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REVIEW PAPER

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How does grassland management affect physical and biochemical properties of temperate grassland soils? A review study

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Abstract

Increasing management intensity of grassland through increased grazing intensity, mowing frequency and fertilizer input have attracted more attention to the consequences of grassland management practices on reduced soil quality and grassland yield. Given the importance of soil attributes in generating resilience in soil-vegetation-livestock systems, a better insight of the dynamic of these complex systems is warranted. The maintenance of proper soil physical, chemical and biological properties indicates the basis of a resilient grassland system. This review summarizes research approaches and outcomes of the effects of grazing, mowing, and applying fertilizer on soil physical and biochemical characteristics with the aim of providing useful guidelines to researchers, land managers, and policy makers to maintaining and improving soil attributes and grassland productivity. Based on the studied literatures, choice of management intensity on grasslands appears to be more critical. Light to moderate grassland management intensities have positive effects on soil properties, but frequent or incorrect management practices may cause undesirable consequences. Various factors such as the geographic region, and plant group functions additionally could have an effect on management regimes, so it can be concluded that optimal management method should be adapted to regional and local circumstances.

KEYWORDS

defoliation management, fertilizer application, forage biomass, grassland uses, soil attributes

1 | INTRODUCTION

Temperate grasslands occupy 9 million km^2, representing 8% of earth's terrestrial surface (Figure 1) (Sala et al., 2013; White et al., 2000). Most permanent grasslands are land-use systems established by humans over centuries and therefore a part of our cultural landscape (Hejcman et al., 2013). Grasslands occur most commonly where site-specific conditions are less favourable for crop farming, while primarily found on marginal land. Grassland herbaceous plant communities evolved in close relation with herbivores and are adapted to defoliation. Defoliation is defined as removing plant shoots by grazing or mowing, and it is described in terms of intensity, interval between events, timing relative to season or plant growth stage, or by its spatial heterogeneity (Sollenberger

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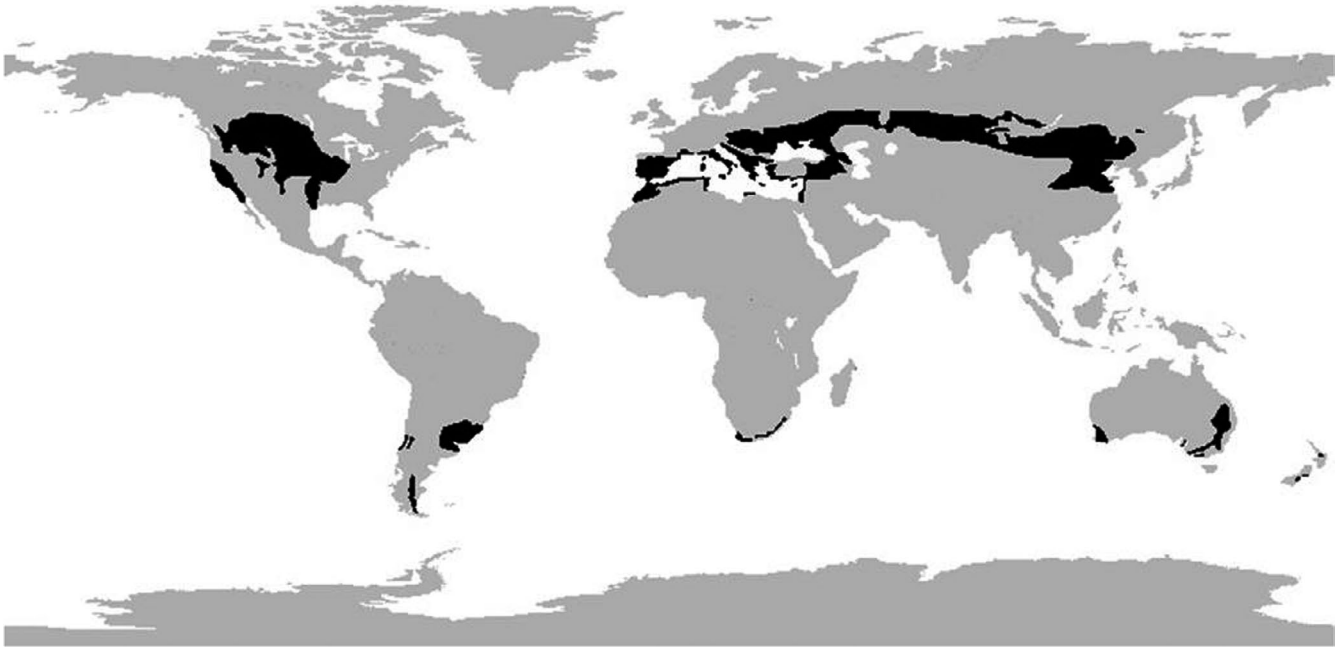

FIGURE 1 Distribution mapping of the global temperate grasslands. Adapted from (Sala et al., 2013)

et al., 2012). Given the importance of grasslands in promoting the most consumed livestock feed in addition to delivery of important ecosystem services (Sollenberger et al., 2019), is getting increasing focus of grassland researches to optimize grassland management. Management practices influence herbage accumulation, fodder quality, soil attributes, nutrient cycles, plant diversity and plant population density (Schmitt et al., 2010; Zeeman et al., 2010) as well as greenhouse gases emission (Hörtnagl et al., 2018). All biological systems, including grassland-herbivore agroecosystems, are regulated by relatively complex feed-back loops, providing these systems with a strong auto-regulation and auto-adaptation capacities. This enables grasslands to evolve within a context of continuous changes, processes which are now accelerating due to climate and other global changes.

Intensification of grassland management is considered by some to be a threat to their adaptation capacity (Gellrich et al., 2007; Guerci et al., 2014). Intensification can be considered from two perspectives: (a) an increase in herbage production (primary production) per unit area through use of fertilizers or irrigation and/or more productive species and cultivars; and (b) an increase in the proportion of the herbage produced that is consumed by herbivores or harvested by mowing. The use of primary production ranges from extensive to intensive and is due in part to socio-economic considerations that impact farming management choices (Tiemeyer et al., 2016). Currently, increasing population and food demand are driving increasing intensity of grassland management or, in some cases, conversion of grasslands to monoculture croplands. Furthermore, global climate change may lead to frequent drought periods which resulting in decreased forage. Thereby, farmers are pushed to manage grasslands intensively. Management intensification of grasslands may result from altering cultivation, fertilization, and grazing and mowing practices (Dusseux et al., 2015; Taube et al., 2014; Xue et al., 2017). These changes affect delivery of ecosystem services and alter ecosystem functions as well as soil properties (Kleijn et al., 2011; Winter et al., 2012) which can cause problems in productivity and landscape protection balance.

Given the importance of soils for livestock production, and for the provision of wider ecosystem services, maintaining the soil in desired condition is crucial. Interactions occur among soil, vegetation, livestock, and management (Figure 2), affecting the flow of C and nutrients across the system. An important question remains: To what extent can management be intensified without deteriorating the soil attributes in the term of system resilience? Since grassland ecosystem functions are a result of complex interactions between herbivores, vegetation, soil, and atmosphere (Sollenberger & Wallau, 2020), desired management outcomes must be reflected in all components of the ecosystem and should include maintaining (a) functional plant communities characterized by sward canopy structure that is well suited for grazing herbivores; and (b) soil cover in order to protect soil health and quality and provide the necessary ecosystem services for sustainable development of human society.

Effects of land use intensity on soil quality have been widely described for cropping systems; however, there is much less published research for grassland systems (Sollenberger, 2015). To maintain grassland services, correcting undesirable trends in grassland response, restoring desired grassland condition, and greater knowledge of soil responses to defoliation are essential in order to evaluate different management choices and techniques for achieving sustainable grassland agroecosystems. Thus, this review assesses the effect of defoliation management on soil physical, biochemical traits

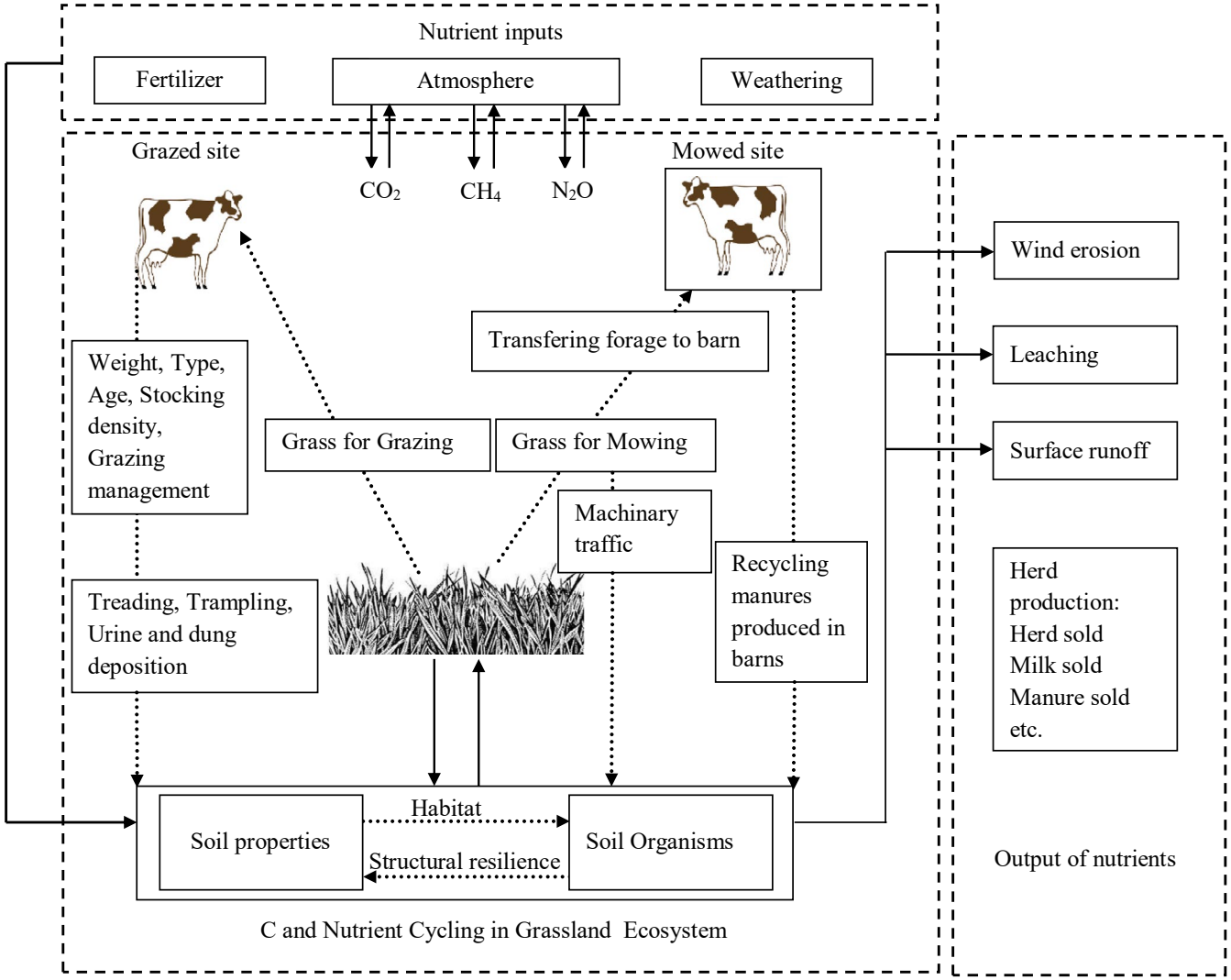

FIGURE 2 Conceptual illustration of C and nutrient inputs and outputs in a grassland ecosystem showing interactions among soil, vegetation, and livestock in grazed and mowed sites. Solid arrows represent fluxes of elements and water. Dashed arrows represent functional influence of grazing and mowing on grassland ecosystem [Colour figure can be viewed at wileyonlinelibrary.com]

in order to understand if implementation of various management practices will affect long-term system productivity and sustainability in temperate grasslands. The specific objective was to address the following questions: (a) How are soil properties affected by implementing different grassland management practices, (b) What is the relative importance of management factors on forage biomass in pastures and meadows? and (c) What knowledge gaps exist relative to the effect of defoliation management practices on soil quality?

