Effects of Yak Dung Collection on Plant Functional Group Traits and Productivity in Alpine Meadows (Postprint)

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Abstract

In the vast pastoral areas of alpine meadows on the Qinghai-Tibet Plateau, yak dung remains the primary domestic fuel source for local herders due to inconvenient transportation, energy shortages, and traditional lifestyles. Long-term and large-scale collection of dung alters the quantity and area of dung patches, preventing nutrients from returning to the grassland ecosystem for recycling on natural grasslands, thereby exerting certain influences on grassland plant community structure and biomass, and consequently increasing ecological risks. To investigate the ecological impacts of dung collection on grasslands, this study took the alpine meadow ecosystem in Henan County, Qinghai Province as the research object, and conducted a three-year experimental study with three treatments on yak dung in moderately grazed grasslands: no collection, half collection, and full collection, to explore the effects of dung collection on plant functional group characteristics and productivity in the alpine meadow ecosystem. The results showed that: grassland productivity under the no-collection treatment was significantly lower than that under the half-collection and full-collection treatments, plant diversity was significantly lower than that under the half-collection treatment, biomass of high-quality grasses (Poaceae) was significantly higher than that under the half-collection and full-collection treatments, and biomass of high-quality sedges (Cyperaceae) was significantly higher than that under the full-collection treatment; the half-collection treatment significantly increased grassland vegetation richness by 31.9% compared with the no-collection treatment, significantly increased plant diversity, and significantly enhanced community productivity by 9.7% (42.6 g · m 2), while the biomass of high-quality forage and edible forage showed no significant changes; full dung collection also significantly increased grassland vegetation richness by 10.7% compared with the no-collection treatment, significantly increased plant diversity, and significantly enhanced community productivity by 4.1% (17.96 g · m 2), but simultaneously led to a significant increase in poisonous weeds, a significant

decrease in high-quality forage and edible forage, and deteriorated forage palatability. Dung collection (both half and full collection) significantly reduced the biomass of high-quality grasses and sedges, with sedge biomass decreasing by over 70% in the full-collection area; legume biomass significantly increased, with an extremely significant increase of more than fivefold in the full-collection area; the biomass of forbs and poisonous weeds, which accounted for 74%~79% of total biomass, also significantly increased, with the greatest increment observed in the half-collection area. Moderate dung collection can increase vegetation richness and diversity, enhance vegetation biomass, and ensure forage nutritional quality and palatability. The findings of this study can provide a scientific basis for moderate dung collection and sustainable management of grassland ecosystems in alpine meadow pastoral areas.

Full Text

Preamble

Influence of Yak Dung Collection on Characteristics and Productivity of Plant Functional Groups in Alpine Meadows

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Abstract

In most pastoral areas of the Tibetan Plateau, yak dung remains the primary domestic energy source for local herders due to transportation constraints, energy shortages, and traditional lifestyles. Long-term and large-scale removal of yak dung alters the quantity and area of dung patches, preventing nutrient recycling within the grassland ecosystem and consequently affecting plant community structure and biomass, thereby increasing ecological risks. To investigate these ecological impacts, this study examined the effects of three dung collection treatments—no collection, half collection, and full collection—conducted over three years on moderately grazed alpine meadows in Henan County, Qinghai Province. The results demonstrated that grassland productivity under the no-collection treatment was significantly lower than under half- and full-collection treatments, while plant diversity was significantly lower than under half-collection. The biomass of high-quality gramineous forage grasses was significantly higher under no-collection compared to both half- and full-collection treatments, and the biomass of high-quality cyperaceous forage grasses was significantly higher than under full-collection. Half-collection increased vegetation richness by 31.9% and significantly enhanced plant diversity and community productivity by 9.7% (42.6 $g \cdot m^{-2}$) compared to no-collection, though biomass of high-quality and edible forage grasses showed no significant changes. Full-collection also significantly increased vegetation richness by 10.7% and plant diversity, raising community productivity by 4.1% (17.96 $g \cdot m^{-2}$), but simultane-

