Grazing and cattle health: a nutritional, physiological, and immunological status perspective

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Summary

Grazing is thought to contribute to behavioral and clinical aspects of cattle welfare. However, little information is available about the effect of grazing on cattle health. The aim of this review was to evaluate the impact of grazing on the physiological, immunological, and nutritional status of cattle and to discuss the means by which we should assess the health of grazing cattle. Due to a mismatch between the nutritional supply of forage and the demand of grazing cattle, grazing often induces an imbalance of protein and energy intake and a negative energy balance in cattle, which impairs hormone (insulin and IGF-1) production, fertility (ovarian cyclicity resumption, pregnancy, embryonic development, and oocyte maturation), and immunity. Grazing also affects the circulation of immune-related cells; however, the impact of grazing on immune function is unclear. In contrast, evidence shows that grazing in diverse vegetation improves the mineral intake balance and reduces oxidative stress in cattle. The impact of grazing on cattle health varies with the grazing conditions, including the pasture condition and outside environment, implying that a stereotypical view of grazing is not beneficial for cattle health. Thus, multiple parameters and a comprehensive approach are crucial to evaluating the health of grazing cattle.

Keywords: cattle health, diverse vegetation, immunomodulation, mineral intake, oxidative stress

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Introduction

The physical and psychological aspects of health are major concerns in current intensive cattle production systems, including confinement systems. Production diseases, such as lameness, mastitis, and hock lesions, occur frequently in confinement systems, including free-stall housing systems (Washburn et al. 2002; Haskell et al. 2006). A comparative study conducted in the US (Washburn et al. 2002) showed that the rate of clinical mastitis in Holstein cows confined in free-stall housing was approximately 1.6 times higher than that in grazing Holstein cows. Similarly, the rate of clinical mastitis in Jersey cows in free-stall housing was two times higher than that in grazing Jersey cows (Washburn et al. 2002). Furthermore, Haskell et al. (2006) showed that cows in a free-stall housing exhibited clinical lameness at a rate 2.3 times higher than that observed in grazing cows. Although the frequencies of production diseases and other health problems vary with management practice in both confinement and grazing systems, current confinement systems may have problems in terms of cattle health (Arnott et al. 2017).

Confinement systems suppress the expression of natural behavior. Cattle in confinement systems spend less time eating than do cattle on pasture. Charlton and Rutter (2017) reviewed that cows
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Cows on pasture spend 9.5 h/day grazing, whereas cows in free-stall housing without pasture access spend only 3-5 h/day eating. Cattle prefer a sternum-lying posture when ruminating; a standing posture during rumination implies that cattle feel discomfort (Ruckbusch & Bueno 1978; Österman & Redbo 2001). When cattle move from a grazing system to a confinement system with tethers, the ratio of adopting a sternum-lying posture when ruminating is reduced by more than half (Higashiyama et al. 2007). Thus, the expression of natural behaviors such as eating and resting is suppressed in confinement systems. Especially, in Japan, approximately 70% of milking cows on dairy farms (ALIC 2015a) and approximately 35% of cows on beef farms have been placed in confinement systems with tethers, including tie-and-stanchion-style tethers (ALIC 2015b). Tethering systems drastically increase abnormal behavior in cattle. Cattle in a tethering system spend 10-30% of their daily time performing abnormal behaviors (Redbo 1993). Thus, the increased frequencies of production diseases under confinement systems relative to grazing systems and the excessive behavioral restriction under confinement systems with tethers are concerns for cattle health and welfare.