2 | GRASSLAND USES

Vegetation-animal-soil interactions occur within the context of grassland uses, resulting in fluxes of carbon (C), nitrogen (N), phosphorous (P), potassium (K), and other minerals among nutrient different pools (Dubeux et al., 2007). Grassland–,soil interactions are mediated by herbivores even when herbivores are excluded from grassland and are fed in barns (Figure 2). Such interactions therefore occurs within the context of a system, and it should be analysed as such. All biological systems are regulated by more or less complex feed-back loops. This gives these systems strong auto-regulation and auto-adaptation capacities, features that are ignored when systems are segmented and studied as single components. This is the rationale for systems approach we have used in this review (Figure 2). In the following sections, the background and context of grassland uses will be discussed.

2.1 | Grazed pasture

The consumption of plant leaf by livestock has a major impact on growth and survival of pasture plants by affecting plant photosynthesis and C supply to the system directly. It can also affect the ecosystem by altering degree of land cover as well as soil physical, chemical, and biological characteristics which are associated with multiple environmental impacts on soil health, plant productivity, and

grassland structure (Dubeux et al., 2009; Yang et al., 2013). Animal-mediated effects on grazed grasslands include poaching, trampling, spatially heterogeneous defoliation, and spatial heterogeneity of dung and urine deposition leading to redistribution of soil nutrients (Dubeux et al., 2007; Sollenberger & Wallau, 2020). Thus, optimal grazing management can deliver benefits including improved forage accumulation and nutritive value, lower feed costs, and improved livestock performance (Jerrentrup, 2013; Wei et al., 2011).

Grazing can be characterized in terms of stocking method (e.g., continuous, rotational, etc.) and grazing pressure (e.g., stocking rate, forage allowance, etc.; Allen et al., 2011). In grazed sites, plant-herbivore interactions occur through defoliation regime and animal grazing behaviour. In such a system, plant communities experience defoliation events with different intensity and frequency depending on grazing animals, stocking rate, and grazing management rules. Rotational stocking allows grasslands to have rest periods between grazing events by subdividing a land area into smaller paddocks where herbivores are concentrated for shorter periods (Bork et al., 2017). Intervals between defoliation events vary under different management systems, with longer intervals often characterizing extensive systems (Gastal & Lemaire, 2015).

Defoliation intensity, defined by the proportion of daily herbage production consumed by animals, is determined by the standardized number of grazer individuals (e.g., cattle, sheep and/or horses; animal unit ha^{-1}; Simons et al., 2017; Sollenberger et al., 2012). Grazing intensity has been described as one of the important grazing management decisions (Sollenberger & Newman, 2007), and intensities have been classified as light grazing (<40% utilization of forage mass), moderate grazing (40%–65%), and heavy grazing (>65%; Evans et al., 2012; Krzic et al., 2013). Defoliation intensity may also be described in terms of post-grazing stubble height (rotational stocking) or canopy height (continuous stocking), a key variable which can affect the time period required to restore whole-plant C balance (Briske & Richards, 1993). The average number of livestock that can be supported over a specified length of time without deterioration of the vegetation or soil also varies with non-management factors (e.g., topography and climate). Consequently, the effects of grazing on a grazed grassland are controlled by the location, timing, duration, and intensity of grazing (Russell & Bisinger, 2015).

2.2 | Mown meadows

Fodder conservation to supply winter feed for livestock has been a priority farming activity for people living at high altitudes for over 2,000 years (Eriksson et al., 2015). Mowing is applied to produce hay or silage, and herbivores are excluded from these grasslands and fed in barns, leading to removal of aboveground biomass with minimal return of plant residue and associated nutrients (Zhang, Hou, et al., 2015). Mowing has an effect on ecosystem services such as the productivity of grassland and fodder quality (Isbell et al., 2013), and nutrient cycles (Giese et al., 2013), and soil C accumulation (Franzluebbers et al., 2000). Generally, mown grasslands are characterized by greater homogeneity of defoliation and nutrient cycling than grazed ones (Mathews et al., 1994). In most cases, nutrients from excreta of barn-fed livestock are applied to meadows for recycling of C and other nutrients, which facilitates maintaining soil quality and closing nutrient cycles. In cases where manures are used on other crop areas, soil quality, and nutrient status is likely to decline year to year because of failure to compensate for nutrients exported in harvested forage. Thus, it is important to consider both the "local system," that is, the individual field level, and the "whole system," that is, the farm level, when assessing nutrient cycles and soil quality evolution in response to grassland defoliation management.

Mowing regime is primarily characterized by the time interval between cuts and frequency (number of cutting events per year), and is performed usually depends on grassland management goals, such as forage nutritive value, vegetation biodiversity, and conservation value. The mowing interval usually varies from 30 to 60 days in cutting systems (Gastal & Lemaire, 2015). Meadows with high biodiversity and conservation value are often extensively managed, that is, mowed only once or twice per year without receiving mineral and organic fertilizers (Tallowin & Jefferson, 1999). In this context, mowing is usually performed at the end of summer (late July to August) or in some cases two times during the growing season (e.g., at the beginning and end of summer) or even every other year (Eriksson et al., 2015; Tälle, 2018). In contrast, for intensive forage production, meadows are cut from three to six times per year while receiving high amounts of mineral and organic fertilizers (Tallowin & Jefferson, 1999). Furthermore, mowing time is also essential for management planning especially for endangered grasslands by affecting reproductive success and genetic diversity (Nakahama et al., 2016; Vannucchi et al., 2015). Mowing history and cutting height are two other indices that should be considered when evaluating the effect of mowing on grassland production (Weigelt et al., 2009), and as indicated by (Walter et al., 2012), mowing history might be more important in explaining productivity than mowing frequency alone. From an agricultural point of view, the number of cuts in any particular year depends on different factors including soil type, location (e.g., altitude, aspect), climate, type of management system, and forage production goals (Eriksson et al., 2015).

2.3 | Systems combining grazing and mowing–mown pasture

There is in fact a continuum ranging from grasslands that are grazed only to those that are mowed only, with various intermediate combinations reflecting different proportions of grazing and mowing. Mown pastures may be cut prior to or after grazing to exploit the plant biomass for hay or silage, they hence experience grazing and mowing within the same year (Tälle et al., 2015). Low intensity grazing with a low frequency of mowing improves plant diversity by reducing competition among plant species by allowing less competitive plants to survive by capturing more light (Olff & Ritchie, 1998). In a system with a high frequency of defoliation, plant diversity can be

reduced because some species have a low aptitude for rapid refoliation after defoliation; however, species diversity depends on species survival ability in response to a defoliation regime (Lemaire, 2001).

Changes in timing of mowing and grazing are crucial. The vegetation recovery time after mowing and grazing events may additionally depend on site conditions (Blüthgen et al., 2012). Traditionally, mown pastures were grazed for a few weeks during spring, mown later after seed set but without applying mineral fertilizers, and perhaps grazed again for several weeks in fall (Hjelle, 1999). Currently, farmers have altered the traditional management to include application of manure and mineral fertilizer following spring grazing (Hjelle, 1999).

3 | HOW DOES GRAZING INFLUENCE GRASSLAND SOIL RESPONSES?

Within a grassland-livestock agroecosystem, each component has an effect on the others. As a result, "emergent properties" arise that cannot be studied only by the exploring direct and linear effects. Whole-system analysis is required, including consideration of feedback loops and trade-offs (Lemaire et al., 2011). Understanding the dynamics of pasture-based systems provides fundamental information to not only manage animals and vegetation but also establish sustainable grazing management practices.

As herbivores graze vegetation selectively, foraging behaviour is a determinant not only of the rate of animal nutrient intake but also the location and intensity of grazing (Lemaire et al., 2011). Selective foraging behaviour by animals can lead to feeding patches which prompt differences in plant physiology, soil properties, and biogeochemical cycles of ecosystems (Ferraro & Oesterheld, 2002; Wang & Fang, 2009). The following sections focus on the assessment of grazing effects on soil physical and biochemical properties. It is recognized that other factors, including climate condition, soil parent material, vegetation cover, types of herbivores, watering points and resting places, play significant effects on the impact of grazing intensity on soil properties.

3.1 | Responses of soil physical properties to grazing

Changes imposed by treading and defoliation on soil physical properties cannot be easily decoupled in grazed sites, but their consequences deserve separate analyses. Grazing has noticeable influences on soil physical properties, for example, soil porosity, bulk density, hydraulic conductivity, and stability of aggregates among other properties, with the nature of the effect depending upon animal types and their excretal returns, soil bearing capacity, soil water content, vegetation cover, and grazing system (Egan et al., 2018; Taboada et al., 2011).

Grazing impacts on soil physical properties are attributed primarily to animal trampling (Zhang et al., 2019). The amount of treading and trampling by each animal depends upon animal type (e.g., animal mass, hoof size, and kinetic energy; Table 1), distance to the water points, grazing period, and forage quantity and cover (Greenwood & McKenzie, 2001; Taboada et al., 2011). The effects of grazing on soil physical characteristics should be evaluated in terms of the exerted pressure on the soil, soil mechanical strength (pre-compression stress which is the maximum load that the soil can resist before taking place a plastic deformation) and soil resilience (Horn et al., 1994). Soil mechanical strength depends on soil water content. With increasing water content, the soil water tension and the internal mechanical strength is decreased which contributes to the likelihood of soil structure deformation under grazing (Dörner et al., 2009). Treading and trampling damages are evident in three forms: poaching, pugging, and compaction (Houlbrooke et al., 2009). Inserted pressure due to cattle hooves causes the deformation of soil physical structure in saturated soils, which is named soil poaching (Bilotta et al., 2007). Soil pugging will occur, if the soil water content is over the plastic limit and animal loads exceed the soil's bearing capacity (Houlbrooke et al., 2009). Pugging and poaching cause soil homogenization and deteriorate soil physical quality (Drewry, 2006). Soil compaction defines a reduction in soil structural stability (Houlbrooke & Laurenson, 2013; Proffitt et al., 1993).Expected damage differs under grazing depending upon soil moisture regime, varying from breaking down soil aggregates in dry soils to pugging in saturated conditions (Drewry et al., 2008; Taboada et al., 2011). In wet seasons, due to the moisture of the rainfall, soils are less resistant to the treading and trampling of animals. In saturated trampled soils, deep hoof-prints (up to 20 cm) can occur (Taboada et al., 2011). In grazed sites, when the exerted pressure on soil is lower than soil pre-compression stress, soil can resist animal hooves without critical detrimental effects on soil physical properties (Negrón et al., 2019). Soil may recover to its original condition at light grazing intensity through mechanisms of structural resilience such as the growth and decomposition of plants and roots, and the activities of soil microorganisms and smaller animals (Zhang et al., 2019). Whereas, if the applied load is greater higher than the soil pre-compression stress, frequent disturbance may override the soil's natural recovery ability and causes soil structural deterioration and consolidation which will negatively affect soil porosity and vital hydraulic properties (Dörner et al., 2012). As grazing intensity increases, soil porosity, air permeability, and conductivity are decreased and bulk density is increased, thereby soil functions would be reduced (Drewry & Paton, 2000). As reported by (Zhang et al., 2019), on average soil bulk density increased from 0.52 to 0.92 g/cm^3 but soil porosity decreased from 0.78% to 0.64% with increasing grazing intensity.

