Rotational grazing increases purple prairie clover frequency in the rangeland plant communities under semi-arid environment

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Source: Canadian Journal of Plant Science, 102(3) : 600-607

Published By: Canadian Science Publishing

URL: https://doi.org/10.1139/CJPS-2021-0141

Canadian Science Publishing

ARTICLE

Rotational grazing increases purple prairie clover frequency in the rangeland plant communities under semi-arid environment

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Abstract: Purple prairie clover (PPC, *Dalea purpurea* Vent.) is a grazing tolerant perennial legume with good nutritional quality and is widely distributed across North America. Deferred rotational grazing (DR) and continuous grazing (CG) are the most widespread grazing systems on North American grasslands. We conducted a 10 yr grazing study to assess the effects of environmental factors and grazing on the frequency of PPC in plant communities. The results showed that the frequency of PPC decreased and then increased with increasing precipitation under CG ($P < 0.05$), while there was no significant change under DR ($P > 0.05$). Meanwhile, PPC frequency increased with temperature under DR ($P < 0.05$), but did not change under CG ($P > 0.05$). Both grazing systems and the number of grazing years had a significant effect on PPC frequency ($P < 0.05$), and there is no interaction between those two factors ($P > 0.05$). We found that from 2011 to 2020, the growth rate of PPC population is 18.24% and 11.69% per year under DR and CG grazing, respectively. Moreover, after 10 yr of grazing, the PPC increase in DR was 22.86% higher than that of CG. Thus, selecting the DR grazing system can increase PPC and is an effective practice for coping with environmental changes.

Key words: Dalea purpurea, deferred rotational grazing, continuous grazing, pasture, warm season legume.

Résumé : La dalée violette (DV, *Dalea purpurea* Vent.) est une légumineuse vivace qui tolère bien la paissance tout en présentant de bonnes qualités nutritives. On la retrouve partout en Amérique du Nord. La paissance en rotation décalée (PR) et la paissance continue (PC) figurent parmi les régimes de mise à l'herbe les plus répandus dans les prairies nord-américaines. Les auteurs ont entrepris une étude de dix ans afin d'évaluer les effets des paramètres environnementaux et de la paissance sur la fréquence de la DV dans les peuplements végétaux. Selon les résultats obtenus, la fréquence de la DV diminue puis remonte quand les précipitations augmentent avec la PC ($P < 0{,}05$), alors qu'on n'observe aucun changement significatif avec la PR ($P > 0{,}05$). Par ailleurs, la fréquence de la dalée s'accroît en même temps que la température dans le régime PR ($P < 0{,}05$), mais elle ne varie pas avec le régime PC ($P > 0{,}05$). La nature du régime et le nombre d'années de paissance ont un effet sensible sur la fréquence de la DV ($P < 0{,}05$), cependant on ne relève aucune interaction entre ces deux facteurs ($P > 0{,}05$). De 2011 à 2020, les auteurs ont observé un taux de croissance annuel de 18,24 % pour les peuplements de DV soumis à la PR et de 11,69 % pour ceux assujettis au régime PC. D'autre part, après dix années de paissance, la population de DV avait augmenté de 22,86 % de plus avec la PR qu'avec la PC. Le régime de paissance en rotation décalée concourt donc à la prolifération de la légumineuse et s'avère efficace pour composer avec les changements environnementaux. [Traduit par la Rédaction]

Mots-clés : Dalea purpurea, paissance en rotation décalée, paissance continue, pâturage, légumineuse de saison chaude.

Received 8 June 2021. Accepted 29 October 2021.

