its amplitude was observed, around 1000 °C day or more (165 days). The influence of the water deficit should be considered a factor related to the decrease in production [40]. In this sense, Calanca et al. [41] linked the declines in daily productivity to the water balance in Swiss meadows throughout the vegetative cycle. However, although water deficits were detected in the first year and not in the second, the decrease in our case occurred in both years. Maestro et al. [57], with results opposite to ours, showed a decrease in CP, digestibility, UF kg DM^{-1}, and UF ha^{-1} in five plots, but production in kg DM ha^{-1} increased. Duru [67], in the same sense, expressed as a percentage, with respect to the production of 23 June, showed an increase in production until 9 July in four plots, and decreases or increases (in meadows grazed in the spring) in the cut of 5 August.

It is evident that, when establishing conservation measures based on delaying harvesting, in addition to the effects on the botanical composition, one must contemplate not only compensating for the decrease in production, but also obtain low-quality forage that does not allow adequate nutrition due to limitations in intake [68].

5. Conclusions

The differences in production and quality, when comparing the maximum values between meadows, are important and are linked to soil depth, slope, and fertilization. Therefore, low-productivity meadows or low forage quality are susceptible to improvement through fertilization, proportional to the potential determined by the depth of the soil and the slope.

The variabilities between the production years, of the same meadows, produces a dysfunction between the annual availability of hay and its quality, and the food needs of the animals on the farm during the winter. The increase in production (56% in kg DM ha^{-1}, 42% in UFL ha^{-1}) and the decrease in forage quality (−12% in CP, −11% in UFL kg DM^{-1}, −7% in PDI and −17% in RFV) is related to the increase in the accumulated rainfall and the growing degree days between the two years. The interannual variations of accumulated rainfall and growing degree days do not show definite effects in advances or delays of the optimal mowing dates.

The maximum production values (in kg DM ha^{-1} and UFL ha^{-1}) are produced in a relatively wide range of dates, accumulated rainfall, and growing degree days. This depends on the meadows and the year and implies that the decision of the mowing date by the farmer adapts to the characteristics of the meadow. As an advantage, it allows a staggering of the work, i.e., of mowing and making hay or silage during a month (20 May to 20 June).

The production losses that occurred with harvests after the maximum production and the quality values were of the order of 18% in kg DM ha^{-1} and 25% in UFL ha^{-1}, until 24 June and 31% in kg DM ha^{-1} and 41% in UFL ha^{-1} until 10 July. The quality decreases were 26% in CP, 16% in UFL kg DM^{-1}, 13% in PDI, and 20% in RFV until 24 June and 36% in CP, 26% in UFL kg DM^{-1}, 21% in PDI, and 30% in RFV until 10 July. The decrease in quality, after the maximum value was less in the meadows that were at higher altitudes, had deeper soils and less slope.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agronomy12040918/s1, Table S1: Flora inventories.

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References

1. Peeters, A. Environmental impacts and future challenges of grasslands and grassland-based livestock production systems in Europe. In *Grassland: A Global Resource Perspective*; Ghosh, P.K., Mahanta, S.K., Singh, J.B., Pathak, P.S., Eds.; International Grassland Congress, Range Management Society of India: Delhi, India, 2015; pp. 365–390. Available online: https://www.researchgate.net/publication/287489163_Environmental_impacts_and_future_challenges_of_grasslands_and_grassland-based_livestock_production_systems_in_Europe (accessed on 8 March 2022).