TABLE 1 Comparative animal weight, foot area, and static pressure of herbivores (adapted from Taboada et al., 2011)

Grazing animal type	Animal weight (kg)	Total foot area (cm^2)	Static pressure (kPa)
Sheep	40–54	55–85	48–83
Cattle	306–612	264–460	98–192
Horse	400–700	736	54–95
Goat	40	55	60–73

Some soil hydrological properties, for example, total porosity, saturated water content and hydraulic conductivity, play an important role in regulating soil water dynamics and plant water-use efficiency which are particularly important in water limited grassland. Decreased soil porosity associated with heavy grazing may be caused primarily by soil compaction-induced collapse of macropores and larger mesopores (Zhang et al., 2019). Soil macropores are important for soil air and water storage and transmission (including infiltration), and are more prone to compaction particularly when soil water content is near or between field capacity and the plastic limit (Laurenson & Houlbrooke, 2016). Available water capacity which describe the amount of water a soil can store can be affected by the loss of macropores, as well as by vegetation removal. Pedocompaction i.e. a reduction in soil pore space lesser soil airflow and oxygen diffusion rate (Hargreaves et al., 2019), and accordingly results in reduced infiltration rates and low saturated hydraulic conductivity compared to ungrazed sites (Taboada et al., 2011). Increased runoff associated with decreased infiltration may lead to increased erosion, with associated loss of organic matter and decreased plant available water (Taboada et al., 2011). Therefore, intensive grazing can have negative effects on water retention capacity by decreasing soil organic matter and changing soil particle size and aggregate structure (Guo et al., 2020). At severe soil degradation, the saturated moisture capacity, capillary moisture capacity, and field moisture capacity of the grassland decrease sharply (Guo et al., 2020). A summary of the reported changes in soil physical properties associated with treading at different soil water conditions is shown in Table 2. These data show that soil consistency and soil compaction are dependent on the soil water content. In dry soil under treading, bulk density starts to increase with increasing soil moisture and reaches a maximum. When soil moisture is beyond a saturated condition, soil particles are pushed further apart, and bulk density is decreased (Drewry et al., 2008; Taboada et al., 2011).

TABLE 2 Changes in soil physical properties due to treading at different soil moisture conditions

Soil property	Soil moisture	Effects	References
Bulk density	Dry	Increase	Drewry et al. (2008)
		No effect	Taboada et al. (2011)
	Moist	Increase	Greenwood and McKenzie (2001); Taboada et al. (2011); Tate et al. (2004)
	Saturated	Increase	Drewry et al. (2008); Schrama, Veen, et al. (2013); Taboada et al. (2011); Ward et al. (2003)
		Decrease	Drewry et al. (2008); Taboada et al. (2011)
Macro porosity	Dry	Decrease	Taboada et al. (1999, 2011); Warren et al. (1986)
		No effect	Taboada et al. (2011)
	Moist	Decrease	Drewry et al. (2008); Taboada et al. (2011); Warren et al. (1986)
	Saturated	Decrease	Chaneton & Lavado, 1996; Schrama, Veen, et al. (2013); Taboada et al. (2011)
Infiltration rate	Dry	Decrease	Taboada et al. (2011); Warren et al. (1986)
	Moist	Decrease	Taboada et al. (2011); Warren et al. (1986)
	Saturated	Decrease	Taboada et al. (2011)

In addition to direct impacts of trampling, changes imposed by defoliation and reduced cover can indirectly affect soil physical properties through their various consequences on vegetation structure and function. Vegetation acts as protective mulch to mitigate the pressure of livestock on soil and protect soil structure from deterioration. Defoliation reduces plant aerial biomass thus reduce the capacity of vegetation to buffer trampling pressure (Zhang et al., 2019). The content and constituents of organic matter affect soil physical properties. The more the aboveground plant biomass is grazed, the less plant litter mass is present on the soil surface and the fewer residues are incorporated into the soil as the main resource of organic matter input (Bilotta et al., 2007; Liu et al., 2011). Due to a reduction of organic matter input into the soil, the proportion of bare soil could be increased which increases daily temperature fluctuations and maximum daily temperatures and then lead to higher soil water evaporation rate (Bremer et al., 2001; Taboada et al., 2011). Soil temperature is affected by the thickness of plant residues on the soil surface, the thicker the plant residues the more insulation provided (Aalto et al., 2013). Defoliation has a very complex effect on the circulation, the retention capacity, and the availability of soil water (Greenwood & McKenzie, 2001; Odriozola et al., 2014). As concluded by (Odriozola et al., 2014), the response of the water content to grazing is linked to the environmental factors and soil properties. Changes in soil temperature and soil water content alter soil processes in grazed sites (Butenschoen et al., 2011; Poll et al., 2013; Schrama, Veen, et al., 2013). Overall, based on the literature reviewed, we conclude that soil physical characteristics are affected by grazing intensity. A summary of some literature reports on the changes in soil physical condition in response to grazing intensity is found in Table 3.

While the effect of grazing on soil physical attributes has been established, the question remains whether grasslands have the capacity to regenerate soil physical properties after a period of deterioration. Natural regenerative processes such as wetting and drying cycles, allow soil to recover its structure and are supported by the concentration of soil organic matter (SOM) which contributes to soil structural stability. Grassland plant root growth, architecture, and decomposition patterns enable soils to sustain favourable physical properties following trampling and poaching, including those which

TABLE 3 Selected studies evaluating soil physical parameters with respect to potential changes by grazing

Soil physical property	Location	Soil type/Classification	Treatments	Outcomes	References
Bulk density	North of Kamloops, Canada	Loam/Brown and Dark Brown Chernozem	Bunchgrass with no grazing versus moderate stocking rate (0.6 cattle unit months/ha) in spring and fall	Greater for grazed than ungrazed sites	Evans et al. (2012)
	Georgia, USA	Acrisol	Bermudagrass with (a) no grazing, (b) low grazing targeted to maintain 3.0 Mg/ha of forage, (c) high grazing targeted to maintain 1.5 Mg/ha of forage	Greater in high than low stocking rate	Franzluebbers and Stuedemann (2010)
	Inner Mongolia, China	Calcic Chernozem	Semiarid steppe ecosystem (Stipa grandis, Leymus chinensis) with (a) no grazing, (b) 0.5 sheep unit ha^{-1} $year^{-1}$, (c) 1.2 sheep unit ha^{-1} $year^{-1}$	Greater in high than low stocking rate	Steffens et al. (2008)
	Hamilton Pastoral Research Station, Victoria, Australia	Silty loam	No grazing versus different stocking rates 10, 15, 19, and 22 sheep/ha	Increased as stocking rate increased	Willatt and Pullar (1984)
	Southwestern Alberta, Canada	Clay loam/Orthic Black Chernozem	Rough fescue with no grazing versus different stocking rates 1.2, 2.4, and 4.8 cattle unit months/ha	Increased as stocking rate increased	Zhang et al. (2019)
Soil aggregate stability	Eastern Galilee area, Israel	Brown Basaltic Protogromosol	Hemicryptophytic grasslands with grazing pattern at different special distance from concentration points with (a) moderate stocking rate 0.55 cows/ha, (b) high stocking rate 1.1 cows/ha	Decreased by an increase in stocking rate	Paz-Kagan et al. (2016)
	Quetta city, Pakistan	Silty loam	Rangeland (Seriphidium quettens, Astragalus spinosus, Chrysopogn auocnherai and Ceymbopogon jaownarancusa) with grazing versus no grazing	Lower in grazed than ungrazed sites	Qasim et al. (2017)
	Southwestern Alberta, Canada	Clay loam/Orthic Black Chernozem	Rough fescue with no grazing versus different stocking rates 1.2, 2.4, and 4.8 cattle unit months/ha	Not affected by grazing intensity	Zhang et al. (2019)
Total porosity	Southwestern Alberta, Canada	Clay loam/Orthic Black Chernozem	Rough fescue with no grazing versus different stocking rates 1.2, 2.4, and 4.8 cattle unit months/ha	Decreased as stocking rate increased	Zhang et al. (2019)
Penetration resistance	Southwestern Alberta, Canada	Clay loam/Orthic Black Chernozem	Rough fescue with no grazing versus different stocking rates 1.2, 2.4, and 4.8 cattle unit months/ha	Increased in depth 0–10 cm at 2.4, and 4.8 stocking rates; increased in depth 10–20 cm at 4.8 stocking rate	Zhang et al. (2019)
	Eastern Galilee area, Israel	Brown Basaltic Protogromosol	Hemicryptophytic grasslands with grazing pattern at different special distance from concentration points with (a) moderate stocking rate 0.55 cows/ha, (b) high stocking rate 1.1 cows/ha	Greater in grazed than ungrazed sites	Paz-Kagan et al. (2016)
Air capacity	Southwestern Alberta, Canada	Clay loam/Orthic Black Chernozem	Rough fescue with no grazing versus different stocking rates 1.2, 2.4, and 4.8 cattle unit months/ha	Lower at 2.4 and 4.8 stocking rates than no grazing and 1.2 stocking rate	Zhang et al. (2019)

(Continues)

TABLE 3 (Continued)

Soil physical property	Location	Soil type/Classification	Treatments	Outcomes	References
Hydraulic conductivity	Hamilton Pastoral Research Station, Victoria, Australia	Silty loam	No grazing versus different stocking rates 10, 15, 19, and 22 sheep/ha	Reduced by an increase in stocking rate	Willatt and Pullar (1984)
	Southwestern Alberta, Canada	Clay loam/Orthic Black Chernozem	Rough fescue with no grazing versus different stocking rates 1.2, 2.4, and 4.8 cattle unit months/ha	Decreased as stocking rate increased	Zhang et al. (2019)
Soil moisture	Basque Country, Spain	Different soil types	Shrublands and grasslands with no grazing versus continuous grazing from May to October or November	Greater for ungrazed than grazed in high amounts of solar radiation	Odriozola et al. (2014)
	Quetta city, Pakistan	Silty loam	Rangeland (Seriphidium quettens, Astragalus spinosus, Chrysopogn auocnherai, and Ceymbopogon jaownarancusa) with grazing versus no grazing	Greater for ungrazed than grazed sites	Qasim et al. (2017)
	Eastern Galilee area, Israel	Brown Basaltic Protogromosol	Hemicryptophytic grasslands with grazing pattern at different special distance from concentration points with (a) moderate stocking rate 0.55 cows/ha, (b) high stocking rate 1.1 cows/ha	Not affected by grazing intensity	Paz-Kagan et al. (2016)
Soil temperature	Basque Country, Spain	Different soil types	Shrublands and grasslands with no grazing versus continuous grazing from May to October or November	Greater for grazed than ungrazed sites	Odriozola et al. (2014)

are very favourable for microflora activity and restoration of plant cover. Dense root systems give grassland agroecosystems a high degree of resilience and promote the development of stable soil structure by minimizing the negative effects of trampling. However, if soil structure is diminished beyond a critical threshold, the capacity for resilience of the soil under grasslands can be exceeded.

Quite a lot of information on critical limits or threshold values of soil physical properties seems to have related to or been done in crops. There seems to be less research in pastures; however, there may be some agreement on critical limits for some properties but certainly not for all. Bulk density as a measurement of soil compaction, can give an indication of the level of compaction, or conversely porosity. Total porosity <0.40 m^3/m^3 would be considered dangerously low to maintain a good balance of air and water in soil. This would correspond to bulk density of >1.7 Mg/m^3. Often, this bulk density level is considered too dense to allow sufficient movement of roots through the soil matrix (Dorner et al., 2010; Houlbrooke et al., 1997). When soil is compacted by animal treading, the volume and functional effectiveness of macro pores are reduced and consequently reduced air and water permeability of soil. Therefore, as underlined by (Drewry et al., 2017), macroporosity value could be a very good and sensitive indicator of soil physical condition. Macroporosity value of <10%, for example, is considered compact and result in a reduction of pasture yield. Although optimum macroporosity values for maximum pasture yield could be vary and are somewhat specific to soil type due to factors including texture, organic carbon, and mineralogy (Drewry et al., 2017). Hence, values for one type of soil may not be terribly applicable to another. Soil penetration resistance with a cone penetrometer is also used to indicate the degree of soil compaction, but it is closely tied with the water content of the soil. Dry soil is simply more resistant to penetration than is wet soil (Singh et al., 2014). For grazing impacts on soil structure and/or physical condition, it would be suggested a combination of bulk density, soil organic C concentration, and aggregate distribution as a function of depth, meaning that multiple depth increments would be ideal to characterize the impacts. Soil organic C and soil biological activity are key factors that transform soil physical properties over time, so they can be as key indicators to measure.