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Introduction

In North America, semi-natural tame pastures support forage self-sufficiency and provide nutrition to livestock (Liebig et al. 2010; Iwaasa et al. 2012). Most of these pastures are managed with deferred rotational grazing (DR) or continuous grazing (CG) systems. Rotational grazing is an intensive grazing management practice that gives livestock the opportunity to consume fresh forage on a continuous basis (Ishii et al. 2005). DR systems provide more precise control over the timing of grazing. Rather than just rotating livestock through the grazing season each year, it would be better to organize grazing through rotational subsets of growing season, thus giving the pasture more time to recover. DR systems are particularly beneficial for mixed pastures, which contain early maturing cool season forages and late maturing warm season forages (Iwaasa et al. 2012). CG, however, in semi-arid grasslands results in less vegetation cover and litter accumulation (Han et al. 2008), soil erosion (Luo et al. 2010), and very low organic carbon and nitrogen concentrations and microbial activities, leading to pastures degradation (Yong et al. 2005). In addition, global warming may also pose a challenge to the provision of forage and other services from grasslands (Deléglise et al. 2015). Grazing management plays a key role in this context as it must maximize the benefits provided to human society and the biosphere, such as beef production and ecosystem services (Hart et al. 1988; Jin et al. 2015; Marty, 2005). These benefits may be maximized by adapting grazing patterns and increasing nitrogen-fixing leguminous plants on tame pasture.

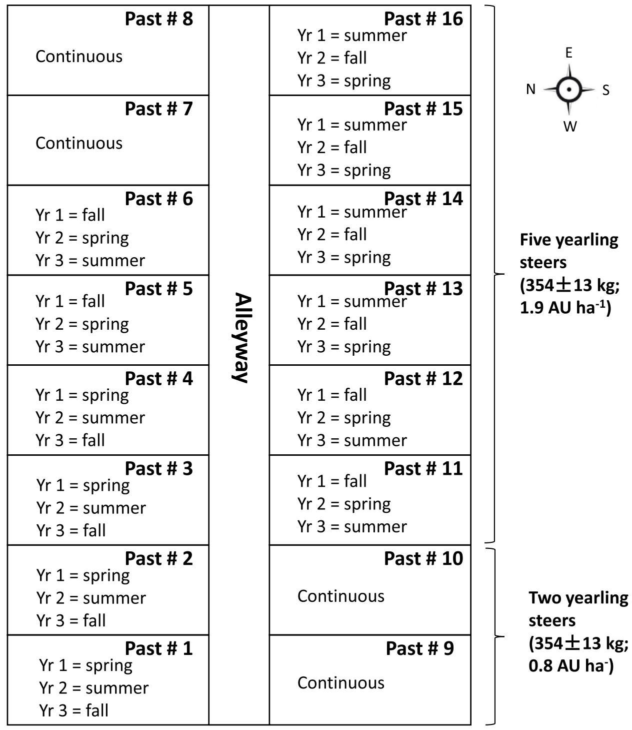
Purple prairie clover (PPC; *Dalea purpurea* Vent.) is a native legume to the North American prairie. It is a perennial herb growing up to 0.9 m tall. Mature PPC has a large taproot up to 2.0 m deep with woody stem and several branches. PPC is a fairly resistant to heavy grazing and trampling, and is also drought tolerant; however, overgrazing inhibits its regeneration, depletes the stands, and alters rangeland ecosystem. Therefore, it can be used as an indicator species for grassland health. It has been shown to contain high concentrations of condensed tannins (Huang et al. 2016) and exhibits strong anti-*Escherichia coli* properties (Jin et al. 2012). PPC is a warm-season legume, which can supply needed forage in summer when cool-season grasses are often unproductive (Tracy et al. 2010). Thus, PPC can extend the grazing season and reduce the cost of beef production in the Northern Great Plains. The incorporation of this highly palatable and nutrient-rich species into pastures has also been proposed as a practical way to improve forage quality and increase native forage biomass (Iwaasa et al. 2012; Schellenberg et al. 2012). In this regard, PPC is of particular interest because it is well adapted to the North American region and has a higher nutritive value (Peng et al. 2016) and better atmospheric nitrogen fixation capacity (Mischkolz et al. 2013) than other native legumes. Therefore, there is a strong necessity to introduce and study the PPC community composition in North American tame pastures.