2. Mottet, A.; Teillard, F.; Boettcher, P.; De'Besi, G.; Besbes, B. Domestic herbivores and food security: Current contribution; trends and challenges for a sustainable development. *Animal* **2018**, *12*, 188–198. [CrossRef] [PubMed]
3. Lacroix, K.; Gifford, R. Reducing meat consumption: Identifying group-specific inhibitors using latent profile analysis. *Appetite* **2019**, *138*, 233–241. [CrossRef] [PubMed]
4. Sanchez-Sabate, R.; Sabate, J. Consumer attitudes toward environment concerns of meat consumption: A systematic review. *Int. J. Environ. Res. Public Health* **2019**, *16*, 1220. [CrossRef]
5. Michaud, A.; Plantureux, S.; Baumont, R.; Delaby, L. Les prairies; une richesse et un support d'innovation pour des élevages de ruminants plus durables et acceptables. *INRAE Prod. Anim.* **2020**, *33*, 153–172. [CrossRef]
6. Peeters, A.; Beaufoy, G.; Canals, R.M.; De Vliegher, A.; Huyghe, C.; Isselstein, J.; Jones, G.; Kessler, W.; Kirilov, A.; Mosquera-Losada, M.R.; et al. Grassland term definitions and classifications adapted to the diversity of European grassland-based systems. In *25th EGF General Meeting on EGF at 50: The Future of European Grasslands*; Hopkins, A., Collins, R.P., Fraser, M.D., King, V.R., Lloyd, D.C., Moorby, J.M., Robson, P.R.H., Eds.; European Grassland Federation EGF: Aberystwyth, UK, 2014; Volume 19, pp. 743–750. Available online: https://edepot.wur.nl/333416 (accessed on 8 March 2022).
7. Montserrat, P.; Gómez García, D.; Montserrat, G. Phytosociologie et dynamique prairiales de quelques cultures pyrénéennes intégrées à leur paysage. In *Ecologie des Milieux Montagnards et de Haute Altitude*; Documents d'Ecologie Pyrénéenne: Gabas, France, 1984; Volumes 3–4, pp. 471–479, ISBN 2-903694-02-8.
8. Chocarro, C.; Fillat, F.; García Ciudad, A.; Miranda, P. Meadows of central Pyrenees: Floristical composition and quality. *Pirineos* **1987**, *129*, 5–33. [CrossRef]

9. Carrillo, E.; Ninot, J.M. *Flora i Vegetació de les Valls d'Espot i de Boí. I*; Institut d'Estudis Catalans, Arxius Secció de Ciències: Barcelona, Spain, 1992; ISBN 84-7283-200-7.
10. Carreras, J. *La Flora i la Vegetació de Sant Joan de l'Erm i de la Vall de Santa Magdalena (Pirineus Catalans)*; Instituto de Estudios Ilerdenses Col. Estudis: Lleida, Spain, 1993; Volume 3, ISBN 84-87029-41-8.
11. Carreras, J.; Carrillo, E.; Masalles, R.M.; Ninot, J.M.; Vigo, J. El poblament vegetal de les valls de Barravés i de Castanesa. I- Flora i vegetació. *Acta Bot. Barc.* **1993**, *42*, 11892. Available online: https://bibdigital.rjb.csic.es/idurl/1/11892 (accessed on 8 March 2022).
12. Barrantes, O.; Reiné, R.; Broca, A.; Ferrer, C. Relaciones diversidad florística-producción-manejo en prados de siega pirenaicos. In *Pastos, Clave en la Gestión de los Territorios: Integrando Disciplinas*; Rebollo, P., Gómez, A., Guerrero, J.E., Garrido, A., Calzado, C., García, A.M., Carbonero, M.D., Blázquez, A., Escuin, S., Casrtillo, S., Eds.; Sociedad Española para el Estudio de los Pastos, Junta de Andalucía: Córdoba, Spain, 2008; pp. 355–360, ISBN 978-84-691-4702-3. Available online: http://www.seepastos.es/wp-content/uploads/2017/08/2008-Actas-SEEP-Cordoba.pdf (accessed on 8 March 2022).
13. Chocarro, C.; Reiné, R.; Juárez, A.; Barrantes, O.; Broca, A.; Ferrer, C. Clasificación florística de los prados de siega del Pirineo de Huesca. In *La Multifuncionalidad de los Pastos: Producción Ganadera Sostenible y Gestión de Ecosistemas*; Reiné, R., Barrantes, O., Broca, A., Ferrer, C., Eds.; Sociedad Española para el Estudio de los Pastos: Huesca, Spain, 2009; pp. 109–115, ISBN 978-84-612-9337-7. Available online: http://www.uco.es/integraldehesa/components/com_booklibrary/ebooks/Multifuncionalidad%20de%20los%20pastos.pdf (accessed on 8 March 2022).