3.2 | Soil biochemical responses to grazing

Vegetation, soil biota, fauna, and microbes are hosted by grasslands and have a significant role in controlling biochemical cycles. They allow grassland ecosystems to adapt and respond to the effects of global environmental change and soil disturbance (Soussana & Duru, 2007). Herbivore effects on grasslands occur through faeces–urine deposition, trampling, and defoliation, which in turn can affect nutrient cycling, microbial activity, and primary production (Bardgett & Wardle, 2003). The effect of grazing management on soil biochemical properties in agricultural and grassland soils has been assessed by different field studies; however, comprehensive studies are few (Schrama, Veen, et al., 2013). Therefore, an integrated approach

TABLE 4 Selected studies describing grazing-induced changes in soil chemical composition of grasslands

Soil properties	Location	Soil type/ Classification	Treatment	Outcomes	References
SOC (%)	Georgia, USA	Acrisol	Bermudagrass with (a) no grazing, (b) low stocking rate, (c) high stocking rate	Greater for grazed than ungrazed; greater for low than high stocking rate	Franzluebbers and Stuedemann (2009)
	Texas, USA	Darco fine sandy loam	Bermudagrass with ryegrass and clover with (a) low stocking rate, (b) high stocking rate	Greater increase in low than high stocking rate	Wright et al. (2004)
	Eastern Galilee area, Israel	Brown Basaltic Protogromosol	Hemicryptophytic grasslands with grazing pattern at different special distance from concentration points with (a) moderate stocking rate, (b) high stocking rate	Greater in soils near the concentration points with moderate stocking rate	Paz-Kagan et al. (2016)
Total N (mg/g)	Hongyuan County, China	Alpine meadow soil	Alpine meadow with (a) no grazing, (b) light grazing, (c) moderate grazing (d) heavy grazing	Greater for grazed than ungrazed; higher in greater grazing intensity	Yang et al. (2018)
	Eastern Galilee area, Israel	Brown Basaltic Protogromosol	Hemicryptophytic grasslands with grazing pattern at different special distance from concentration points with (a) moderate stocking rate, (b) high stocking rate	Greater in soils near the concentration points with high stocking rate	Paz-Kagan et al. (2016)
Water soluble ion concentration (AP, Na^+, K^+, Mg^{2+}, Ca^{2+}, SO_4^{2-})	Southwestern Alberta, Canada	Clay loam/ Orthic Black Chernozem	Rough fescue with (a) no grazing, (b) light grazing, (c) heavy grazing (d) very heavy grazing	Higher in greater grazing intensity	Zhang et al. (2019)
Total P (mg/g)	Hongyuan County, China	Alpine meadow soil	Alpine meadow with (a) no grazing, (b) light grazing, (c) moderate grazing (d) heavy grazing	Greater for grazed than ungrazed; higher in greater grazing intensity	Yang et al. (2018)
EC (μs/cm)	Eastern Galilee area, Israel	Brown Basaltic Protogromosol	Hemicryptophytic grasslands with grazing pattern at different special distance from concentration points with (a) moderate stocking rate, (b) high stocking rate	Greater elevated salt concentrations in soils near the concentration points with high stocking rate	Paz-Kagan et al. (2016)
pH	Southwestern Alberta, Canada	Clay loam/ Orthic Black Chernozem	Rough fescue with (a) no grazing, (b) light grazing, (c) heavy grazing (d) very heavy grazing	Higher in greater grazing intensity	Zhang et al. (2019)

Abbreviations: AP, available phosphorus; Ca^{2+}, Calcium; EC, electric conductivity; K^+, Potassium; Mg^{2+}, Magnesium; Na^+, Sodium; SO_4^{2-}, Sulphate.

is needed to have a better insight on the effects of grazing on soil processes. A number of previous studies on grassland soil chemical properties are summarized in Table 4.

Livestock excreta deposition is a main mechanism in returning most chemical elements to the soil, thereby ecosystem nutrients cycling is accelerated (Zhang et al., 2019). The amount and composition of livestock defecation is a function of stocking rate, size, and digestive characteristics of herbivore species present (Hirata et al., 2009). The heterogeneity of excreta deposition often leads to redistribution of soil nutrients across the grassland (Dubeux et al., 2007; Mathews et al., 1994), with concentrations typically increasing in high traffic areas around shade, water, and supplemental feeding stations (Dubeux & Sollenberger, 2020).

Defoliation intensity (which proportion of leaf areas are removed), and frequency of defoliation (interval between two successive defoliations) affect soil nutrient concentrations through the combined effect of animal trampling, reduced organic matter input and root growth (Stumpp et al., 2005; Turner, 1998; West et al., 1989). By animal trampling, the size of the litter particles is reduced and a better contact between litter and soil is established, which facilitates the decomposition of the litter and promotes the input of nutrients into the soil. Meanwhile, soil pH increased with grazing intensity through decrease in the depth of Ah horizon under animal trampling and causing carbonates being closer to the surface. Thus, soil pH increases most water-extractable chemical constituents (e.g., Na^+, K^+) in the soil (Zhang et al., 2019). Vegetation cover reduction in result of intensive defoliation regime imposes an increase in evaporation rate and the upward movement of water and soluble salts from salinized horizons to the top soil. Consequently, salts accumulate in top soils and lead to a decrease in vegetation growth (Taboada et al., 2011). However, in low and moderate grazed sites, due to more ground cover, this problem can be controlled (Taboada et al., 2011). These grazing-induced changes on the vegetation cover and soil properties may prompt considerable changes in SOM storage. As demonstrated by (Derner & Schuman, 2007; Eze et al., 2018; George et al., 2013), SOM input in grasslands is affected by different factors including climate conditions, grazing regimes, and soil properties. The increase of SOM input in long-term low grazed sites has considerable potential to improve soil fertility and nutrient retention and increase soil biological activity (Wright et al., 2004). As SOM performs as a buffer by supplying and storing nutrients at low and high nutrient availability respectively, and helps to synchronize availability of soluble nutrients to plant requirements. So by this buffer mechanism, SOM can be accumulated in grassland ecosystem for a long time (Soussana & Lemaire, 2014). In contrast, in intensive defoliation regimes, removal of more leaves and the reduction of plant cover reduce SOM content, total N, total Sulphur (S), and uptake of C in photosynthesis (Lu et al., 2017; Paz-Ferreiro et al., 2010; Steffens et al., 2008). Soil C cycle is linked to photosynthesis, respiration and soil organic matter decomposition (Soussana & Lemaire, 2014). In grassland, soil–vegetation interactions create a strong coupling among main nutrient cycles such as C and N. It is likely that in extensive pastures, the C and N cycles are locally coupled, but in intensive grassland management, these cycles become progressively uncoupled (Soussana & Lemaire, 2014). For instance, soil organic carbon (SOC) content decreased from 130 Mg C/ha under 0.10 ewe ha^{-1} $year^{-1}$ stocking rate to 50 Mg C/ha at 0.70 ewe ha^{-1} $year^{-1}$stocking rate due to a decline in plant cover and loss of SOM (Peri, 2011). Increasing soil C and N losses in heavy grazed-sites could be attributed to the alteration in the soil microbial community structure by promoting lower fungal to bacterial ratios (Yong-Zhong et al., 2005; Zhang, Li, et al., 2018). Therefore, by improving grazing managements with low or moderate stocking rates, C sequestration could be increased. Herbivores can alter the rate of N mineralization and the quality of litter due to the changes in soil biochemical conditions through faeces–urine deposition (Bardgett & Wardle, 2003; Hamza & Anderson, 2005). For instance, grazers can speed up the rate of N mineralization and improve the litter quality through the deposition of dung and urine by promoting fast growing species with a low C/N ratio. In contrast, the N mineralization rate could be slowed down by decreasing litter quality due to growth of low-quality plant species with a high C/N ratio (Ritchie et al., 1998). Therefore, it can be concluded that management improvements that increase SOM input might have a strong influence on soil nutrient cycles.

4 | HOW DOES MOWING AFFECT GRASSLAND SOIL RESPONSES?

The emphasis is to review the response of soil property values under cutting managements which may have effects on plant growth conditions. Machine mowing as a widely-used grassland management strategy across the world, mimics grazing and thus has significant consequences on the ecosystem (Hou et al., 2017). Mowing is a uniform activity and removes plant biomass evenly at once and creates a spatially homogeneous species composition (Lepš, 2014). Mowing by removing litter and harvested biomass and providing suitable sites to establish the small seeded species can increase the rate of seedling germination (Socher et al., 2012), facilitates plant species richness, and plant productivity. Finding a reasonable balance between conservation activities and mowing frequencies is crucial to mitigate the impact of cutting activities on soil quality indicators in meadows. Besides, considering the specific site conditions plays a significant role in determining a suitable mowing intensity. Applied either lower or higher mowing frequencies have both positive and negative effects. At less mowing frequencies, the amount of litter is higher than high mowing frequencies, although seedling germination and establishment might be hindered. More frequent mowing might limit the seed-setting of species and cause a serious threat for plant species survival (Loydi et al., 2013). Within this context, investigating the effect of mowing has emerged as an important topic of scientific inquiry.

TABLE 5 Selected studies describing the effect of mowing frequency on some soil physical properties

Soil properties	Location	Soil type/ classification	Treatments	Outcomes	References
Soil temperature	Schorfheide-Chorin, Hainich, Schwäbische Alb, Germany	A wide range of soil types	0–4 cuts/year	Increased as number of cutting increased	Simons et al. (2017)
Soil moisture	Ningxia Hui Autonomous Region, China	Haplic Calcisol	Perennial rhizome grasses, perennial bunch grasses, perennial forbs, shrubs and semi-shrubs, annuals, biennials with 1 cut/year	Decrease	Chai et al. (2019)
	Inner Mongolia, China	Haplic Calcisol	Perennial species with (a) no mowing, (b) light mowing (7 cm stubble), (c) heavy mowing (2 cm stubble)	Greater decrease in heavy than light or no mowing	Qu et al. (2018)
Soil compaction	Netherlands	Sandy soil	2 cuts/year versus hand mowing	Increase	Schrama, Cordlandwehr, et al. (2013)
Soil porosity	Netherlands	Sandy soil	2 cuts/year versus hand mowing	Decrease	Schrama, Cordlandwehr, et al. (2013)
	Northern China	Sandy loam	Steppe plant community (Stipa krylovii, Leymus chinensis and Artemisia frigida) with mowing versus no mowing	No effect	Wang et al. (2020)
	Kiel, Germany	Stagnic Luvisol	Different plant species (Lolium perenne, Festuca pratensis, Dactylis glomerata, Poa pratensis, Phleum pratense, Trifolium repens and Medicago sativa) with 3 cuts/year versus 5 cuts/year	Higher amounts of large macroaggregates under the 5 cutting/year than 3 cutting/year	Nüsse et al. (2018)
Soil bulk density	South of Maribor, Slovenia	Dystric Cambisol	Permanent and wet grassland with (a) 12–14 cuts/year, (b) 6 cuts/year, (c) 4 cuts/year, (d) 3 cuts/year, (e) 2 cuts/year, (f) 2 cuts/year, with 2, 4, 6, 8, 10 ,12 weekly intervals respectively	Increased as number of cut increased (0–10 cm soil depth); no effect (10–20cm soil depth); the lowest value in 2 cuttings/year with 12-weekly intervals	Kramberger et al. (2015)
	Georgia, USA	Acrisol	Bermudagrass with mowing versus no mowing	Increase	Franzluebbers and Stuedemann (2010)

4.1 | Soil physical properties

Soil physical properties (e.g., soil porosity, bulk density, water retention capacity) are indices to reflect soil structure condition under different management practices. Changes in mowing regime therefore lead to changes in the soil physical attributes due to the deterioration of soil structure and decrease in SOM content. Selected studies assessing the effect of mowing on soil physical properties are summarized in Table 5.