Amid the context of the current production system, societal attention has turned to grazing for improving the quality of cattle health and welfare. For example, some studies show that compared with current confinement systems, grazing reduces the prevalences of health problems such as lameness, mastitis, and hock lesions in cattle (Washburn et al. 2002; Haskell et al. 2006; Arnott et al. 2017; Charlton & Rutter 2017). In addition, grazing cattle are free to express normal behaviors. Basic behaviors such as eating, resting, and ruminating together account for approximately 90% of the daily behavior of grazing cattle (Roca-Fernández et al. 2013). Furthermore, approximately 90% of rumination in grazing cattle occurs when the cattle are in a sternum-lying posture (Higashiyama et al. 2007). In addition, grazing is beneficial for reducing the frequency of abnormal behaviors, including tongue rolling (Krohn 1994; Rushen et al. 2007). Thus, from the perspective of these clinical disease and behavioral aspects, grazing has been considered beneficial to cattle health and welfare. In addition, grazing is a major component of organic animal husbandry (Council Regulation (EC) No. 834/2007). This regulation prescribes that grazing should be adopted as allowed by weather and land conditions and that the manager must always allow the animals outdoor access.

However, grazing occasionally impairs cattle health depending on the management practices (Bulter 2014). For example, grazing cattle are directly exposed to heat and cold stress (Tucker et al. 2007; Higashiyama et al. 2013), occasionally leading to the suppression of immune functions and a reduction in reproduction and milk production (Carroll & Burdick Sanchez 2013). Gastrointestinal parasitism is another major concern in grazing systems because it induces a reduction in both milk yield and body weight and causes clinical diseases (Mertz et al. 2005; Charlier et al. 2009; Perri et al. 2011). These findings imply that grazing does not necessarily contribute to cattle health.

Although grazing can positively or negatively affect cattle health, scientific evidence revealing the relationship between grazing and physiological and immunological status of cattle is limited. Behavioral parameters such as the expression of natural and abnormal behaviors do not reflect the physical health of cattle. Clinical signs such as lameness and mastitis suggest an animal’s health status; however, such signs appear only when the animal is in a critical health condition. Thus, the consideration of only behavioral and clinical signs is inadequate for evaluating the influence of grazing on cattle health.

Grazing is a complex livestock production system because it is composed of various elements such as vegetation, weather, temperature, and humidity conditions. These factors affect the nutritional, immunological, and physiological condition of grazing cattle. Moreover, the increase in activity such as exercise alters immunity in horse and cattle (Anderson et al. 1991; Hines et al. 1996). Thus, to evaluate the relationship between grazing conditions and cattle health, a multifaceted or comprehensive approach involving nutritional, physiological, immunological, and behavioral aspects is indispensable. The aim of this review was to clarify the relationship between grazing and cattle health and to evaluate the impact of grazing on the physiological, immunological, and nutritional status of cattle.

The effect of grazing on nutritional status

Factors inducing a nutritional shortage and imbalance by grazing

Grazing occasionally impairs the nutritional...
condition of cattle. The following three reasons often induce a nutritional shortage and imbalance in grazing cattle: 1) seasonal change, 2) stocking rate, and 3) type of grassland.

1) Seasonal change: the quality and quantity, including the protein, mineral, and fiber content, of grazing plants vary seasonally (White & Hodgson 1999); meanwhile, the nutritional requirements of grazing animals depend on their growth and physiological stage. Thus, the balance of nutritional supply and demand between the plants and the animals is often discordant during the grazing season, resulting in a shortage and/or imbalance of nutrient intake (Vallentine 2000).

2) Stocking rate: an inappropriate stocking rate is another important factor that often induces a nutrient intake shortage. In general, forage intake decreases as the stocking rate exceeds a threshold (Vallentine 2000), whereas energy expenditure increases as the stocking rate increases (McCarthy et al. 2011). Aninut et al. (2006) showed that the energy expenditure of sheep increased from 562 to 628 kJ/kg BW^{0.75} when the stocking rate increased from 10 to 20 animals per hectare of pasture. The stocking rate also changed the nutritional value, such as the contents of crude protein and neutral and acid detergent fiber, in a pasture (Baudracco et al. 2011). Thus, the stocking rate quantitatively and qualitatively affects the nutritional status of grazing animals.