A previous study showed that rotational grazing using grass-legume pastures can decrease the amount of hay needed to feed animals over winter and can provide risk management for summer grazing in drought years (Janovick et al. 2004). Livestock impact pastures in several ways, particularly through selective defoliation, trampling, and excrement deposition (Wrage et al. 2011). Rotational grazing can make reasonable use of these disturbances to increase grassland utilization. Derner et al. (1994) indicated that rotational grazing provides greater managerial control over the frequency, intensity, and uniformity of tiller defoliation compared with CG. Rotational grazing can help farmers increase net profit by increasing the yield of animal products per acre, improve pasture botanical composition, and allocate pasture to animals more efficiently based on their nutritional needs (Briske et al. 2008). In semi-arid pastures, optimal livestock pressure can be achieved using specific grazing management practices (Ford et al. 2018) and by adjusting the grazing schedule and system (Metera et al. 2010). Ishii et al. (2005) found that an intensive rotational grazing system for dwarf and late-heading grass pasture oversown with Italian ryegrass can expand the grazing period for beef cows from October to late November.

Grazing is an important form of land use on North American grasslands but there is uncertainty about how it will be affected by precipitation and temperature. Summer droughts are expected to be among the main consequences of a warming climate (Liebig et al. 2010). They may have short-term as well as persistent consequences for pastures (Jentsch and Beierkuhnlein 2008). CG reduces vegetation cover and litter accumulation, which in turn accelerates ground wind erosion and loss of soil organic matter (Yong et al. 2005). This phenomenon is more obvious in dry years (Lozano et al. 2018). A modeling study on the effects of increased temperatures, increased or decreased precipitation, and grazing, showed that increases in these environmental variables predisposed the system to make shrubs the dominant species in the community (Christensen et al. 2004). Therefore, it is important to include grazing in studies of the ecosystem response to precipitation and temperature changes. However, environmental changes can lead to negative impacts on human use of resources because such changes can disrupt the balance between grazers and plants (Alward et al. 1999).

Grazing management (e.g., the choice between rotational and CG) has a significant impact on system stability, especially in the face of environmental change. Therefore, it is essential to understand the interactions between environmental change and grazing practices to prevent overgrazing and to select more optimal grazing systems (Christensen et al. 2004). The following

Fig. 1. Pasture design of different grazing systems (continuous grazing (CG) vs. deferred rotational grazing (DR)). Past, pasture; Yr, year; AU, animal unit.



hypotheses were tested through a decade of grazing: (*i*) PPC frequencies in the North American rangelands will differ between continuous and DR systems; and (*ii*) PPC frequencies would vary with precipitation and temperature.

Materials and Methods

Study site

Our study on PPC frequency was conducted from 2011 to 2020 at Agriculture and Agri-Food Canada Swift Current Research and Development Centre (50°25 N′, 107°44′W), Saskatchewan, Canada. The soils classified as Orthic Brown Chernozem in the Canadian soil classification system, had a silt loam texture containing 28% sand, 49% silt, and 23% clay, and with an organic C content of 20 g kg^{-1} and pH ($CaCl_2$) of 6.5 in the top 0.15 m depth at the beginning of the experiment. Precipitation and temperature data were obtained from Environment Canada's online climatic data (www.climate.weatheroffice.ec.gc.ca).

Experimental design

Our tame pastures experiment consist of 16 paddocks of 2.1 hectares each, which were enclosed after seeding in 2001; for more details on pasture establishment see Iwaasa et al. (2012). Briefly, there are four treatments in the current study as follows (Fig. 1):

(i) CG
(ii) DR grazing: Fall (Yr1) - Spring (Yr2) - Summer (Yr3) grazing sequence for 3 yr
(iii) DR grazing: Spring (Yr1) - Summer (Yr2) - Fall (Yr3) grazing sequence for 3 yr
(iv) DR grazing: Summer (Yr1) - Fall (Yr2) - Spring (Yr3) grazing sequence for 3 yr

Each treatment is replicated four times. The grazing period started at the end of June and ends by August for the CG system and lasted until the end of September for DR. This corresponds to the common grazing season in southern Saskatchewan that extended between June and end of September (90 to 120 d long). We used 68 commercial Angus yearling steers (354 ± 13 kg) each year. Five yearling steers were placed on each pasture for each DR treatment and two yearling steers were placed on each CG pasture. Stocking rate for the DR was five steers per pasture (1.9 AU ha^{-1}) and the CG was two steers per pasture (0.8 AU ha^{-1}). The animals used for these experiments were cared for in accordance with the Canadian Council on Animal Care (2009) guidelines.