ously increased poisonous weeds while decreasing high-quality and edible forage grasses, resulting in poorer palatability. Both half- and full-collection significantly reduced the biomass of high-quality gramineous and cyperaceous forage grasses, with cyperaceous grasses decreasing by over 70% under full-collection. Leguminous plant biomass increased significantly, multiplying more than five-fold under full-collection. The combined biomass of weeds and poisonous weeds, accounting for 74%–79% of total biomass, also increased significantly, with the greatest increment observed under half-collection. Moderate dung collection can enhance vegetation richness and diversity while improving biomass and maintaining forage nutritional quality and palatability. These findings provide a scientific basis for sustainable dung collection practices and ecosystem management in alpine meadow pastoral regions.

Keywords: Alpine meadow; Yak dung collection; Plant functional group; Plant richness; Biomass

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1.1 Study Area Description

The experimental site was located in Amuhu Village, Youganning Town, Henan Mongolian Autonomous County, Huangnan Tibetan Autonomous Prefecture, Qinghai Province. Henan County is situated in southern Qinghai at the junction of three provinces (Qinghai, Gansu, and Sichuan) between 34°50 -34°56 N and 100°3 -102°6 E, with an average elevation of 3,600 m. The county borders Maqin and Tongde Counties to the southwest, Zeku County to the north, Xiahe and Luqu Counties of Gansu Province to the east, and Maqu County of Gansu to the south. The total land area is 6,997.45 km^2, of which 6,471.81 km^2 is grassland with 5,998.29 km^2 being utilizable. The region experiences a plateau continental climate and subfrigid plateau humid climate zone, with warm, rainy conditions from May to October and cold, dry conditions from November to April. The mean annual temperature ranges from -1 to 1.4°C. Precipitation is abundant, with annual rainfall of 597.1–615.5 mm and a higher average evaporation rate of 1,349.7 mm. The dominant grassland type is alpine meadow, with key species including *Kobresia humilis*, *Kobresia pygmaea*, and *Elymus nutans*, accompanied by more than 20 associated species such as *Poa pratensis*, *Stipa capillata*, and *Festuca sinensis*.

1.2.1 Experimental Design

The experiment was conducted on native grassland with relatively uniform vegetation distribution, flat terrain, and consistent parent material in Amuhu Village. The experimental area was fenced with wire mesh in September 2010 and managed under a seasonal grazing system (winter-spring grazing, summer-autumn rest) with moderate stocking rates and consistent livestock numbers. Three parallel 50 m × 10 m plots were established for three treatments: full dung collection, half dung collection, and no dung collection, maintained for three

years. Within each plot, three 1 m × 1 m quadrats were randomly selected as replicates, positioned at least 2 m from the fence edges. Dung collection occurred every 3–4 days, with collection quantity measured by dung pile counts. For the half-collection treatment, total dung piles were counted and then half were removed at regular intervals.

1.2.2 Survey and Sampling

Plant community surveys and sampling were conducted from late July to mid-August 2013 when aboveground biomass reached its peak. For each quadrat, plant species, height, and vegetation coverage were recorded first. Plants were then clipped at ground level from a randomly selected 0.5 m × 0.5 m area within each quadrat, sorted by species, and weighed fresh. Samples were placed in envelopes, transported to the laboratory, and oven-dried at 75°C for 12 hours, with subsequent weighing every 2 hours until constant weight was achieved to determine aboveground biomass dry matter for functional group analysis.

1.3.1 Functional Group Classification

Multiple classification methods exist for grassland plant functional groups. Following common practices in grassland ecosystem research and considering the species composition characteristics of alpine meadows on the Tibetan Plateau, plants were categorized by life form into: annual/biennial plants, perennial grasses, perennial forbs, and sedges. Based on forage palatability, they were divided into five groups: poisonous weeds, poor-quality, medium-quality, good-quality, and excellent-quality forage. According to economic value, they were classified into five groups: gramineous grasses, sedges, legumes, forbs, and poisonous weeds. Since legumes in alpine meadows include both edible and toxic species, legumes were treated as a separate category, excluding toxic legumes from the poisonous weeds group. Given that grassland utilization in alpine meadows primarily emphasizes economic value, this study adopted the economic functional group classification approach.