In general, grassland vegetation has desirable effects on soil structure and porosity through the granulation effect of root systems, protective impacts of vegetation cover, and production of organic substances, resulting in grassland soils with high SOM content, stability of soil aggregates, porosity, and low bulk density (Pavlů et al., 2016). Mowing managements by removal of above-ground biomass causes a reduction in litter cover and an increase in bare ground. It is therefore expected that soils under mowing would be particularly sensitive to daily temperature fluctuation and would be exposed to freezing and thawing, leading to earlier ground frost and deeper freezing in autumn (Pavlů et al., 2013). In warm-season, when the above-ground biomass is removed, the soil absorbs more light, which increases soil temperature and soil evaporation and significantly reduces soil moisture (Chai et al., 2019; Simons et al., 2017). Soil available water is exhausted especially in the intensive-mowed soils through high evaporation rate in comparison to un-mowed soils. Higher soil water losses could lead to a reduction in the resistance of ecosystem to heat and drought (Qu et al., 2018).

More machinery traffic in result of intensive use of grasslands due to the high demand for high quality fodders productivity, causes soil compaction (Schrama, Cordlandwehr, et al., 2013). Soil compaction is considered a problem in meadows and changes soil properties through two sets of factors: (a) machinery factors including wheel pressure, mowing time, and frequency (Horn et al., 2003) (b) stability of soil structure such as soil aggregation (Horn & Rostek, 2000). It is easy to understand that a higher weight of mowing machines increases soil compaction due to exerting pressure onto soils by tractor wheels (30 to 150 kPa; Proffitt et al., 1993; Schrama, Cordlandwehr, et al., 2013). Machine mowing creates wheel tracks which may cause surface runoff to flow downslope and create ponds in low lands which are vulnerable to more compaction (Batey, 2009). A wide variation in the degree of compaction may observe in different soil texture, soil structure and soil moisture status. In this context, organic soils with a fine pore structure are more vulnerable to compaction under mowing in comparison with sandy soils (Schrama, Cordlandwehr, et al., 2013). Soil compaction increases soil bulk density, and pre-compression stress, decreases soil air capacity, the percentage soil porosity, air conductivity, soil water content, root distribution, and hydraulic conductivity (Batey, 2009; Krebstein et al., 2013, 2014; Schrama, Cordlandwehr, et al., 2013). Moreover a high range of soil pores in compacted soils would fill with water thus the potential of soil redox and the oxygen diffusion in soil pore space would be decreased (Schrama, Cordlandwehr, et al., 2013). Considering the specific site conditions and type of vegetation are also important when determining the effect of mowing on soil physical attributes. In summary, our study indicated that mowing can be integrated into a grassland system without deteriorating soil physical properties, especially if meadows are managed with conservation aim and have a higher chance to recover after mechanical disturbances.

4.2 | Soil biochemical properties

Mowing with harvesting plant biomass reduces the amount of plant residue returning into soil and thereby have effects on SOM pools which has a critical role for nutrient biogeochemical cycles (Li et al., 2017). On the other hand, mowing can increase the rate of plant residue decomposition in result of adding fresh plant residue to the soil surface and convert them into SOM; consequently, maintain biomass productivity in grasslands in high level in comparison with un-mowed sites (Maron & Jefferies, 2001; Shimoda, 2017). Long period harvesting plant biomass without fertilizer application leads to nutrient depletion from the soil (Oelmann et al., 2009). Therefore, the composition of ecosystem (Isbell et al., 2013), biomass production (Oelmann et al., 2009) and nutrient cycles would be progressively affected by different mowing regimes (Giese et al., 2013). Previous studies reported that the impact of mowing on soil nutrient availability; however, their results are not straightforward, so it is important to know when and why these different responses have been reported. A summary of the effect of mowing on some soil nutrient availability is shown in Table 6.

Nutrient content in soils and plant uptake might be increased after mowing. Mowing increases soil carbon and nitrogen stocks in meadows not only by facilitating plant species richness and plant productivity but also by more input of organic C and N derived from root biomass, root exudates, and photosynthetic products (Cong et al., 2014; Foster & Gross, 1998; Socher et al., 2012). In this context, moderate mowing managements could be beneficial for more microbes to degrade the labile SOC to provide N for plant growth, and then SOC input would be increased (Li et al., 2017). By increasing mowing frequency to provide sufficient feed for increased livestock, plant species diversity is limited and also soil C and N turnover is reduced due to fewer soil microorganisms in the degraded soil (Li et al., 2017). Mowing can decrease soil C sequestration as a result of decreasing returned plant residues into the soil which in turn leads to a decrease of SOC content, biochemical activity and photosynthetic C allocation to belowground pools (Wei, Liu, et al., 2016). On the other hand, as reported by (Ziter & Macdougall, 2013), mowing increases soil C sequestration through increasing the production of short-lived lignin rich roots.

Comprehensive assessments of nutrient availability are relatively rare. As suggested by (Pavlů et al., 2013) to investigate the effects of mowing on the total N, P, Ca and Mg in the soil, multi-year studies are required. For example, long-term above-ground biomass removal accelerates the depletion of soil P content; however, performing a

TABLE 6 Selected studies describing effects of long-term mowing on some soil nutrient availability

Nutrient Availability	Location	Soil type/ Classification	Treatments	Responses to mowing frequencies	References
Total C (%)	Vancouver, Canada	Clay-silt-loam Glaceomarine	C_3 grasses (Alopecurus pratensis, Poa pratensis, Festuca rubra) and broad-leaved N2-fixer (Vicia spp., Trifolium spp.) with 1 cut/year versus no mowing	Greater in mowed sites by adding fresh plant residue	Ziter and Macdougall (2013)
	Kiel, Germany	Stagnic Luvisol/ Sandy loam to Loamy sand	Different plant species (Lolium perenne, Festuca pratensis, Dactylis glomerata, Poa pratensis, Phleum pratense, Trifolium repens and Medicago sativa) with 3 cuts/year versus 5 cuts/year	Greater in 5 cut/year due to promoting leaf growth	Nüsse et al. (2018)
	Inner Mongolia, China	Calcic-Orthic Aridisol	Different plant species (L. chinensis and S. krylovii) with (a) no mowing, (b) six stubble heights stubble 14 cm, 12 cm, 10 cm, 8 cm, 6 cm, and 0.3 cm	No effect across the stubble height treatments.	Yang et al. (2020)
N stock (%)	Czech Republic	Cambisol	Different species of grasses, legumes and forbs with 1 cut/ year versus no mowing	No effect of treatments	Pavlů et al. (2013)
	Kiel, Germany	Stagnic Luvisol	Different plant species (Lolium perenne, Festuca pratensis, Dactylis glomerata, Poa pratensis, Phleum pratense, Trifolium repens and Medicago sativa) with 3 cuts/year versus 5 cuts/year	Greater under 5 cut regime	Nüsse et al. (2018)
	Inner Mongolia, China	Calcic-Orthic Aridisol	Different plant species (L. chinensis and S. krylovii) with (a) no mowing, (b) six stubble heights stubble 14 cm, 12 cm, 10 cm, 8 cm, 6 cm, and 0.3 cm	No effect across the stubble height treatments.	Yang et al. (2020)
P (mg/kg)	Czech Republic	Cambisol	Different species of grasses, legumes and forbs with 1 cut/ year versus no mowing	No effect of treatments	Pavlů et al. (2013)
	Inner Mongolia, China	Calcic-Orthic Aridisol	Different plant species (L. chinensis and S. krylovii) with (a) no mowing, (b) six stubble heights stubble 14 cm, 12 cm, 10 cm, 8 cm, 6 cm, and 0.3 cm	No effect across the stubble height treatments	Yang et al. (2020)
Na (mg/kg)	Inner Mongolia, China	Haplic Calcisol	Temperate steppe with plant species Leymus chinensis and Stipa grandis with 1 cut/year versus no mowing	Greater in mowed sites due to uplifting to the top soil for plant uptake	Wang et al. (2018)
Ca (mg/kg)	Czech Republic	Cambisol	Different species of grasses, legumes and forbs with 1 cut/ year versus no mowing	No effect of treatments	Pavlů et al. (2013)
	Inner Mongolia, China	Haplic Calcisol	Temperate steppe with plant species Leymus chinensis and Stipa grandis with 1 cut/year versus no mowing	Greater in mowed sites due to uplifting to the top soil for plant uptake	Wang et al. (2018)
Mg (mg/kg)	Inner Mongolia, China	Haplic Calcisol	Different plant species (Leymus chinensis and Stipa grandis) with 1 cut/year versus no mowing	No effect of treatments	Wang et al. (2018)
	Czech Republic	Cambisol	Different species of grasses, legumes, and forbs with 1 cut/ year versus no mowing	No effect of treatments	Pavlů et al. (2013)

(Continues)

TABLE 6 (Continued)

Nutrient Availability	Location	Soil type/ Classification	Treatments	Responses to mowing frequencies	References
K (mg/kg)	Czech Republic	Cambisol	Different species of grasses, legumes and forbs with 1 cut/year versus no mowing	Decreased in mowed sites due to nutrient depletion by herbage removal	Pavlů et al. (2013)
	Inner Mongolia, China	Haplic Calcisol	Different plant species (Leymus chinensis and Stipa grandis) with 1 cut/year versus no mowing	No effect of treatments	Wang et al. (2018)
Fe and Cu (mg/kg)	Inner Mongolia, China	Calcisorthic Aridisol	Different plant species (Stipa krylovii, Agropyron cristatum, Artemisia frigida) with 1 cut/year versus no mowing	Greater in mowed sites due to returning plant residue to the soil	Cai et al. (2017)
	Inner Mongolia, China	Haplic Calcisol	Different plant species (Leymus chinensis and Stipa grandis) with 1 cut/year versus no mowing	Greater in mowed sites due to returning plant residue to the soil	Wang et al. (2018)
Mn and Zn (mg/kg)	Inner Mongolia, China	Calcisorthic Aridisol	Different plant species (Stipa krylovii, Agropyron cristatum, Artemisia frigida) with 1 cut/year versus no mowing	Decreased due to antagonistic relationships	Cai et al. (2017)
	Inner Mongolia, China	Haplic Calcisol	Different plant species (Leymus chinensis and Stipa grandis) with 1 cut/year versus no mowing	Decreased due to antagonistic relationships	Wang et al. (2018)

few years of mowing does not affect soil P (Pavlů et al., 2013).There are several other examples where mowing is performed for a long period and affected soil chemical conditions. Availability of Ca and Na in the soil surface might be increased via uplifting Ca and Na from the subsoil due to more plant uptake for the leaf regrowth after cutting (Han et al., 2014; Ziter & Macdougall, 2013). Root mortality, in response to mowing, also causes more Ca and Na to return back to the soil (Liu & Huang, 2002; Wang et al., 2018). However, Mg and K availability may not be similar to the Ca and Na (Wang et al., 2018), which can refer to selective weathering of these elements across the soil profile (Ca > Na > Mg > K; Lu et al., 2014). As underlined by (Wang et al., 2018), mowing could increase available Fe and Cu but decrease available Mn and Zn concentration in soil, but it is unclear why mowing increased soil available Fe and Cu. The different behaviour of soil Fe and Cu with Mn and Zn concentrations could be due to their antagonistic relationships (Fe vs. Mn and Cu vs. Zn) during plant uptake (Cai et al., 2017). It could be expected that after mowing, Mn and Zn soil availability decreases which is related to the removal of plant residue, and Fe and Cu soil availability increases which might be due more root uptake from deeper soil layers and upward movement of these elements to the soil surface for reproduction (Wang et al., 2018). All of these responses may affected soil quality. It is important to note the optimal mowing frequency for maximum forage production without deterioration of the biochemical cycles in the soil. This review suggests that when mowing is performed over a long period, the depletion of soil nutrients would have to be compensated by the application of fertilizer. The authors conclude a single mowing event with a long recovery interval will only have a marginal effect while frequent repeated mowing, even if less severe, will have more important effects. Therefore, this implies that an intermediate level of mowing intensity and frequency is favourable.