Sample collection

PPC frequencies were determined annually using point sampling along 14, 30-m transects where each transect consisted of 100 points spaced 30 cm apart for a total of 1400 points. The transect randomly distributed among all 16 paddocks. A "hit" was recorded when a point fell on any part of a PPC plant. The PPC frequency in each pasture per year was equal to the sum of all "hits" divided by 1400. PPC was sampled before grazing.

Fig. 2. Growing season precipitation (bar) and temperature (dashed line) from 2010 to 2019 in the study area.

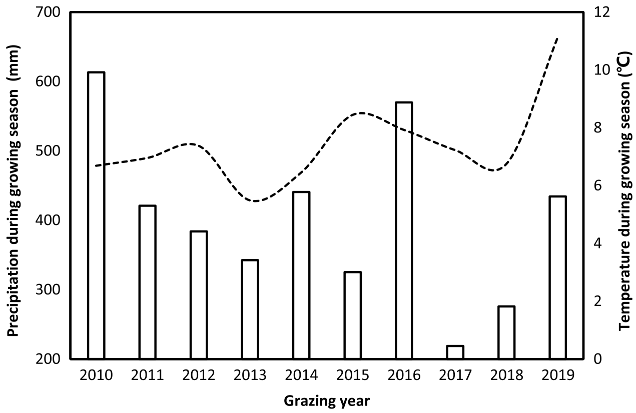
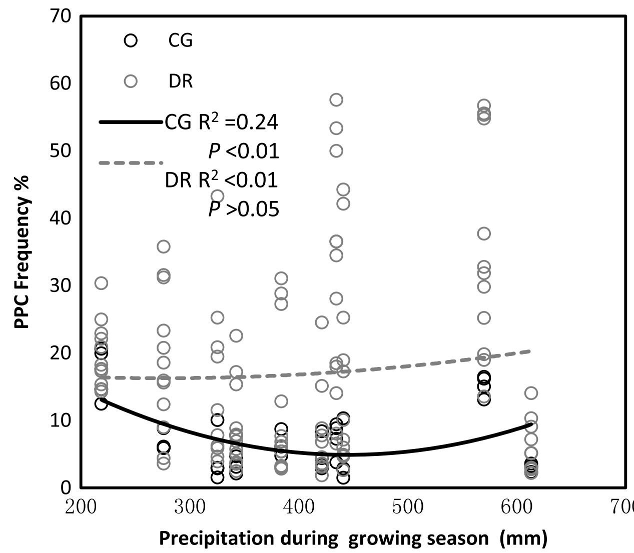


Fig. 3. Variation in purple prairie clover (PPC) frequency with growing season average precipitation. R^2: coefficient of determination. *P* value: the significance of the equation. The black dots and solid line represent continuous grazing (CG); the gray circle and dashed line represent deferred rotational grazing (DR).



Statistical analysis

Linear or nonlinear regression models were used to fit the relationships between PPC frequency and number of grazing years, and growing season temperature and precipitation (Table S1[1]). We selected the best-fitting model based on the highest R-squared of each model. All statistical analyses were performed in R 3.5.1 (R Core Team 2018). We used the *lm* function to develop a linear model to demonstrate the effect of temperature and precipitation on PPC frequency during the growing season. We used the *nls* function to set up a nonlinear model to explore the pattern of changes in PPC frequency with the number of grazing years. The response of PPC frequency to number of grazing years and grazing methods were analyzed using repeated measure analysis (Fig. S1[1]). Statistical significance was set at $P < 0.05$. Multiple comparisons of means were based on Duncan's post hoc test.

Results

Environmental effects

Within the 10-yr period of our study, annual average temperatures of the growing season (March-November) ranged between 5.49 °C and 11.15 °C in 2013 and 2019, respectively, with an overall average of 7.45 °C (Fig. 2). The decadal growing season extreme mean precipitation was 613.3 mm and 218.9 mm in 2010 and 2017, respectively; the annual mean precipitation was 402.63 mm (Fig. 2). Our results showed that the frequency of PPC was not significantly related to growing season precipitation under DR ($P > 0.05$; Fig. 3); however, the PPC frequency showed initially a decreasing and then increasing trend with increasing pattern precipitation during the growing season under CG and was lowest between 400-450 mm ($P < 0.01$; Fig. 3). Interestingly, the frequency of PPC was not significantly correlated with the temperature of the growing season under CG ($P > 0.05$; Fig. 4). The frequency of PPC increased in a quadratic relationship with the temperature of the growing season under DR ($P < 0.01$; Fig. 4). The model showed that the PPC frequency was still increasing at the maximum of 11.15 °C.

