Relationship between the sum of temperatures and forage yield and quality of the first growth cycle in intensively managed Swiss permanent grasslands

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Permanent grasslands, accounting for almost 38% of agricultural areas in Europe, are mostly unfavorable for crop production and have been used for centuries as the main feed source for ruminant livestock. Considering the economic importance and acreage of intensively managed permanent grasslands, it is important to maximize the yield (*i.e.,* dry matter, DM) and quality of the forage they produce through optimized management. Forage quality refers to forage nutritive value and digestibility, typically determined by chemical analyses. Forage quality is influenced by several variables linked to the plant phenological stage, and thus plant morphology and leaf/stem ratio along the growing season (Bruinenberg et al. 2002). Due to the difficulties in estimating forage yield and quality across space and time, many studies attempted to determine easily obtainable proxies for forage yield and quality.

Temperature and precipitation are among the most important factors affecting forage yield and quality because they directly influence plant growth, community composition, nutrient concentration in plant tissues, and forage digestibility. Compared to all the other growth cycles, the first growth cycle is the most productive in permanent grasslands. During the first growth cycle, temperature seems to be the most important factor affecting forage yield and quality, since precipitation and soil moisture remain relatively high at the end of winter and beginning of spring and are thus less limiting for plant growth (Perotti et al. 2021). Previous studies performed by INRA (National Institute for Agronomic Research) in France highlighted the role of the sum of temperature as important driver of plant phenological stage and forage yield during the first growth cycle (Ansquer et al., 2004).

Moreover, other research carried out in France, identified six main functional types of permanent grasslands depending on the dominance of grass species that are characterized by different precocity (Cruz et al., 2010). The sum of temperatures, which is freely and easily real-time available each year on meteorological websites (e.g., www.agrometeo.ch), has thus been used as a good proxy for estimating forage yield, but the validity of this index across various grassland types and climatic conditions remain unclear. Furthermore, despite the well-known negative correlation between forage quality and yield, direct links between the sum of temperatures and forage quality have been poorly investigated. The goal of our experiment was therefore to highlight the relationship between the sum of temperatures and both forage yield and quality in intensively managed permanent grasslands in Switzerland. Specifically, the study aims to answer the two following questions: i) Is there a significant relationship between the cumulated sum of temperature and forage yield and quality during the first growth across different grassland functional types? ii) What is the number of degree days at which forage should be harvested to optimize yield and quality in intensively managed grasslands in Switzerland?

We conducted the present experiment during 3 years (2017, 2018, 2019) in 23 intensively managed permanent grasslands across Switzerland, covering a wide gradient of climatic conditions, altitude, soil features, and relative abundance of plant functional groups. To emphasize the role of botanical composition, we classified the grasslands into 4 types (A, AB-BA, bA-Ab, Bb-bB) based on the dominance of the six main functional types of grasses (Cruz et al. 2010). Grasslands classified as 'A' are dominated by *Lolium multiflorum*, *Lolium perenne*, and *Poa trivialis*, 'AB-BA' by *L. perenne*, *Poa pratensis*, and *Dactylis glomerata*, 'bA-Ab by *L. perennne, P. trivialis, L. multiflorum*, and *P. pratensis* ' and 'Bb-bB' by *P. trivialis, D. glomerata, P. pratensis, L. perennne, Agrostis capillaris,* and *Elymus repens*. We calculated the cumulated sum of temperature (growing degree days, GDD) following the method developed at INRA (Theau and Zerourou 2008). Briefly, the cumulated sum of temperature is calculated with daily mean temperatures > 0°C from February 1st and only degrees between 0 and 18°C are taken into account because daily mean temperatures higher than 18°C do not further accelerate growth. Within each site, four replicated plots of 1 x 5 m were established in 2017 and managed using common, intensive cutting practices (*i.e.,* 4-6 harvests/year). At each site, forage cut was set at 6 cm aboveground level. Forage was harvested every 2 weeks in different plots from the beginning of the vegetation growth (*i.e.,* plot 1 harvested at 2 weeks, plot 2 harvested at 4 weeks, plot 3 harvested at 6 weeks and plot 4 harvested at 8 weeks), corresponding to 4 successive harvests during the first growth cycle. The beginning of the vegetation growth was defined at a thermal sum of 200 growing degrees day (GDD). Harvested forage samples were dried,