5 | EFFECT OF FERTILIZATION ON SOIL PROPERTIES

Liming and fertilizer application are common management activities for improving or maintaining grassland productivity which are intensively used after modernizing agricultural practices during the second half of the 20th century (Eze et al., 2018; Tälle et al., 2016). Liming practice is confined to acidic soils to improve crop growth and yields by altering nutrient levels and acid status through increasing the soil pH, which lead to an increased litter production as well as more root exudates (Eze et al., 2018). The positive effects of liming usually occur through soil aggregation stability improvement due to the role of calcium (Ca^{2+}), which makes a cationic bridge between organic and inorganic substances (Keiblinger et al., 2016; Six et al., 2004), and an increase in smaller aggregate fractions mass; however, large aggregate mass might be decreased (Egan et al., 2018). Besides, liming can ameliorate Al and Mn toxicity and alleviate Ca deficiency resulting in an improvement in plant shoot and root growth which in

turn increase the returns of C to the soil in the form of dying roots and decaying crop residues. Therefore, they will result in an increase in soil organic matter content, consequently, improve soil structure (Haynes & Naidu, 1998). As expected, at high rate of liming reduces soil acidity-related limitations (Tian et al., 2017), and consequently cause an increase in microbial respiration, organic material decomposition and dissolved organic C level in soil solution. (Mijangos et al., 2010).

Fertilizer application can maintain the amount of nutrient availability on an optimal level and affect the forage production and supply high quality herbage for cattle which can play a key role in the human food chain (Reijneveld et al., 2014). Recently, some efforts have focused on efficient use of fertilizers to promote soil quality along with minimum environmental damages (Cui & Holden, 2015; Ussiri & Lal, 2013). Applying fertilizers can compensate the depletion of nutrients from the soil and maintain the sustainability of grassland production especially when cutting with herbage removal is performed over a long period without fertilizer application (Pavlů et al., 2011). It is reasonable to mention that adequate available nutrients can help plants to be recovered rapidly under treading by animal hooves and/or machinery load (Grant et al., 2014). The main effect of fertilizer application is to improve plant growth, thereby greater increases of organic matter returns which lead to higher SOM content (Wang et al., 2020). Especially long-term manure application improve soil physical properties in result of an increase in SOM content. SOM plays a major role in the formation of stable aggregates by mixing with soil fractions, and also in binding soil aggregates together. Thereby leads to a reduction in bulk density and surface crusting and an increase in soil water holding capacity, porosity, infiltration capacity, hydraulic conductivity, and aggregation (Haynes & Naidu, 1998). Widely applied fertilizers can significantly affect nutrient cycling through modifying the chemical composition of the soil solution, its ionic strength, pH, thereby greatly influence dispersion or flocculation of soil particles and thus soil aggregation stability (Bronick & Lal, 2005). In this context, soil C and N cycles are closely associated with the stability and structure of soil aggregates and affected by N addition (Wei, Ma, et al., 2016). A brief summary of selected results from some previous literatures about impact of fertilization on soil properties are shown in Table 7. It can be concluded that contradictory results regarding the effect of fertilization on soil properties may be due to varying levels of forage yield, plant litter quality and soil aggregation in both hay production and grazing systems. For instance, soil C content were positive in most studies, including those using organic and inorganic fertilizers, while other studies showed that fertilizer addition has no effect on soil C. Possible reasons for increasing soil C with applying fertilizer include stimulating plant growth and changing the quality of plant litter, developing greater root systems, and in some cases, soil microbial biomass (Yang et al., 2018; Ziter & Macdougall, 2013).

Although good fertilization recommendation may lead to an improvement of the grasslands function, fodder quality, and soil quality, it is important to note applying large quantities of fertilizer can impose some detrimental effects on soil attributes, e.g., surface crusting, increased detachment by raindrops and decreased hydraulic conductivity (Haynes & Naidu, 1998). For instance, by applying large quantities of organic manures, on the one hand, content of monovalent cations (Na^+ and K^+) would be increased which resulted in soil structural breakdown. The concentration of NH_4^+ would be increased through mineralization of organic waste N. Indeed, when high rates of organic manures is applied, these cations may become the dominant exchangeable cations and disperse soil colloids, and then the salinity level of soil can also increase (Haynes & Naidu, 1998).

Another problem sometimes noted regarding high rates of fertilizer application is an increase in the nutrient leaching from the sites. However, if nutrients are not exported with harvested herbage in abandoned grasslands, soil nutrient availability may increase through nutrient input from atmospheric deposition, mineralization of SOM, or by weathering of soil minerals (Köhler et al., 2001). Preferential flow is the transport of water and solutes via macropore-dominated pathways of soils, through which most of the soil solution is discharged, and consequently, may accelerate contaminant transport to groundwater and thus threatens water quality. In this context, as N fertilizer inputs increase, excess nitrate-N will tend to be leached either by rainfall or irrigation water. Thus the concentrations of nitrate-N in drainage water is increased which may contribute to pollution of groundwater. As reported by (Monaghan et al., 2005), total losses of nitrite- and urea-N lost in drainage is negligible and dominated by the nitrate form. Therefore, it is important to mitigate the negative impacts of N losses by considering the amount of presented N in fertilizer which is efficiently assimilated by grassland plant and also the amount of N which is washed out from grassland soil. Thus, it would seem prudent to minimize these losses by targeting total N inputs to the pasture system or reducing animal excreta-N losses, rather than focusing on adjustments to fertilizer timing, form or pattern of splitting annual applications.

6 | GRASSLAND MANAGEMENT EFFECTS ON VEGETATION

6.1 | Plant richness and the vegetation parameters

Plant communities are the main elements of grassland ecosystems and reflect the ecological conditions of the habitat and thus can consider as an important bioindicator. Grassland resilience to disturbance may be enhanced by greater plant diversity through the presence of certain highly productive species, species with particular rooting characteristics, or legumes. Long-term changes of the chemical and physical properties of soil which are induced by various managements such as grazing, hay making, and fertilization influence the condition of plants growth and development (Ignatavičius et al., 2013). Various results are reported about the effect of species

richness on soil quality. In this context, the presence of particular functional groups, legumes, can be crucial for enhancing C and N storage in grasslands. Legumes may also increase SOM concentration by inhibiting SOM decomposition through formation of decay-resistant polymers (Sollenberger et al., 2019).

Grazing due to selective defoliation, treading, and nutrient cycling affects botanical diversity. Stocking rate and the duration between the grazing periods are two main influential factors on plant richness. Grazing at low stocking rates maintain plant biodiversity and provides conditions for grasses to grow sufficiently and inhibit the abundant of woody plants; however, intensive grazing produces short dense swards with low amount of seeds (Ignatavičius et al., 2013). Long-term extensive grazing can increase the number of plant types, maintain the natural fertility which improve the soil parameters. Animal trampling have positive effects on grasslands by creating gaps in the sward which can establish the annual and bi-annual species and allowing seeds to sprout then accelerates the growth of grasses (Ignatavičius et al., 2013). Generally, vegetation height, diversity and coverage will be reduced with continuous and high stocking rate (Gao et al., 2009; Milchunas et al., 1998; Wei et al., 2011; Wu et al., 2009), percent grasses in the mixture will increase as they are more resistant to grazing pressure, although with time more forbs will likely enter the stand, especially those that are unpalatable to livestock and then they start to proliferate. Number of flowers of different species is also depend on the grazing intensity and if they are allowed to express themselves with sufficient growth before being consumed by livestock. In well managed grazing systems with moderate stocking and sufficient rest periods, forage height will attain moderate height in temperate grasslands and a well-balanced mix of grasses, forbs, and legumes will be present. Flowers will be abundant during different parts of the year, depending on species present (Sanderson et al., 2005; Scimone et al., 2007; Tallowin et al., 2007).

In meadows, mowing frequency is considered as the factor to determine the grassland fertility and forage quality; which means that increasing the number of harvest, weakens the grasslands and decrease the soil fertility, besides spreading the grasses with the low value (Ignatavičius et al., 2013). Moreover the time of mowing has an impact on the maturation of seeds of different plant species. Mowing should be applied when grass seeds are matured and seeded out. Furthermore, after mowing, the competitiveness of plants for light declines and seeds are able to capture more light, therefore they can germinate easier (Endels et al., 2007). However, it should be noted that if mowing is performed later, the quality of forage declines (Lemaire & Belanger, 2020).

Previous literatures express that mineral and organic fertilizers may decrease the variety of grassland plants (Schellberg & Pontes, 2012) due to the different plant abilities for light capture. Light is one of the most important ecological factors for plant growth, so more rapidly growing plants have the advantage in the competitive fight for light (Pärtel et al., 2005). In fertile grasslands, the relative difference of growth increases and only those plant species that can capture light would be dominated which eliminate lesser competitive species and consequently the variety of the grassland vegetation would be decreased (Pykälä, 2007). Besides, grassland species composition can be changed through applying organic fertilizers due to the presence of non-digested plant seeds in manures which can be germinated and thereby enter the non-typical plants in the grasslands (Plantureux et al., 2005).

6.2 | Grassland yield responses to soil attribute changes

Given the effect of grazing, mowing and fertilizer on soil properties, the question is that how management-induced changes in soil quality can affect grassland yield. The management regime influences not only soil and plant nutrient properties, but also biomass production (Hejcman et al., 2010). Above- and below-ground productivity are influenced by soil disturbance under different management regimes. Previous researches have shown that damage of soil properties in arable land decreased crop yield. However, these studies in grassland are not as extensive as crop land (Hargreaves et al., 2019). Generally, management activities could have important consequences on grassland yield through providing pleasant conditions for fodder growth. However, recently, the more intensive and extended duration of management practices cause an increase in the potential of soil compaction due to animal trampling and vehicle traffic, which have a negative effect on the soil quality, for example, soil structure, soil water storage, air capacity, and then potentially decrease grassland yield (Drewry et al., 2008; Hargreaves et al., 2019). The increase in soil bulk density and water-filled pore space as a result of compaction has been shown to reduce root growth (Tracy et al., 2011), nutrient uptake from the soil (Arvidsson, 1999), and soil drainage. Increased soil moisture as a result of reduced drainage, made the microbial population more anaerobic with reduced efficiency of the turnover of nutrients available to the crop (Cui & Holden, 2015). Since soil compaction decreases physical fertility of the soil by reducing the storage and supply of water and nutrients, so it could lead to additional fertilizer requirements and higher production costs (Hamza & Anderson, 2005). Irrigation is also applied in some grasslands, either when water scarcity is an important constraint for forage growth (Tianming et al., 2012) or when land use is also intensified (Drewry et al., 2020). Experiments have shown that soil physical properties are important for efficient irrigation with affecting water storage, water availability to plants, water and air transmission, soil workability, drainage, and resilience of soil to change, all of which can consequently affect forage yield to have higher and more stable rates (Drewry et al., 2020).