Grazing effects

The PPC frequency was significantly correlated with the number of grazing years (Fig. 5). As the grazing years increased, the PPC frequency increased in DR, which was 22.86% higher than that of CG after 10 yr of grazing. Moreover, the PPC frequency under DR grazing increased more rapidly than CG (the slopes of the equations for DR and CG are 0.18 and 0.12, respectively; Fig. 5). Both grazing methods and number of grazing years had a significant effect on the PPC frequency ($P < 0.01$, Fig. 6), and there was no interaction between those two factors ($P > 0.05$, Fig. 6). The average PPC frequency under DR treatments were significantly higher than CG, at 19% and 7.3%, respectively ($P < 0.01$, Fig. 6). During 2011–2017, the PPC frequency gradually increased under DR grazing and reached the highest in 2017 (frequency = 36%). Then, the PPC frequency decreased in 2018–2019, and it started to increase again in 2020. In 2011–2016, the PPC frequency did not change significantly under the CG, until it reached the highest level in 2017–2018, with frequencies of 15% and 17%, respectively, then decreased in 2019–2020 (Fig. 6).

[1]Supplementary data are available with the article at https://doi.org/10.1139/cjps-2021-0141.

Fig. 4. Variation in purple prairie clover (PPC) frequency with growing season average temperature. R^2: coefficient of determination. *P* value: the significance of the equation. The black dots and solid line represent continuous grazing (CG); the gray circle and dashed line represent deferred rotational grazing (DR).

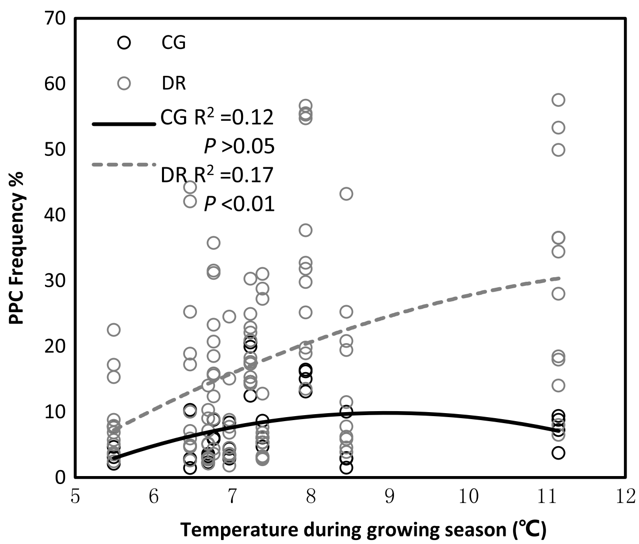
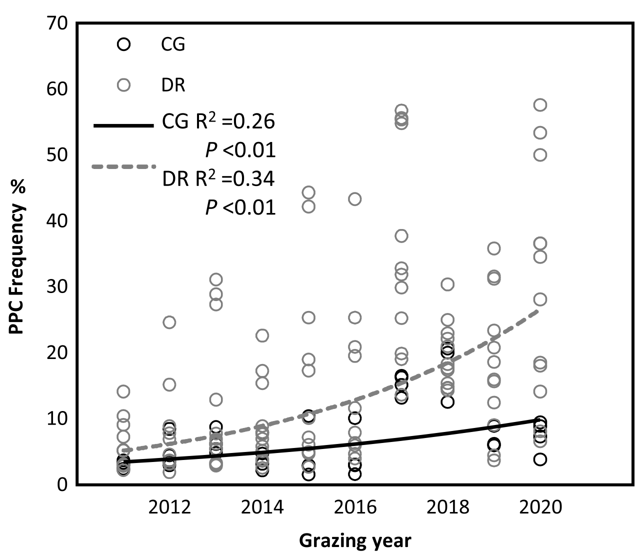