14. Reiné, R.; Chocarro, C.; Juárez, A.; Barrantes, O.; Ferrer, C.; Broca, A. Características de la producción herbácea en los prados de siega del Pirineo de Huesca. In *La Multifuncionalidad de los Pastos: Producción Ganadera Sostenible y Gestión de Ecosistemas*; Reiné, R., Barrantes, O., Broca, A., Ferrer, C., Eds.; Sociedad Española para el Estudio de los Pastos: Huesca, Spain, 2009; pp. 101–107, ISBN 978-84-612-9337-7. Available online: http://www.uco.es/integraldehesa/components/com_booklibrary/ebooks/Multifuncionalidad%20de%20los%20pastos.pdf (accessed on 8 March 2022).
15. Rodríguez Rojo, M.P.; Fernández González, F.; Tichý, L.; Chytrý, M. Vegetation diversity of mesic grasslands (Arrhenatheretalia) in the Iberian Peninsula. *Appl. Veg. Sci.* **2014**, *17*, 780–796. [CrossRef]
16. Chocarro, C.; Juarez, A. Influencia de la tipología del margen en la diversidad florística de prados pirenaicos. In *Innovación Sostenible En Pastos: Hacia una Agricultura de Respuesta al Cambio Climático*; Báez Bernal, M.D., Campo Ramírez, L., Pereira, S., Bande, M.J., López Díaz, J.E., Eds.; Sociedad Española para el Estudio de los Pastos: Lugo-La Coruña, Spain, 2016; pp. 39–45, ISBN 978-84-608-7722-6. Available online: http://www.seepastos.es/wp-content/uploads/2017/08/2016-Actas-SEEP-Lugo.pdf (accessed on 8 March 2022).
17. Ocaña, M. *Ensayo de Planificación Ganadera en Aragón*; Institución Fernando el Católico: Zaragoza, Spain, 1978; ISBN 84-00-03792-8.
18. Chocarro, C.; Reiné, R. El cultivo de los prados en el Pirineo. In *Pastos del Pirineo*; Fillat, F., García González, R., Gómez García, D., Reiné, R., Eds.; Consejo Superior de Investigaciones Científicas: Madrid, Spain, 2007; pp. 141–158, ISBN 978-84-00-08614-5.
19. Huyghe, C.; Peeters, A.; De Vliegher, A. La prairie en France et en Europe. In *Colloque Presentant les Methodes et Resultats du Projet Climagie (Metaprogramme ACCAF)*; INRA: Poitiers, France, 2015; pp. 13–23. Available online: https://hal.archives-ouvertes.fr/hal-01233899 (accessed on 8 March 2022).
20. García Manteca, P.; de la Fuente, L.G.; Aguiar, C.; Azevedo, J.; Reiné, R.; Ascaso, J.; Guzmán, D.; Díaz González, T.E. Mountain hay meadows: Assessing the loss of surfaces and ecosystem services in Iberian areas. Restoration in the Era of Climate Change. In Proceedings of the 11th SER Europe Conference, Reykjavik, Iceland, 9–13 September 2018; pp. 9–13. Available online: https://www.sospraderas.eu/wp-content/uploads/2019/07/Abstract-SER_GT1.pdf (accessed on 8 March 2022).
21. Ascaso, J.; Reiné, R.; Barrantes, O. Evolution of Hay Meadows between 1956, 1986, and 2016 and Its Relation to the Characteristics and Location of the Parcels in the Valley of the River Esera (Pyrenees, Spain). *Agronomy* **2020**, *10*, 329. [CrossRef]
22. de la Fuente, L.G.; Guzmán, D.; Mora, A.; Nobre, S.; Brau-Nogué, C. Informe de Iniciativas Existentes para Promover la Siega a Través de los P.D.R. y los Instrumentos de la Nueva P.A.C. en la U.E. Unpublished Report Developed within the Interreg SUDOE Project "SOS PRADERAS". 2017. Available online: https://www.sospraderas.eu/en/documentacion/ (accessed on 8 March 2022).
23. Lampkin, N.; Stolze, M.; Meredith, S.; de Porras, M.; Haller, L.; Mészáros, D. *Using Eco-Schemes in the New CAP: A Guide for Managing Authorities*; IFOAM EU, FIBL and IEEP: Brussels, Belgium, 2020; Available online: https://enrd.ec.europa.eu/news-events/news/using-eco-schemes-new-cap_es (accessed on 8 March 2022).