3) Type of grassland: the type of grassland also affects the nutritional condition of grazing animals. The components and contents of nutrients vary with plant species, maturity and part (White & Hodgson 1999). Generally, sown species have relatively higher protein contents than energy contents. Native grasses, forbs and shrubs contain various minerals but often have lower energy and protein contents than sown species.

Under grazing management, these three factors influence each other, and the mixed effects act on the nutritional condition of grazing animals. Thus, the nutrition of grazing cattle is often complicated and may be a risk factor impairing cattle health.

Energy and protein intake under grazing and their effects on physiological condition

A shortage of energy (negative energy balance: NEB) as suggested by high levels of nonesterified fatty acids (NEFAs) in the blood occasionally appears in grazing cattle (Boken et al. 2005; Tucker et al. 2007; Vance et al. 2012), as we mention above. An increase in NEFA levels in follicular fluid impairs not only oocyte maturation and fertilization but also embryonic development (Leroy et al. 2005). The NEB also affects hormone secretion. Several studies suggested that NEB in grazing cattle leads to a reduction in insulin concentration (Beam & Butler 1997; Butler 2014). The insulin concentration in grazing cows (0.47 ng/dL) was lower than that in cows in a free-stall barn (0.61 ng/dL) (Boken et al. 2005). Insulin is associated with reproductive performance because it directly stimulates both mitosis and steroid production in granulosa cells (Butler 2014). In addition, NEB affects circulating IGF-1 concentrations. A low IGF-1 concentration decreases the rates of conception and pregnancy (Drackley & Cardoso 2014). The plasma IGF-1 concentrations in cows with an ovulatory follicle were 40-50% higher than those in cows with a nonovulatory follicle (Beam & Bulter 1997). Moreover, IGF-1 is associated with earlier resumption of estrous cyclicity (Patton et al. 2007). Thus, insulin and IGF-1 are critical factors in the maintenance of reproductive performance in grazing cattle.

An imbalance of protein and energy intake and an excess intake of protein are additional concerns in grazing cattle because fresh forages often contain high protein contents relative to energy contents. An imbalance of protein and energy can negatively affect reproductive performance by increasing plasma levels of metabolites, such as blood urea nitrogen (BUN) (Beam & Butler 1997; Wittwer et al. 1999; Kay et al. 2005); in dairy cows, high BUN levels decrease the rates of conception and pregnancy (Ferguson et al. 1993; Wittwer et al. 1999). Thus, identifying the relationships among grazing conditions and the secretion of metabolites and hormones is crucial for improving reproductive performance.

Mineral intake in grazing

An excess or shortage of ingested minerals occasionally occurs in grazing cattle, because mineral deficiency and sufficiency in grazing cattle depend on the type of grasslands, such as sown and seminatural grasslands, used for pasture (Nakano et al. 2009). Grazing animals are generally believed to rarely meet all mineral requirements when foraging pasture alone (McDowell 1992; Khan et al. 2004). Deficient mineral intake often induces a reduction in the growth and fertility rates in grazing animals.
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(McDowell 1997; Khan et al. 2004). Mineral supplements such as copper, zinc, and manganese improve the reproductive performance of grazing cattle (Ahola et al. 2004). Supplementation of organic minerals bound to carbon, which has high bioavailability and repairs damaged uterine tissue, also improved the pregnancy rate in cows (Stanton et al. 2000). However, a high amount of mineral supplementation reduces average daily gain in steers (Ahola et al. 2004). Thus, controlling the quality and quantity of mineral intake in grazing cattle by supplementation alone might be difficult.