weighed and analyzed for protein content and fibers, which then allowed estimating forage digestibility, net energy for milk production (NEL) and absorbable proteins by intestine from degraded nitrogen matter (PAIN). Relationships between degree days and forage yield, protein content, digestibility, NEL, PAIN were then determined for the 3 years and the 4 grassland types, together and separately.

Forage yield of the first mowing of the year (*i.e.,* harvest at 8 weeks) showed strong variability across the 23 grassland sites ranging from 21.7 to 66.1 dtDM.ha^{-1}, thus well representing the different growing conditions across Switzerland. Forage yield was strongly positively correlated to GDD for the three years of the experiment (R^2 = 0.86 in 2017, R^2 = 0.93 in 2018, R^2 = 0.94 in 2019) and the 4 different grassland types (grassland of type A: R^2 = 0.90 ; type AB-BA: R^2 = 0.90 ; type bA-Ab: R^2 = 0.92 ; type Bb-bB: R^2 = 0.91). The relationship between yield and GDD was slightly different among years and grassland types. Indeed, the same forage yield was achieved 50 GDD earlier in 2018 compared to 2017 and 2019. Furthermore, type AB-BA, bA-Ab and Bb-bB grasslands showed different regression curves compared to type A, with about 100 GDD extra needed to achieve the same yield than type A grasslands. Altogether, including the three years and the four grassland types, we found an excellent average relationship between forage yield and degrees day (R^2 = 0.91). Overall, mowing intensively managed permanent grasslands between 650 and 750 GDD provide between 35.8 and 42.7 dtDM.ha^{-1} on average. Farmers aiming to maximize forage yield during the first growth cycle should consider that waiting other 100 GDD after that threshold could provide on average additional 6.9 dtDM.ha^{-1} (*i.e.,* 850 GDD = 49.6 dtDM.ha^{-1}).

Forage digestibility, protein content, NEL and PAIN were strongly negatively correlated to degrees day for the three years of the experiment and the four different grassland types. Similar regression curves were observed among years and grassland types. Altogether, including the three years and the four grassland types, we found an excellent average relationship between degrees day and forage digestibility (R^2 = 0.89), protein content (R^2 = 0.86), NEL (R^2 = 0.91) and PAIN (R^2 = 0.86). Overall, mowing intensively managed permanent grasslands between 650 and 750 degrees day corresponds to forage digestibility ranging from 76.2 to 73.8%, protein content ranging from 146.6 to 128.1 g.kg^{-1}, NEL ranging from 6.2 to 6.0 MJ, and PAIN ranging from 97.4 and 84.9 g. Farmers aiming to maximize forage quality during the first growth cycle should consider that waiting another 100 GDD after that threshold (*i.e.,* at 850 GDD) could on average reduce digestibility to 71.4%, protein content to 109.5 g.kg^{-1}, NEL to 5.8 MJ and PAIN to 72.4 g.

Findings from our study show that farmers have to clearly define their priority (*i.e.,* forage yield or quality) in order to decide on the cutting time for a given forage yield and quality threshold. Overall, our results suggest that the optimal cutting time to obtain good forage biomass production having high digestibility and quality levels during the first growth cycle in intensively managed permanent grasslands would be situated between 650 and 750 degrees day. These results are quite different from those obtained in French permanent grasslands since results from INRA suggest that harvest for the first growth cycle should occur between 800 (early hay harvest) and 1200 degrees day (flowering hay). This might be related to both differences in the characteristics of the ecotypes of the dominant grass species (*e.g.,* different precocity depending on the adaptation to specific pedo-climatic conditions) and to differences in local management practices, with delayed cuttings aiming to maximize forage yield and early cutting to maximize forage quality.

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