24. Baumont, R.; Aufrere, J.; Niderkorn, V.; Andueza, D.; Surault, F.; Peccatte, J.-R. La diversité spécifique dans le fourrage: Conséquence sur la valeur alimentaire. *Fourrages* **2008**, *194*, 189–206. Available online: https://hal.archives-ouvertes.fr/hal-02666789/ (accessed on 8 March 2022).
25. Michaud, A.; Plantureux, S.; Amiaud, B.; Carrère, P.; Cruz, P.; Duru, M.; Dury, B.; Farruggia, A.; Fiorelli, J.-L.; Kerneis, E.; et al. Identification of environmental factors which drive the botanical and functional composition of permanent grasslands. *J. Agric. Sci.* **2012**, *150*, 219–236. [CrossRef]
26. Andueza, D.; Rodrigues, A.M.; Picard, F.; Rossignol, N.; Baumont, R.; Cecato, U.; Farruggia, A. Relationships between botanical composition, yield and forage quality of permanent grasslands over the first growth cycle. *Grass Forage Sci.* **2015**, *71*, 366–378. [CrossRef]
27. Hilpold, A.; Seeber, J.; Fontana, V.; Niedrist, G.; Rief, A.; Steinwandter, M.; Erich Tasser, E.; Tappeiner, U. Decline of rare and specialist species across multiple taxonomic groups after grassland intensification and abandonment. *Biodivers. Conserv.* **2018**, *27*, 3729–3744. [CrossRef]
28. Tälle, M.; Deák, B.; Poschlod, P.; Valkó, O.; Westerberg, L.; Milberg, P. Similar effects of different mowing frequencies on the conservation value of semi-natural grasslands in Europe. *Biodivers. Conserv.* **2018**, *27*, 2451–2475. [CrossRef]

29. Andueza, D.; Cruz, P.; Farruggia, A.; Baumont, R.; Picard, F.; Michalet-Doreau, B. Nutritive value of two meadows and relationships with some vegetation traits. *Grass Forage Sci.* **2010**, *65*, 325–334. [CrossRef]
30. Duru, M.; Cruz, P.; Theau, J.-P. Évaluer la souplesse d'utilisation des prairies permanentes par la caractérisation de la composition fonctionnelle de la végétation et la phénologie des espèces. *Fourrages* **2010**, *201*, 3–10. Available online: https://hal.inrae.fr/hal-02666696 (accessed on 8 March 2022).
31. Carrère, P.; Chabalier, C.; Farruggia, A.; Landrieaux, J.; Orth, D.; Piquet, M.; Rivière, J.; Seytre, L. Diagnostic prairial en zones fromagères AOP du Massif central. In *OUTIL 1: Typologie Multifonctionnelle des Prairies*; Pôle Fromager AOP Massif Central: Aurillac, France, 2011; ISBN 978-2-9540077-0-0.
32. Baumont, R.; Picard, F.; Delmas, B.; Violleau, S.; Zapata, J.; Chabalier, C.; Torrent, A.; Piquet, M.; Louault, F.; Andueza Urra, J.D.; et al. Production et valeur nutritive des prairies permanentes dans les fermes productrices de fromages AOP du Massif central en France. *Fourrages* **2012**, *209*, 23–32. Available online: https://hal.inrae.fr/hal-02749651 (accessed on 8 March 2022).
33. Michaud, A.; Plantureux, S.; Pottier, E.; Baumont, R. Links between functional composition; biomass production and forage quality in permanent grasslands over a broad gradient of conditions. *J. Agric. Sci.* **2015**, *153*, 891–906. [CrossRef]
34. Meisser, M.; Vitra, A.; Stévenin, L.; Mosimann, E.; Mariotte, P.; Buttler, A. Impact de la sécheresse sur le fonctionnement des systèmes herbagers. *Rech. Agron. Suisse* **2018**, *9*, 82–91. Available online: https://www.agrarforschungschweiz.ch/fr/2018/03/impacts-de-la-secheresse-sur-le-fonctionnement-des-systemes-herbagers/ (accessed on 8 March 2022).