Recent studies, however, suggest that diverse vegetation in grasslands might be a solution for mineral deficiency in grazing cattle. Some previous studies have shown that diverse vegetation is beneficial for improving the balance and sufficiency of mineral intake (Ohlson & Staaland 2001; Ogura et al. 2017). Plant species differ in mineral content (NARO 2009). A simulation study (Yoshihara et al. 2013) indicated that more diverse vegetation may improve mineral intake balance in grazing cattle. When the number of plant species in a grassland increases, the number of plant species ingested by grazing animals also increases (Ogura 2011), implying that diverse vegetation might improve mineral intake in grazing cattle. Thus, considering diverse vegetation in grazing systems may solve imbalances in mineral intake in grazing cattle and contribute to the health of grazing cattle.

The effect of grazing on physiological and immunological status

Grazing and stress

Grazing is not always beneficial for reducing physiological and psychological stress. Although grazing reduces behavioral restrictions and abnormal behaviors (Redbo 1993; Krohn 1994), it carries a variety of stress risks. Weather and temperature are typical risks that increase stress in grazing cattle. Generally, the plasma cortisol concentration in cattle exposed to cold weather is consistently low (Muller & Botha 1995; Zähner et al. 2004). However, cortisol secretion was increased in cattle directly exposed to wind and rain in winter (Tucker et al. 2007). Hot weather in summer also induces physiological stress in grazing cattle. For example, the concentration of urinary cortisol increased when grazing cattle stayed in hot and humid conditions (temperature-humidity index (THI) > 72 vs THI < 72: 12 ng/mg vs 8 ng/mg creatinine), suggesting that the temperature and humidity during grazing affect the secretion of cortisol (Higashiyama et al. 2013). However, when a grazing cow was moved to indoor housing, the urinary cortisol level in the cow increased just after the move; conversely, the urinary cortisol level did not increase when the cow was returned to pasture from indoor housing (Higashiyama et al. 2007), suggesting that grazing has a positive effect on stress reduction. Thus, the degree of stress under a grazing system depends on the grazing conditions.

Grazing cattle often avoid unfavorable weather conditions by fleeing to shelters such as the shade of trees and forests; however, the stress conditions of cattle in various grazing environments are unclear. Poor ambient conditions, including inhospitable temperatures, are especially likely to induce chronic stress in grazing cattle. Chronic stress not only causes severe physiological and psychological problems such as immunosuppression and hyperglycemia but also reduces productivity and reproductive performance (Carroll & Burdick Sanchez 2013). Stress has been frequently evaluated using cortisol levels in blood, saliva, and urine because cortisol is one of the major stress hormones that reflect the physiological status of cattle. However, the secretion of cortisol in blood, saliva, and urine is strongly affected by the measurement conditions, such as the time and day of sampling and the sampling procedure (Do Yup Lee & Choi 2015); thus, it is important to consider such conditions when using cortisol level to evaluate cattle stress. Using multiple parameters to identify the stress environment under various grazing conditions is therefore necessary.

Magnesium may be a useful index for assessing physiological and psychological stresses because magnesium controls the activity of the hypothalamic-pituitary-adrenocortical (HPA) axis (Sartori et al. 2012), which is considered the main stress response system. Blood magnesium concentrations are decreased in cattle exposed to transportation stress (non-transported cattle: 0.77 mmol/L versus transported cattle: 0.69 mmol/L) (Parker et al. 2007). In addition, magnesium is related to psychological health aspects such as anxiety (Sartori et al. 2012).

As described in the next section, oxidative stress is another stress parameter to consider when evaluating cattle health. Oxidative stress results from the increased production of free
radicals and reactive oxygen species (ROS). An increase in oxidative stress causes cell and tissue damage and leads to health disorders in cattle (Miller et al. 1993). Some infections, such as mastitis and pneumonia, in cattle are associated with oxidative stress (Lykkesfeldt & Svendsen 2007). In addition, oxidative stress has an impact on the severity of udder edema and mastitis in dairy cows (Sretenović et al. 2007). Thus, reducing ROS and increasing antioxidant activity are important for maintaining cattle health. Oxidative stress parameters, such as thiobarbituric acid-reactive substances (TBARs) and oxidized DNA, are used to evaluate chronic pathological conditions caused by long-term psychological stress (Lykkesfeldt & Svendsen 2007). In addition, these parameters are used to evaluate acute stresses, such as transport stress; therefore, they may be useful for evaluating not only chronic stress but also acute stress.