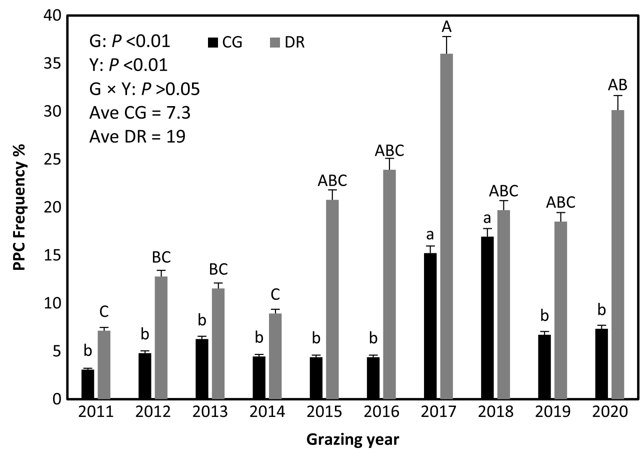
Fig. 5. Variation in purple prairie clover (PPC) frequency with the number of grazing years. R^2: coefficient of determination. *P* value: the significance of the equation. The black dots and solid line represent continuous grazing (CG); the gray circle and dashed line represent deferred rotational grazing (DR).



Discussion

The average annual precipitation showed a significant decreasing trend during the decade of our study, but there was a significant increase in precipitation in 2016 and 2019 compared with the 30 yr average. The decrease in precipitation leads to a decrease in soil moisture,

Fig. 6. The purple prairie clover (PPC) frequency in the different grazing year. CG, continuous grazing; DR, deferred rotational grazing. Different letters indicate a significant difference at the $P \leq 0.05$ level. G, grazing methods; Y, years; G × Y, the interaction between the two.



which reduces the growth rate of community plants (Christensen et al. 2004). Lower growth rates are not sufficient for herbaceous plants to respond to grazing, and once herbaceous vegetation is suppressed, some long-rooted plants are able to use available resources (Archer, 1996). Low-productivity systems are often dominated by more grazing-resistant plants, such as tough tussock grasses and stem woody plants (Milchunas and Lauenroth 1993). Mature PPC have a coarse root system with strong woody taproots that are up to 2.0 m deep. The taproot may give rise to several finely branched lateral roots. Therefore, under conditions of less water, PPC still has more opportunities to absorb water from deeper soil horizon and grow better than other herbaceous plants because of its deep root system. We argue that when the moisture required for PPC growth is restricted and disturbed by CG, it will prefer vegetative growth to regenerate new shoots and branches. Conversely, when moisture is sufficient, PPC tends to invest more towards reproductive growth. This may be the reason why the frequency of PPC showed a decrease in frequency in initial dry years and then an increase in frequency with increasing precipitation in the later years under CG in our results (P < 0.01, Fig. 3). On the contrary, under DR, PPC had more sufficient recovery time and it was less disturbed by grazing, so its frequency was not affected by precipitation (P > 0.05, Fig. 3). A previous study showed that PPC frequency may be strongly influenced by changes in precipitation compared with grazing effects (O'Connor et al. 2001). Schönbach et al. (2010) found different compensatory growth responses to grazing in different years, possibly due to precipitation. In years with higher precipitation, the ability of plants to partially compensate for grazing damage may be enhanced when soil water content increases.

Our study considered that the PPC frequency increased significantly with increasing temperature when moisture conditions were not restricted under DR ($P < 0.01$, Fig. 4). Grazing and climate warming increase soil temperature, resulting in lower soil moisture during the growing season (Lin et al. 2011). It has been shown that grazing increases the area of bare ground and decreases the litter mass, which in turn leads to an increase in soil temperature (Luo et al. 2010). Removal of plants by grazing significantly increases soil temperature, and plant carbon fixation is temperature sensitive, affecting soil organic matter carbon stocks (Grogan et al. 2005). Soil moisture is significantly altered due to litter loss, and increased temperature reduces soil moisture under grazing disturbance. Thus, grazing causes litter loss, and the magnitude of this effect varies depending on the temperature and likely also alters soil microbial activity to the benefit of plant growth (Peco et al. 2017). Temperature tends to be the main environmental factor affecting seed germination when moisture is not restricted (Cane 2006). PPC germinates at soil temperatures of 15 °C–30 °C (Belcher 1985), while seed dormancy is broken at temperatures as low as 5 °C (Bjugstad and Whitman 1982). As a warm-season legume, PPC usually blooms from July to September. Therefore, our study hypothesized that changes in soil temperature due to spring grazing may affect PPC seed germination and summer and fall grazing may affect PPC blooms.