35. Amaudruz, M.; Meisser, M. Stades de Développement des Prairies. Valeur des Fourrages. Production Herbagère. 2018. Available online: https://www.agridea.ch/fileadmin/AGRIDEA/Theme/Productions_vegetales/Production_fourragere/Document/HERB-FT--0273-2018-ValeurFourrages-StadesDeveloppementPrairies.pdf (accessed on 8 March 2022).
36. Bossuyt, N.; Wirthner, J.; Dussoulier, C.; Frund, C.; Meisser, M.; Kragten, S.A.; Mosimann, E. Quand faut-il faucher les prairies intensives? *Rech. Agron. Suisse* **2018**, *9*, 12–19. Available online: https://www.agrarforschungschweiz.ch/fr/2018/01/quand-faut-il-faucher-les-prairies-intensives/ (accessed on 8 March 2022).
37. Andueza, D.; Picard, F.; Note, P.; Carrère, P. Relationship between the chemical composition, nutritive value and the maturity stage of six temperate perennial grasses during their first growth cycle along an altitude gradient. *Eur. J. Agron.* **2021**, *130*, 126364. [CrossRef]
38. Perotti, E.; Huguenin-Elie, O.; Meisser, M.; Dubois, S.; Probo, M.; Mariotte, P. Climatic, soil, and vegetation drivers of forage yield and quality differ across the first three growth cycles of intensively managed permanent grasslands. *Eur. J. Agron.* **2021**, *122*, 126–194. [CrossRef]
39. Duru, M.; Calvière, I.; Balent, G.; Langlet, A. Pédoclimat, fertilisation et croissance des prairies permanentes au printemps. II- Précocité du départ en végétation. *Fourrages* **1993**, *133*, 43–57. Available online: https://afpf-asso.fr/index.php?secured_download=1213&token=c16b0ba6e27c1efb0d74a94026afe433 (accessed on 8 March 2022).
40. Deléglise, C.; Meisser, M.; Mosimann, E.; Spiegelberger, T.; Signarbieux, C.; Jeangros, B.; Buttler, A. Drought-induced shifts in plants traits, yields and nutritive value under realistic grazing and mowing managements in a mountain grassland. *Agric. Ecosyst. Environ.* **2015**, *213*, 94–104. [CrossRef]
41. Calanca, P.; Deléglise, C.; Martin, R.; Carrère, P.; Mosimann, E. Testing the ability of a simple grassland model to simulate the seasonal effects of drought on herbage growth. *Field Crops Res.* **2016**, *187*, 12–23. Available online: https://hal.inrae.fr/hal-02637502 (accessed on 8 March 2022). [CrossRef]
42. Bittar, A.; Meisser, M.; Mosimann, E.; Calanca, P. Simulation de la croissance de l'herbe et des rendements des pâturages avec ModVege. *Rech. Agron. Suisse* **2018**, *9*, 186–191. Available online: https://www.agrarforschungschweiz.ch/wp-content/uploads/pdf_archive/2018_06_f_2391.pdf (accessed on 8 March 2022).
43. Lambert, R.; Van der Veeren, B.; Decamps, C.; Cremer, S.; De Toffoli, M.; Javaux, M. Production Fourragère et Sécheresse; quelles Solutions en Wallonie? Journées de Printemps de l'AFPF—Produire des fourrages demain—25–26 Mars 2020. Available online: https://afpf-asso.fr/article/production-fourragere-et-secheresse-quelles-solutions-en-wallonie (accessed on 8 March 2022).
44. Vitra, A.; Deléglise, C.; Meisser, M.; Risch, A.C.; Signarbieux, C.; Lamacque, L.; Delzon, S.; Buttler, A.; Mariotte, P. Responses of plant leaf economic and hydraulic traits mediate the effects of early- and late-season drought on grassland productivity. *AoB Plants* **2019**, *11*, plz023. [CrossRef]
45. Braun-Blanquet, J. *Plant Sociology—The Study of Plant Communities*; Hafner Publishing Company: New York, NY, USA, 1965; pp. 1–439. ISBN 9783874292085.
46. IGN. Instituto Geográfico Nacional, Ministerio de Transportes, Movilidad y Agenda Urbana, Gobierno de España. 2021. Available online: https://www.mitma.gob.es/geoinformacion (accessed on 8 March 2022).