The usefulness of multiple parameters, including magnesium concentration and oxidative stress parameters, in evaluating responses to chronic and acute stress should be verified under various grazing conditions to improve cattle health and welfare.

Grazing and oxidative stress

Environmental factors in grazing such as heat exposure often affect the level of oxidative stress. For example, the levels of TBARs and superoxide dismutase (SOD) are higher in summer than in spring (Bernabucci et al. 2002; Di Trana et al. 2006). Exercise is another factor that increases the level of oxidative stress (Lykkesfeldt & Svendsen 2007) because it stimulates the production of ROS. Oxidative stress caused by exercise is sometimes responsible for oxidation lesion and muscle injury, whereas exercise also enhances the antioxidant capacity in rats and humans (Lykkesfeldt & Svendsen 2007; Gomez-Cabrera et al. 2008). Thus, various elements in grazing need to be considered for oxidative conditions in cattle.

Recent studies (Haga et al. 2014, 2016) have suggested that grazing in forest improves the total antioxidant capacity (TAC) of cattle. Shrubs and tree leaves in forests have a high TAC (Han et al. 2004), and the activity of glutathione peroxidase, an antioxidant enzyme, is influenced by plant species and the condition of pasture soils (Andrés et al. 1997). Thus, the ingestion of various plant species, including native grasses, shrubs, and tree leaves, during grazing may be useful for the enhancement of antioxidant substances. In addition, fresh grasses contain high amounts of vitamins E and C and carotenoids, which function as antioxidants (Sies & Stahl 1995; Castillo et al. 2013). Supplementation of these nutrients not only reduces the occurrence of udder infections (Castillo et al. 2013) but also enhances the life span of immune cells associated with other bacterial infections in dairy cattle (Sretenović et al. 2007). However, little is known about the content of these vitamins and carotenoids in relation to pasture type, plant species, and maturity and their potential effects on animal health (Hopkins & Holz 2006).

We should clarify the effect of environmental factors such as ambient temperature, animal factors including exercise, and grassland factors including vegetation type on oxidative stress and antioxidant capacity in grazing cattle.

Grazing and immunomodulation

Grazing may affect the circulation of some immune-related cells and the secretion of cytokines and antibodies. However, which factors influence immunity in grazing cattle remains unclear. For example, the number of lymphocytes, a representative immune cell, in grazing calves ($9.3 \times 10^3$ cells/$\mu$L) was higher than that in calves housed ($8.0 \times 10^3$ cells/$\mu$L) after weaning (Lynch et al. 2010, 2011). In addition, calves in a grazing system and with free access to their mothers had a greater proportion of $\gamma\delta$ T cells, which help to defend against infectious intracellular parasites, than calves in conventional housing (Baldwin et al. 2000). The population of WC1-positive T cells, which maintain the homeostasis of immune function in calves, also decreased by three weeks after the movement of calves from a grazing environment to conventional housing. Furthermore, Lynch et al. (2011) reported that grazing increased cytokine release in calves after weaning. In contrast, Hickey et al. (2003) reported that cytokine production was suppressed in grazing calves after weaning. Thus, further research regarding the effect of grazing on cytokine production is needed.

Some reports suggest that inappropriate nutritional conditions cause deterioration in immunological status (Hammon et al. 2006; Martinez et al. 2012; Ribeiro et al. 2013; Butler 2014). As mentioned above, grazing occasionally induces NEB in cattle. The lack of protein absorption in cattle with NEB causes the decrease in the circulating lymphocyte count (Lewicki et al.
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In addition, increases in plasma NEFA and β-hydroxybutyrate concentrations under NEB induce neutrophil dysfunction, followed by uterine health disorders (Hammon et al. 2006). Thus, the NEB induced by grazing may suppress immune function. Currently, information needed to evaluate the direct relationship between nutrition and immunity is limited under grazing condition. However, the effect of grazing on the immune system is extremely crucial for clarifying the appropriate grazing conditions for cattle welfare and health.