1.3.2 Population Characteristics

Species Richness Index: Typically expressed as species number per unit area (species density) or species per square meter. Due to high population density in the study area, visual estimation was employed. Richness was represented by species count in a 1 m^2 quadrat: Species Richness Index = number of species in 1 m^2 quadrat.

Species Diversity Index: Analyzed using important value, Shannon-Wiener index, and Pielou evenness index. The important value was calculated as:

$$\text{Important Value} = \frac{\text{Relative Density} + \text{Relative Frequency} + \text{Relative Coverage}}{3}$$

Shannon-Wiener index (H) and Pielou evenness index (J) diversity formulas were:

$$H' = -\sum_{i=1}^{S} p_i \ln(p_i)$$

$$J = \frac{H'}{\ln(S)}$$

Where: p_i represents the important value of species i; S represents total species number in the quadrat, i.e., the species richness index.

1.3.3 Data Analysis

All values for aboveground dry biomass, richness index, and diversity index were calculated as means from three quadrats per treatment. Statistical analysis was performed using SPSS 22 software.

2.1 Plant Composition in the Study Area

Survey results revealed 37 species belonging to 33 genera and 14 families, all angiosperms with no gymnosperms observed. Dicotyledons comprised 12 families, 27 genera, and 30 species, while monocotyledons comprised 2 families, 6 genera, and 7 species. Among the 33 genera, Asteraceae was most abundant with 5 genera (15.15% of total), followed by Poaceae, Ranunculaceae, and Leguminosae with 4 genera each. Gentianaceae and Scrophulariaceae each had 3 genera, while remaining families had 1–2 genera each (Table 1).

2.2 Effects of Dung Collection on Dominant Species

Important value calculations revealed distinct dominant species across treatments (Table 2). The full-collection plot was dominated by *Pedicularis kansuensis* (important value 11.60%), with subdominants including *Poa pratensis*, *Ranunculus tanguticus*, and *Kobresia humilis*. The half-collection plot was dominated by *Elymus nutans* (9.04%), with *Poa pratensis* and *Carex heterostachya* as subdominants. The no-collection plot was dominated by *Poa pratensis* (12.23%), with *Elymus nutans* as subdominant. Notably, the full-collection plot' s dominant species were not high-quality forage, whereas half- and no-collection plots were dominated by excellent forage species, indicating reduced palatability under full-collection.

2.3 Effects of Dung Collection on Functional Group Characteristics and Biomass

Vegetation coverage ranged 93%–95% across treatments, with half-collection slightly higher than no- and full-collection. Vegetation height varied 5.40–5.70

cm, with no significant difference between no- and half-collection, both significantly higher than full-collection. Biomass differed significantly among treatments, peaking in half-collection (9.7% higher than no-collection), followed by full-collection (4.1% higher than no-collection), with no-collection lowest. Richness index was significantly higher under half-collection compared to both other treatments, with no-collection lowest, demonstrating that dung collection significantly increased plant richness by 31.9% under half-collection and 10.7% under full-collection. Shannon-Wiener diversity index ranged 1.64–1.77, significantly higher in half-collection than full-collection, but not significantly different from no-collection. Pielou evenness index showed no significant differences among treatments, indicating minimal impact on vegetation uniformity (Table 3).