47. AEMET. Sede Electrónica de la Agencia Estatal de Meteorología. 2021. Available online: https://sede.aemet.gob.es/AEMET/es/GestionPeticiones/home (accessed on 8 March 2022).
48. FAO. Cropwat v.8.0. A Computer Program for Irrigation Planning and Management. Water Resources Development and Management Service. Land and Water Development Division. Food and Agriculture Organization of the UN. 2009. Available online: https://www.fao.org/land-water/databases-and-software/cropwat/es/ (accessed on 8 March 2022).
49. Theau, J.P.; Zerourou, A. Herb'âge; une méthode de calcul des sommes de températures pour la gestion des prairies. In Outil pour la gestion des prairies permanentes. Presented at Symposium International INRA-UMR AGIR (Agrosystèmes et Développement Territorial): Outils Pour la Gestion des Prairies Permanentes, Castanet-Tolosan, France. 2008, pp. 91–102. Available online: https://hal.inrae.fr/hal-02758340/document (accessed on 8 March 2022).

50. Ansquer, P.; Al Haj Khaled, R.; Cruz, P.; Theau, J.P.; Therond, O.; Duru, M. Characterizing and predicting plant phenology in species-rich grasslands. *Grass Forage Sci.* **2009**, *64*, 57–70. [CrossRef]
51. Van Soest, P.; Robertson, J.; Lewis, B. Methods for dietary fiber; neutral detergent fiber; and nonstarch polysaccharides in Relation to animal nutrition. *J. Dairy Sci.* **1991**, *74*, 3583–3597. [CrossRef]
52. INRA. *Alimentation des Ruminants*; Éditions Quæ: Versailles, France, 2018; pp. 1–728, ISBN 9782759228683.
53. Linn, J.G.; Martin, N.P. Forage Quality Tests and Interpretations (Revised 1989). Univ. Minnesota; Agricultural Extension Service: Retrieved from the University of Minnesota Digital Conservancy. 1989. Available online: https://conservancy.umn.edu/handle/11299/207442 (accessed on 8 March 2022).
54. Nègre, R. La végétation du Bassin de l'One (Pyrénées centrales). 5ª note: Les reposoires; les groupements hygrophiles et les prairies de fauche. *Bol. Soc. Brot.* **1972**, *46*, 271–343.
55. Gruber, M. Les prairies de fauche des Arrhenatheretea Br.-Bl. des Hautes-Pyrénées. *Bull. Soc. Linn. Provence* **1986**, *37*, 101–108.
56. Reiné, R.; Chocarro, C.; Juárez, A.; Barrantes, O.; Maestro, M.; Ferrer, C.; Broca, A. Riqueza específica de prados pirenaicos y su incidencia en el valor nutritivo. In *Pastos: Fuente Natural de Energía*; Calleja, A., García, R., Ruíz, A., Peláez, R., Eds.; Sociedad Española para el Estudio de los Pastos, Área de Publicaciones, Universidad de León: León, Spain, 2010; pp. 189–196, ISBN 978-84-9773-502-5. Available online: https://www.researchgate.net/publication/339941945_Riqueza_especifica_en_prados_pirenaicos_y_su_incidencia_en_el_valor_nutritivo (accessed on 8 March 2022).
57. Maestro, M.; Ferrer, C.; Amella, A.; Broca, A.; Ascaso, J. Praderas naturales de secano de los fondos de valle del Pirineo central (Huesca): Suelo; manejo; flora; producción y calidad. In *Actas XXX Reunión Científica de la Sociedad Española Para el Estudio de los Pastos*; Sociedad Española para el Estudio de los Pastos: San Sebastián, Spain, 1990; pp. 176–183. Available online: https://www.researchgate.net/publication/337012658_Praderas_naturales_de_secano_de_los_fondos_de_valle_del_Pirineo_Central_Huesca_Suelo_manejo_flora_produccion_y_calidad (accessed on 8 March 2022).