Forage selection may affect animal immunity. Many native plant species contain various types of secondary metabolite compounds (SMCs). SMCs may have beneficial effects on animal health (Provenza et al. 2010) by protecting animals from harmful bacteria, parasites, and fungi (Lozano 1998). This observation implies that SMCs in native plants could improve the immunity of grazing animals by increasing the availability of SMCs via forage selection. Grazing animals may attempt to ensure immunity by changing their forage selection based on their physiological status. Sheep infected with parasites have been shown to alter their plant species intake, and many medicinal plant species, such as Lotus corniculatus, enhance immunity (Min et al. 2002; Egea et al. 2014). Therefore, ensuring forage selectivity by providing lands with diverse vegetation for grazing may be key for enhancing the health of grazing cattle. The studies described above suggest that grazing contributes to immunity; however, the underlying factors and the degrees to which they influence cattle immune systems remain unclear.

**Conclusion**

Grazing has various effects on cattle health via modulating behavior, nutrition, physiology, and immunity. Although grazing affects behavior and clinical signs, it is not necessarily beneficial for the nutritional, physiological, and immunological status of cattle. In reality, grazing often causes the imbalance of nutritional intake and either insufficient or excessive mineral intake, and it occasionally increases physiological and psychological stress. Although some parameters such as stress hormones, oxidative stress markers, and magnesium reflect the stress condition of cattle, these parameters occasionally lack reliability and scientific evidence supporting their use as stress indices, leading to ambiguities in interpretation. This limitation suggests that the use of multiple parameters should be required and would be helpful for evaluating stress. In addition, although grazing may have positive effects on antioxidant capacity and immunity, the effects of grazing can be expected to vary with grazing conditions, such as the diversity of vegetation and hygrothermal conditions. Again, using a multifaceted approach comprising nutritional, physiological, and immunological parameters is crucial to evaluating the degree and persistence of the effect of each grazing condition on cattle health. In addition, behavioral selectivity factors such as diet selection are associated with controlling the health status of grazing cattle. Therefore, enhancing forage selectivity in grazing systems is important for improving the health of grazing cattle. Further evaluation is needed to use multiple parameters, including a behavioral index, for assessing the physiological and psychological health of grazing cattle.

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生理学的・免疫学的・栄養学的観点からの牛の健康に対する放牧の効果

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要 約

放牧は行動学的見地及び動物の臨床症状の観点からアニマルウェルフェア上有用と考えられているものの、健康に対する効果の検証例は少なく、特に放牧の生理学的及び免疫学的効果は明らかになっていない。本稿の目的は、近年の知見を元に生理学的、免疫学的、栄養学的観点から放牧の影響を評価し、その影響度をどのように評価するべきか明らかにすることである。栄養面では、タンパク質とエネルギーの摂取アンバランスやエネルギー不足が放牧によってしばしば引き起こされ、家畜のホルモン生産、繁殖、免疫を害することが報告されている。また、放牧は免疫関連細胞の動態に変化を与えることが示されているものの、免疫機能への効果は明らかになっていない。一方で、多様な植生を持つ草地に放牧することとはミネラル摂取バランスの改善に有効であることや林内放牧が酸化ストレスの軽減に有効であることが報告されており、放牧方法とこれら項目との関連性が示されつつある。しかしながら、これらの効果は放牧条件に依存しているため、放牧に関する条件を考慮した上で生理・免疫・栄養学といった多面的指標を用いて放牧の効果を評価していくことが今後必要不可欠である。

キーワード：牛の健康、酸化ストレス、多様な植生、ミネラル摂取、免疫調節

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