2.4 Effects of Dung Collection on Economic Functional Group Productivity

The five economic functional groups (gramineous grasses, sedges, legumes, forbs, and poisonous weeds) responded differently to dung collection treatments (Table 4). Aboveground biomass of gramineous grasses decreased with increasing dung collection, showing significant reductions of 27.7% and 9.6% under full-collection compared to no- and half-collection, respectively. Sedge biomass showed no significant difference between no- and half-collection, but was significantly higher than under full-collection. Legume biomass showed no significant difference between no- and half-collection, but was significantly higher under full-collection, exceeding the other treatments by more than fivefold. Forb biomass was highest under half-collection, significantly greater than both other treatments, which did not differ significantly. Poisonous weed biomass was highest under full-collection and lowest under half-collection, with significant differences among all treatments.

Gramineous and cyperaceous grasses represent high-quality forage; their proportion of total biomass reflects grassland quality. The proportion of gramineous grass biomass was significantly lower under half- and full-collection than no-collection. Sedge proportion decreased dramatically under full-collection to only 23.8% of that under no-collection, with no significant difference between no- and half-collection. Legume proportion under full-collection exceeded that under no- or half-collection by more than fivefold. Since over 90% of legumes in the study area are toxic, their substantial increase combined with sedge reduction under full-collection indicates grassland degradation. Forbs and poisonous weeds, both undesirable forage, collectively accounted for 74%–79% of total biomass, with their combined proportion significantly higher under both collection treatments than no-collection. These results demonstrate that no-collection maintained high forage quality and palatability, while increased weed and poisonous weed biomass under collection treatments reduced grassland quality.

3 Discussion and Conclusions

Previous research has demonstrated that dung decomposition influences grassland nutrient cycling, primary productivity, and species diversity. This study' s comparison of vegetation diversity and economic group productivity across three dung collection intensities corroborates these findings, showing that dung collection alters plant diversity, richness, and biomass. Davis et al. [3] similarly concluded that livestock dung significantly contributes to plant biomass, richness, and herbaceous abundance. In this study, vegetation coverage, richness, diversity, and biomass were all lower under no- and full-collection compared to half-collection, suggesting that moderate, appropriate dung collection can promote sustainable grassland ecosystem management. This likely occurs because partial dung collection exposes bare ground beneath dung patches, facilitating colonization by other plant species, while remaining dung provides sufficient nutrients for new populations, thereby increasing richness, diversity, and productivity.

Regarding productivity, half-collection yielded the highest productivity while no-collection produced the lowest, consistent with Jiang et al. [12] who reported that dung accumulation reduces plant growth area to only 3–5 cm around dung piles, decreasing grassland productivity by 11.2% within the affected zone. This reduction likely results from impaired photosynthesis and air circulation beneath dung patches, causing rapid plant mortality.

Analysis by plant category revealed that no-collection maintained significantly higher yields of high-quality forage than both collection treatments, while full-collection showed higher proportions of poisonous weeds. This may occur because dung decomposition releases nutrients into the soil, promoting aboveground plant growth. Additionally, dung carries seeds of plants consumed by yaks, which germinate under suitable conditions after decomposition. The study also observed that monocotyledonous plants responded more strongly to dung than dicotyledonous plants, though supporting literature for this finding is lacking and requires further investigation.

This study employed only three treatments (no-, half-, and full-collection). Determining optimal dung collection rates would require additional intermediate treatment levels to draw more robust conclusions, representing a direction for future research.

In summary, dung collection significantly impacts grassland vegetation characteristics and biomass. Complete non-collection causes dung accumulation and reduces grassland productivity, though it increases high-quality and edible forage production. Moderate dung collection enhances grassland productivity, richness, and diversity while promoting healthy grassland development. Excessive collection, while increasing richness and diversity to some extent, compromises forage quality. Different economic functional groups respond variably to dung collection: gramineous and cyperaceous forage biomass decreases, with sedges declining over 70% under full-collection; legume biomass increases, multiplying

more than fivefold under full-collection; and forb plus poisonous weed biomass increases, most notably under half-collection. Large-scale dung collection can shift community dominance to weeds and poisonous weeds, degrading forage nutritional value and palatability.

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Note: Figure translations are in progress. See original paper for figures.