58. Balent, G.; Duru, M. Influence des modes d'explotation sur les caractéristiques et l'évolution des surfaces pastorales: Cas des Pyrénées centrales. *Agronomie* **1984**, *4*, 113–124. Available online: https://hal.archives-ouvertes.fr/hal-00884618 (accessed on 8 March 2022). [CrossRef]
59. Duru, M.; Balent, G.; Gibon, A.; Magda, D.; Theau, J.P.; Cruz, P.; Jouany, C. Fonctionnement et dynamique des prairies permanentes. Exemple des Pyrénées centrales. *Fourrages* **1998**, *153*, 97–113. Available online: https://hal.inrae.fr/hal-02696285 (accessed on 8 March 2022).
60. Reiné, R.; Barrantes, O.; Broca, A.; Ferrer, C. Influencia de los factores ambientales en la diversidad florística y en la producción de prados de siega pirenaicos. In *Pastos; Clave en la Gestión de los Territorios: Integrando Disciplinas*; Rebollo, P., Gómez, A., Guerrero, J.E., Garrido, A., Calzado, C., García, A.M., Carbonero, M.D., Blázquez, A., Escuin, S., Casrtillo, S., Eds.; Sociedad Española para el Estudio de los Pastos, Junta de Andalucía: Córdoba, Spain, 2008; pp. 361–367. Available online: https://www.researchgate.net/publication/339942022_Influencia_de_los_factores_ambientales_en_la_diversidad_floristica_y_en_la_produccion_de_prados_de_siega_pirenaicos (accessed on 8 March 2022).
61. Andrés, S.; Giráldez, F.J.; López, S.; Mantecón, Á.R.; Calleja, A. Nutritive evaluation of herbage from permanent meadows by near-infrared reflectance spectroscopy: 1. Prediction of chemical composition and in vitro digestibility. *J. Sci. Food Agric.* **2005**, *85*, 1564–1571. Available online: http://hdl.handle.net/10261/13368 (accessed on 8 March 2022). [CrossRef]
62. Carrère, P.; Pontes, L.S.; Andueza, D.; Louault, F.; Rosseel, D.; Taini, E.; Pons, B.; Toillon, S.; Soussana, J.F. Evolution de la valeur nutritive de graminées prairiales au cours de leur cycle de développement. *Fourrages* **2010**, *201*, 27–35. Available online: https://hal.archives-ouvertes.fr/hal-02667395/ (accessed on 8 March 2022).
63. Reiné, R.; Ascaso, J.; Barrantes, O. Nutritional Quality of Plant Species in Pyrenean Hay Meadows of High Diversity. *Agronomy* **2020**, *10*, 883. [CrossRef]
64. Magda, D.; Theau, J.P.; Duru, M.; Coleno, F. Hay-meadows production and weed dynamics as influenced by management. *J. Range Manag.* **2003**, *56*, 127–132. Available online: https://hal.archives-ouvertes.fr/hal-02675213/ (accessed on 8 March 2022). [CrossRef]
65. Pierik, M.E.; Gusmeroli, F.; Della Marianna, G.; Tamburini, A.; Bocchi, S. Meadows species composition; biodiversity and forage value in an Alpine district: Relationships with environmental and dairy farm management variables. *Agric. Ecosyst. Environ.* **2017**, *244*, 14–21. Available online: https://www.researchgate.net/publication/316575268_Meadows_species_composition_biodiversity_and_forage_value_in_an_Alpine_district_Relationships_with_environmental_and_dairy_farm_management_variables (accessed on 8 March 2022). [CrossRef]
66. Chocarro, C.; Fanlo, R.; Fillat, F.; Villar, L. Sur les communautés prairiales et leur gestion dans deux vallées des Pyrénées centrales espagnoles. *Colloq. Phytosociol.* **1990**, *14*, 457–472.
67. Duru, M. Mode d'exploitation des prés de fauche dans les Pyrénées centrales (Références biologiques, pratiques des agriculteurs). *Fourrages* **1981**, *87*, 53–89. Available online: https://afpf-asso.fr/index.php?secured_download=896&token=c16b0ba6e27c1efb0d74a94026afe433 (accessed on 8 March 2022).
68. Faverdin, P.; Baumont, R.; Boval, M.; Agabriel, J.; Delagarde, R. Ingestion des aliments. In *Alimentation des Ruminants. Editions Quae*; INRA: Paris, France, 2018; ISBN 9782759228683.