Our study showed that PPC frequency increased with grazing years ($P < 0.05$, Fig. 5). The trampling effect during grazing may help proper contact seeds with soil, chancing the chance of germination. Similarly, animal movement during grazing may help pollen dispersal and cross pollination. In a grassland study in Wisconsin, 45% of hand-pollinated, outcrossed flowers produced large, viable seeds and 19% of self-incompatible flowers produced seeds (Cane 2006). Seeds of PPC have a specialized dispersal mode, so that under normal conditions, most seeds would only fall near the mother plant (Wasser and Shoemaker 1982). Therefore, we assume that grazing disturbance also contributes to PPC seed dispersal. Moreover, our previous study on PPC seed viability and germination reported that the germination rate of PPC seeds in cow dung was two times higher than that of naturally dropped ones and that highly viable seeds are important for germination and self-renewal (Gu et al. 2019). In this study, the frequency of PPC under DR was higher than that of CG (Fig. 5). It is generally accepted that long-term CG hinders the growth of community plants (HilleRisLambers et al. 2001). The growth of PPC under DR can be recovered during non-grazing periods. In contrast, the growth and regenerative capacity of PPC under CG was inhibited by continuous grazing.

Our study suggests that DR is important for the sustainable use of grasslands. In spring and early summer, cattle prefer younger mesotrophic vegetation (Probo et al. 2014). In summer and fall, when mesophilic vegetation becomes more senescent and less nutritious, PPC are selected by cattle as highly nutritious, palatable plants (Ganskopp and Bonhert 2006). Because of its long roots, PPC can absorb more water as the snow melts in the spring, a characteristic that becomes more apparent especially in dry years as other plants appear less frequently. Annual snowfall and winter weather can affect the success of plant strategies to cope with grazing (Adams et al. 1986).

Cattle can influence PPC frequency by defoliation, trampling, and depositing excrement. In our study, we considered defoliation as the main way in which cattle affect PPC communities. Periodic PPC defoliation is essential to control the succession of this plant. Cattle usually defoliate selectively, and PPC is one of the preferred plants. Selective defoliation encourages the growth of other plants that support the survival of PPC in continuously grazed landscapes. DR grazing can control PPC defoliation with intermittent recovery time. Thus, our experimental results indicate that PPC frequency is significantly higher under DR than under CG, thereby increasing the sustainable use of PPC. Major reason for the higher frequency of PPC under DR grazing is that after a given season of grazing, the plants have enough time to recover and grow for the remainder of the growing season. This finding is consistent with the proposal of Derner et al. (1994) that in DR systems, some plants will remain more competitive and productive due to reduced defoliation events throughout the growing season, and therefore maintain pasture in productive and regenerative conditions over time.

Conclusion

Our study demonstrated that PPC frequency was affected by environmental variability (i.e., precipitation and temperature) and different grazing patterns as well as the number of grazing years. In our 10-yr grazing study, PPC frequency was higher under DR than CG. Therefore, we suggest the need to use DR to increase PPC frequency as an effective grazing management method in response to environmental changes, and that DR grazing would be a very low-cost way to increase the proportion of PPC in existing pastures. In addition, our findings suggest that range managers in semi-arid regions could increase the proportion of PPC seeding in response to changes in environmental conditions. More PPC can increase the utilization of nutrients and water in pastures, while being more beneficial for cattle breeding. Continued and long-term research is required to better understand the effects of rotational grazing and PPC on grassland ecosystems and their response to environmental changes.

Conflict of Interest Statement

All the authors declared no conflict of interest.

Acknowledgements

This study was supported by Agriculture and Agri-Food Canada and the South West Saskatchewan Forage Cooperative Association Ltd. Appreciation is expressed for the support of the field and technical staff of the Agriculture and Agri-Food Canada Swift Current Research and Development Centre.

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