In grassland ecosystems, vegetation properties such as biomass, height and coverage are considered as main factors for assessing changes imposed by management activities in grassland yield. From Table 8—which represents results from previous literatures about impact of grazing and mowing on forage yield—it can be concluded that

TABLE 7 Selected studies describing soil properties changes imposed by effect of fertilizer application

Location	Soil type/ classification	Treatment	Outcome	References
Soil C				
Switzerland	Cambisol	Grass–clover mixtures with intensive management (4–5 cuts/year) plus 230 kg N ha^{-1} $year^{-1}$ versus extensive management (3 cuts/year) without fertilization	Greater increases in intensive than extensive	Ammann et al. (2009)
Pennsylvania, USA	Silt loam	Perennial forage species with high fertilization (>200 kg N ha^{-1} $year^{-1}$) versus low fertilization (<100 kg N ha^{-1} $year^{-1}$)	No effect of treatments	Skinner (2013)
Study from 17 countries	A wide range of soil types	Grassland field studies with mineral and organic fertilization versus no fertilization	Greater increases in fertilized sites than unfertilized; no differences between mineral and organic fertilizers	Conant et al. (2001)
Kansas, USA	NA	Cheatgrass with 88 kg N/ha: (a) in one application, (b) in 15 weekly additions of 5.87 kg N/ha	No effect of treatments	Verburg et al. (2004)
Germany and Netherlands	Cambisol, Fluvisol, Shallow Cambisol, Loamy Cambisol, Luvisol	Seven different long-term grassland experiments with mineral fertilization versus no fertilization	Greater increases in fertilized than unfertilized sites	Poeplau et al. (2018)
Northern Ireland	Clay loam	Perennial ryegrass with mineral and organic (Cattle slurry) fertilization versus no fertilization	Greater increases in organic than unfertilized sites; no differences between mineral and unfertilized sites	Fornara et al. (2016)
Georgia, USA	Acrisol	Bermudagrass with nutrient sources: (a) mineral, (b) a mixture of organic and mineral, (c) organic	No differences among nutrient sources	Franzluebbers and Stuedemann (2010)
A global study	A wide range of soil types	Grassland field studies with nitrogen and phosphorus fertilization	Increasing effect of nitrogen fertilizer; No effect of phosphorus fertilizer	Eze et al. (2018)
Northern China	Sandy loam	Steppe plant community (Stipa krylovii, Leymus chinensis and Artemisia frigida) with nitrogen fertilization versus no fertilization	No effect of treatments	Wang et al. (2020)
		Total soil N		
Georgia, USA	Acrisol	Bermudagrass with nutrient sources: (a) mineral, (b) a mixture of organic and mineral, (c) organic	No differences among nutrient sources	Franzluebbers and Stuedemann (2010)
Kansas, USA	NA	Cheatgrass with 88 kg N/ha versus no fertilization	Increasing effect of nitrogen fertilizer	Verburg et al. (2004)
		Total soil P		
Kansas, USA	NA	Cheatgrass with 88 kg N/ha versus no fertilization	Increasing effect of nitrogen fertilizer	Verburg et al. (2004)
		Micronutrient availability		
Inner Mongolia, China	Haplic Calcisol	Different plant species (Leymus chinensis and Stipa grandis) with nitrogen fertilizer intensities (ranged 0 to 50 g N m^{-2} $year^{-1}$) with two frequencies (2 versus 12 applications/year)	Increased soil available micronutrients in both frequencies	Wang et al. (2018)
		Soil pH		

(Continues)

TABLE 7 (Continued)

Location	Soil type/ classification	Treatment	Outcome	References
Inner Mongolia, China	Haplic Calcisol	Different plant species (Leymus chinensis and Stipa grandis) with fertilization intensities (ranged 0 to 50 g N m^{-2} $year^{-1}$) with two frequencies (2 versus. 12 applications/year)	Decreased with increased N intensities	Wang et al. (2018)
Inner Mongolia, China	Calcis-Orthic Aridisol	Different grasses species (Stipa krylovii, Agropyron cristattum and Cleistogenes squarrosa) with using 100 kg N ha^{-1} $year^{-1}$ versus no fertilization	Decreased with N addition	Zhang, Yang, et al. (2018)
		Soil bulk density		
Northern Ireland	Clay loam	Perennial ryegrass with mineral and organic fertilization versus no fertilization	No effect of treatments	Fornara et al. (2016)
Georgia, USA	Acrisol	Bermudagrass with nutrient sources: (a) mineral, (b) a mixture of organic and mineral, (c) organic	No differences among nutrient sources	Franzluebbers and Stuedemann (2010)
		Soil respiration		
Kansas, USA	NA	Cheatgrass with 88 kg N/ha versus no fertilization	Increasing effect of nitrogen fertilizer	Verburg et al. (2004)
A global study	A wide range of soil types	Grassland field studies with different types of fertilization versus no fertilization	Increasing effect of fertilizations	Wang and Fang (2009)
		Soil porosity		
Northern China	Sandy loam	Steppe plant community (Stipa krylovii, Leymus chinensis and Artemisia frigida) with nitrogen fertilizer versus no fertilization	No effect of treatments	Wang et al. (2020)

Abbreviation: NA, not available.

aboveground biomass was strongly affected by mowing and grazing, but root biomass is less sensitive. Low to moderate management practices have a potential to improve herbage production and can be considered as an effective management for promoting productivity due to a direct soil quality enhancement (George et al., 2013; Jeddi & Chaieb, 2010; Rong et al., 2014). While undesirable conditions for plant growth may occur in result of frequent or incorrect grazing and mowing practices, which may lead to a decline in plant productivity.

Herbivores have a direct impact on plant shoot, as the proportion of daily herbage production consumed by animals is increased, the vegetation height, vegetation coverage, and vegetation biomass are decreased (Wei et al., 2011). In this context, in intensively grazed pastures, herbivores may ingest up to 60% of herbage aboveground biomass production (Evans et al., 2012; Krzic et al., 2013). Low to moderate grazed pastures are mostly dominated by slow-growing plant species with a lower litter quality and a higher C/N ratio. As C/N ratio in plants increases, organic matters can remain in the soil for long time due to a decrease in mineralization rate by soil microorganisms (Klumpp & Soussana, 2009; Soussana & Lemaire, 2014). In contrast, in intensive grazed sites, C and N cycles are markedly affected by various reasons. One possible reason is replacing productive forage plants by fast-growing plant species with a higher litter quality and a lower C/N ratio, and the other one is reducing the plant leaf area (Klumpp & Soussana, 2009; Soussana & Lemaire, 2014). Herbage quality mainly depends on stocking rate, which means that by applying a high stocking rate the herbage quality could be maintained in homogeneous swards due to the limitation of reproducing stem growth and herbage senescence (Garcia et al., 2003). However, decreasing in the stocking rate causes an imbalance between herbage offer and animal intake, and provide a condition for a coexistence of short vegetative patches in grazed areas (Marriott et al., 2005). Therefore, stocking rate is a crucial management choice which has a strong impact on pasture productivity, residual herbage mass, and consequently, soil quality (Monaghan et al., 2005).

Long-term excessive defoliation in meadows leads to a decrease in herbage productivity due to the greater nutrient depletion of the soil, which is probably caused by an increased export of harvestable nutrients in high defoliation intensity (Li et al., 2017; Nüsse et al., 2018). Furthermore, because of reduced sward vitality under high mowing frequency, the proportion of bare soil increases, resulting in a greater reduction in soil moisture. Soil moisture reduction would consequently feedback into plant production due to the importance of soil water content in plant growth (Chai et al., 2019). For instance, the highest above ground biomass is obtained in three times cutting regimes compared to five times cutting regimes (Nüsse et al., 2018) due to recovery interval after each cut, although vegetation types response to mowing differently (Liang et al., 2019). This may be due to less mowing-induced damages in low intensity

TABLE 8 Selected studies describing changes on plant production under different grassland managements

Management	Location	Soil type/ Classification	Treatment	Outcome	References
			Above-ground production		
Grazing	Yellowstone National Park, USA	A wide range of soil types	Nine grassland sites at different elevation gradient with grazing versus no grazing	Increased in grazed sites	Frank et al. (2002
	Inner Mongolia, China	Calcic Chernozem	Perennial plants with grazing intensity: (a) non-grazed, (b) very light, (c) light, (d) light-moderate, (e) moderate, (f) heavy, (g) very-heavy	Decreased as grazing intensity increased	Schönbach et al. (2011)
	Northern Tibetan Plateau	Sandy loam	Different plant species (Kobresia pygmaea, accompanied by Potentilla bifurca, Potentilla saundersiana, Leontopodium pusillum, and Carex moorcrofti) with grazing versus no grazing	Increased in grazed sites	Zhang, Zhang, et al. (2015)
Mowing	Vancouver, Canada	Clay-silt-loam Glaceomarine	C_3 grasses (Alopecurus pratensis, Poa pratensis, Festuca rubra) and broad-leaved N2-fixer (Vicia spp., Trifolium spp.) with mowing versus no mowing	Decreased in mowed sites	Ziter and Macdougall (2013)
	Montana, USA	Mollisol Ustoll	C_4 (Bouteloua gracilis) and C_3 (Pascopyrum smithii) grasses with mowing (2 cut/year in 2cm and 5cm stubble) versus no mowing	Decreased in mowed sites	Balogianni et al. (2014)
			Below-ground production		
Grazing	Yellowstone National Park, USA	A wide range of soil types based on topographic position	Nine grassland sites at different elevation gradient with grazing versus no grazing	Increased in grazed sites	Frank et al. (2002)
Mowing	Montana, USA	Mollisol Ustoll	C_4 (Bouteloua gracilis) and C_3 (Pascopyrum smithii) grasses with mowing (2 cut/year in 2cm and 5cm stubble) versus no mowing	No effect of treatments	Balogianni et al. (2014)
	Vancouver, Canada	Clay-silt-loam Glaceomarine	C_3 grasses (Alopecurus pratensis, Poa pratensis, Festuca rubra) and broad-leaved N2-fixer (Vicia spp., Trifolium spp.) with mowing versus no mowing	Increased in mowed sites	Ziter and Macdougall (2013)

management systems below the threshold level which decrease the vegetation yield (Rakkar & Blanco-Canqui, 2018). The authors conclude that it seems that efficient nutrient cycling in different grassland uses is an important responsible for the higher biomass productivity.

It is important for grassland management and livestock farming to find the relation between forage accumulation and the correlative decline in forage nutritive value in order to apply the best strategy in the timing of grazing or mowing. The overall relationship of herbage accumulation and nutritive value is well-established in the previous literature (Lemaire & Belanger, 2020). As underlined by (Lemaire & Belanger, 2020), generally, concentration in crude protein and total digestible nutrients can be considered as two characteristics for estimating the nutrient value of forage. As the plant gets bigger and crop mass increases, the concentration of crude protein and digestibility would be decreased which is due to the rapid increase in plant structural tissues with higher fibre content that have a low N concentration and low digestibility than metabolic tissues that have a high N concentration and high digestibility (Figure 3). The slope of the relationship between decreasing nutritive value with increasing yield is going to vary considerably based on growing conditions for different plant species, seasons, climate, and crop N nutrition.

7 | EFFECTS OF GRASSLAND MANAGEMENTS ON GREENHOUSE GASES

Grassland managements such as the intensity of grazing, the frequency of cutting and the amount and type of fertilizer application affect the exchange of greenhouse gases (GHGs) particularly carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O; Soussana et al., 2007). CO_2 is exchanged with the soil and vegetation, CH_4 is emitted by livestock at grazing and can be exchanged with the soil and N_2O is emitted by soils (Soussana et al., 2004). Soil properties have the potential to change depending on the management events (Hörtnagl et al., 2018). In this case, induced-compaction by animals trampling or machinery use can negatively affect soil structure and thereby affect soil conditions such as

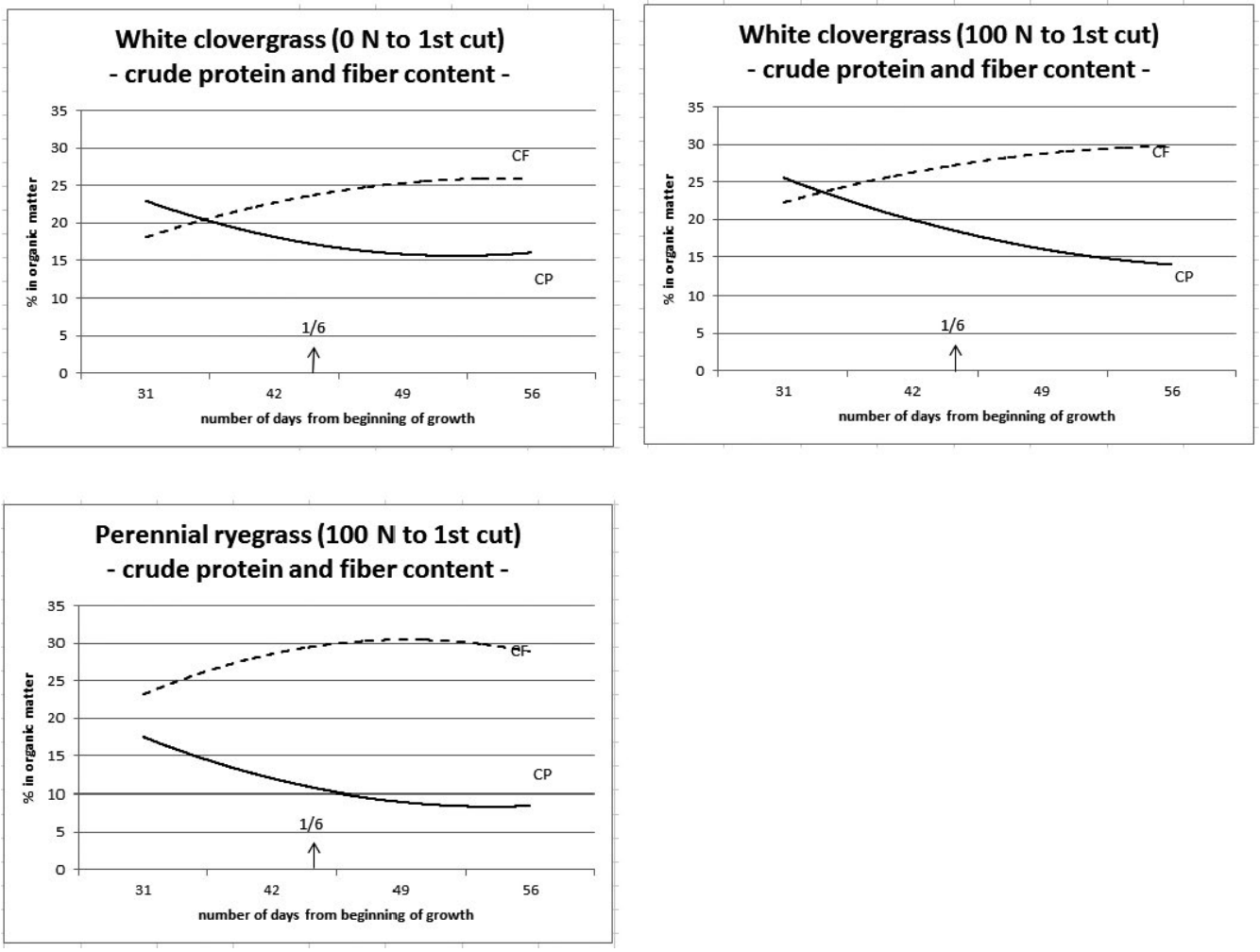

FIGURE 3 Changes in crude protein (CP) and crude fiber (CF) content by increased maturity of rye grass and grass-white clover under different levels of N fertilizer applications. 1/6 represents June 1st. Adapted from (Hermansen et al., 2017)

water-filled pore space which are crucial to the production or consumption of GHGs in the soil.

The important component of the grassland C cycle is the net ecosystem exchange of CO_2 (Hörtnagl et al., 2018) by absorbing CO_2 through photosynthesis and releasing it by respiration (Leahy et al., 2004) which has the noticeable role of the CO_2 flux for the GHGs budget (Soussana et al., 2007). When grasslands are regularly mown to produce fodder, harvested biomass can be returned to the atmosphere as emission of CO_2 and CH_4 through the digestion of the animals or through the decomposition of manure and slurry (Chang et al., 2015). Grazing management has an important role in the emission of GHGs by influencing diet quality, animal performance, and soil C change, as underlined by (Sollenberger et al., 2019), at light to moderate grazing intensities due to the more C sequestration than heavy grazing intensities, the mitigation of GHGs emission is observed. In grazed sites, the ingested biomass by herbivores contains digestible and non-digestible organic compounds. Most of the C ingested part is digestible and would be respired as CO_2 shortly after intake. While the non-digestible part of the C of the intake (25%–40% of the intake which reflects the digestibility of the grazed herbage) is returned to the field in excreta mainly as faeces (Soussana et al., 2010). Furthermore, a small part of the C fraction is exported from the grassland ecosystem as animal mass or animal products (Soussana et al., 2010). Small part of the digested C is emitted by ruminant enteric fermentation in the form of CH_4. CH_4 is mainly produced by methanogens—the end point of the anaerobic breakdown of organic matter (Whalen, 2005) – that are found in anaerobic microsites in the soil, water-saturated zones with high C content and the rumen of ruminants (Baldocchi et al., 2012; Hiller et al., 2014). The high proportion (77%) of CH_4 emissions originates from enteric fermentation and are primarily varied with the stocking rate, although a considerable amount (9%) of CH_4 is released as a result of manure decomposition processes (FAOSTAT, 2017). Management practice affects forage nutritive value, and thus can have an effect on enteric CH_4 emissions. Forage nutritive value, especially digestibility have inversely correlation with enteric CH_4 production which means that forages with high digestibility due to increased intake may decrease the amount of produced CH_4 per unit of feed consumed and per unit of animal product (Sollenberger et al., 2019). Therefore, grazing with high forage nutritive value and at a stocking rate that optimizes animal performance can potentially reduce CH_4 emission (Sollenberger et al., 2019).

N_2O is emitted from soils as a result of nitrification and denitrification processes by microbial activities. The production of soil N_2O is controlled by soil pH, soil moisture, temperature, and the amount of available labile C and N (Hörtnagl et al., 2018). Less information is reported about the effects of managements on N mineralization due to the high special variability of N_2O fluxes and also complexity of the N_2O emission drivers (Billings et al., 2002; Blüthgen et al., 2012). In pastures, application of organic (animal excreta) and inorganic fertilizers causes soil N_2O emission, the magnitude of which depends on form, amount and timing of applied N as well as presence or absence of organic matter (Laville et al., 2011). Fore-studies have indicated that mowing with complete removal of the plant residues compared to the un-mowed sites can decrease the rate of N mineralization in soil due to a reduction in plant litter and above ground biomass, thereby decrease the substrates supplied for soil microorganisms which play a role in N mineralization processes (Zhang, Hou, et al., 2015). From the previous literatures, it can be understood that N_2O emission periods are very often localized immediately after cutting and strongly associated with the application of N fertilizers. That is why, the increase in N_2O emission with a higher cutting frequency is in fact a consequence of the increase in the intensity and frequency of N fertilizer application. Besides, soil properties can provide ideal condition for N_2O flux, for example, at high soil water content, during the last step of denitrification, the needed time for the reduction process of N_2O to N_2 is increased and causes a reduction in the release of N_2O to the atmosphere (Hörtnagl et al., 2018). A summary of some literature reports on greenhouse gases emission in response to grassland managements is found in Table 9. The GHGs emission cannot be avoided in grassland systems; however, it is expected by applying proper managements the degree of emission can be reduced.

8 | CONCLUSION

It is most likely that soil physical, chemical and biological properties have a mutual relationship, thus an efficient management activity leads to maintain this cycle. Soil properties significantly influence dynamics of soil resources such as water, air, and nutrients, as well as above- and below-ground production and, ultimately, grassland functions. Thus, it is important to understand the response of soil physical and chemical properties to anthropogenic disturbance. The presented review is conducted to integrate previous literature outcomes about grassland management impacts on soil quality indices. This review appears that no resource can be considered independently of the others. Thus, study of the adaptive response of soil to different grassland managements could be a worthwhile guidance for better understanding the dynamics of grassland systems to develop best management practices. Although grassland productivity is significantly associated with the management practices, different responses could be observed by implementing the same management, depending environmental impacts such as climate, soil, landscape position, and plant community. Therefore, interpreting research achievements on various impacts of land use types and their associated practices (grazing intensity, cutting frequency, fertilization, and livestock type) is complicated due to simultaneous effects of site conditions (e.g., slope, elevation, soil type), and climate conditions. It could be discussed that in each specific site, there is a threshold level of grassland intensification which can be determined by stocking density and/ or cutting frequency in order to obtain maximum productivity and ecosystem services. Long-term sustainability and

TABLE 9 Selected studies of greenhouse gases (GHGs) emission under different grassland managements

Location	Treatment	Outcome	References
North west to South east in Europe	(a) grazing, (b) grazing and cutting, (c) cutting: intensive, with and extensive without 300 kg mineral and organic N ha^{-1} $year^{-1}$	European grasslands are large atmospheric CO_2 sinks, livestock off-site digestion add emissions of CO_2 and CH_4	Soussana et al. (2007)
Inner Mongolia, China	(a) no grazing, (b) light grazing, (c) moderate grazing, (d) heavy grazing, e) cutting	Significant source of GHGs for moderate and heavy grazing than ungrazed	Schönbach et al. (2012)
Kaunas, Lithuania	(a) abandoned grassland, (b) intensive cultural pasture with 8 different treatment of mineral fertilizers	Greater emission in grassland than cultural pasture	Balezentiene and Kusta (2012)
Sierra Foothill Research and Extension Center in Browns Valley California, USA	Rotational grazing: (a) with composted organic matter amendments, (b) without amendment	Greater soil respiration in amended sites, no effect on N_2O or CH_4 emission	Ryals and Silver (2013)
Cowpark, Scotland	(a) control (b) mineral fertilizer 100 kg N/ha (c) organic manures 150 kg N/ha	Greater N_2O emission in higher manure	Jones et al. (2005)
Southern Ireland	Intensively grazed grassland with monthly application of organic and mineral fertilizer	Greater N_2O emission in higher fertilizer application; greater CH_4 emission at higher stocking rate	Leahy et al. (2004)
Central European grasslands	Wide range of different management practices: (a) grazing, (b) mowing, (c) organic and mineral fertilizer	Greater emission in intensive than extensive grasslands; Greater N_2O and CH_4 emission at high animal slurry application	Hörtnagl et al. (2018)

development of grasslands are related to an optimal rate of grazing intensities and mowing frequencies to avoid soil disturbances through implementing long rest grazing periods or changing from continuous to rotational managements and applying periodic mowing without removing biomass as well as limiting the usage of the invasive machinery. The absence of mechanical compression and animal trampling can slightly increase aggregate stability and decrease grassland species which can be observed in abandoned grasslands, while grazing or mowing of these areas would improve productivity and forage quality. Thus, this review shows that knowledge of factors affecting soil attributes is the key to improve the soil quality and diminish the negative environmental impacts so as to have a successful management.

Despite all efforts on investigating different management system impacts on soil properties in grasslands, at this stage of knowledge, more research about impacts of mowing on physical and chemical soil properties is still needed. Most grassland studies have focused on the impacts of different grazing intensities rather than the effects of different mowing frequencies. Moreover it should be taken into account in studies to consider the interaction effects of different grassland managements on soil characteristics for a long term experiment. Since integration of crop, pasture, and livestock is mutually beneficial to each other, so for having sustainable grassland productivity in regions along with mitigating the negative impact of the environment, integration of forage and livestock into a cropping system, for example, could be beneficial. In such a system, crop residues can be used as animal feed, while animal manure can be utilized to enhance soil fertility, and carbon sequestration thereby future food security and environmental sustainability could be achieved.

9 | RECOMMENDATION

A growing demand for animal products globally combined with climate change causes a need to have more resilient and productive forage-livestock systems to be able to deal with stresses and disturbances as a result of change. The maintenance of soil quality in grasslands that will supply sufficient forage for livestock can be achieved with the efficient management choices. This review paper evident some ideas as guides to future research. A few suggestions include:

- Consider grassland capacity to apply the optimal management practices.
- Further researches to identify site-specific critical limits or threshold values of soil attributes like soil porosity, soil penetration resistance, surface soil layer bulk density, water infiltration, and water runoff which have important effects on root penetration, water movement into soils, oxygenation of soils, and sediment and nutrient runoff from the soil surface.
- Quantify yield loss in result of management-related damages to soil properties to help land managers achieve maximum productivity.
- Provide site-specific fertilization guideline to increase nutrient use efficiency and decrease high losses of applied nutrients to aid in increasing yield.
- Better use of organic fertilizer and amendments to reduce mineral fertilizers to improve nutrient availability efficiency in grassland systems.
- Further studies to detect the relationship between plant-available nutrients in the soil and their concentrations in the fodder under different grassland management regimes.

- Further investigation to assess the effects of fertilization, both in intensity and frequency of application, on soil attributes as affected by different mowing managements.
- More attention to the consequences of grassland management practices that enhance natural rejuvenation of degraded soils.

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CONFLICT OF INTEREST

All authors declare no conflicts of interest with the subject matter or materials discussed in this manuscript.

AUTHOR CONTRIBUTION

Sonia Mayel: Conceptualization (equal); Investigation (lead); Writing-original draft (lead); Writing-review & editing (lead). **Mahboube Jarrah:** Conceptualization (equal); Investigation (supporting); Writing-original draft (supporting); Writing-review & editing (supporting). **Katrin Kuka:** Conceptualization (equal); Investigation (supporting); Supervision (lead); Writing-review & editing (supporting).

DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available within the article.

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