

Analysis of Labor Productivity in Single and Multi-household Grassland Management Patterns: A Case Study in Maqu County, Qinghai-Tibetan Plateau

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Abstract

This study investigated labor productivity in meat and milk/dairy production within single and multi-household management patterns, based on primary data collected from 156 randomly selected herder households in Maqu County, Tibetan Plateau. The results showed that in the rotational grazing system, herder households in both single and multi-household management patterns achieved higher labor productivity for meat production (70.36 Kg/man-day and 51.21 Kg/man-day, respectively) compared to the overall study households (40.89 Kg/man-day). In contrast, within the continuous grazing system, the single-household management pattern recorded lower labor productivity for meat production (23.04 Kg/man-day). Significantly, regional variations in the distance between pastures and market centers led herder households in the single-household management pattern within the continuous grazing system to achieve superior labor productivity for milk and dairy production (19.74 \$/man-day) compared to the overall study households (15.44 \$/man-day). In the rotational grazing system, labor productivity for milk and dairy production stood at 12.63 \$/man-day for the single-household management pattern and 8.30 \$/man-day for the multi-household management pattern. These findings underscore the complexities associated with achieving high labor productivity simultaneously in both meat and milk/dairy production within the same grassland management pattern. While the multi-household management pattern shows promise in reducing labor inputs, it also grapples with challenges in achieving substantial production levels for meat and milk/dairy products. To address these challenges, policymakers should consider follow-up measures that prioritize the simultaneous enhancement of meat and milk/dairy production within the multi-household management pattern. Special attention should be given to reducing the distance between herder households and market centers to facilitate the sale of milk/dairy products. Simply advocating for the broader adoption of the multi-household management pattern may fall short without addressing these production-related hurdles.

Keywords: labor productivity, meat production, milk and dairy production, grassland management patterns, Tibetan Plateau

1. Introduction

China's expansive grasslands, covering a substantial 400 million hectares, represent approximately 42% of the world's total land area. Among these, the Qinghai-Tibetan Plateau (QTP) stands as the largest alpine grassland globally, serving as a crucial habitat for nearly 41 million Tibetan sheep, 13 million yaks (Long et al., 2009), and more than 1.3 million cattle and cattle-yak hybrids. This unique ecosystem supports a human population exceeding 9.8 million individuals (Long, 2003). However, ecological challenges, including reduced biodiversity, soil erosion, and the emergence of sandstorms resulting from inadequate grassland management practices (Akiyama & Kawamura, 2007), combined with the impact of climate change (Hao et al., 2014), have placed constraints on the sustainable development of animal husbandry and posed substantial threats to the fundamental ecological and societal stability of the QTP (Pulido et al., 2018).

The privatization of grasslands has garnered support in various countries and regions, including China, Central Asia, and South Africa, as a strategy to address ecological challenges stemming from overgrazing. This approach is also intended to incentivize herders to embrace sustainable grassland management practices (Ybarra, 2009;

Mwangi, 2016). In China, the Household Responsibility System (HRS) was instituted in the 1980s, leading to the privatization of grasslands and livestock through the implementation of fixed fencing (Yang et al., 2020). This marked a shift away from the collective model characteristic of the communist revolution, which had spurred labor motivation and yielded a period of heightened agricultural production in the 1990s (Li et al., 2018). Nevertheless, the rigid property ownership, defined pasture boundaries, and independent livestock management inherent in the single-household management pattern (SHMP) have constrained the flexibility of grassland management and the mobility of grazing (Hobbs et al., 2008). Over time, this has contributed to the progressive degradation of grasslands, resulting in diminished pastoral productivity and escalating production costs. Consequently, a segment of herders has been compelled to discontinue livestock rearing (Zhou & Dong, 2013).

In response to the challenges stemming from the HRS, the central government of China introduced the Grassland Ecological Protection Award Policy in pastoral areas across the country, a measure initiated in 2011. This policy involves stringent controls on the number of livestock that herder households are permitted to raise per unit area (Zhang et al., 2019). While numerous ecological studies have affirmed that grassland degradation in China has been mitigated and improved (Zhao et al., 2021; Wang et al., 2022), herder households have incurred substantial economic losses as the policy subsidies have not adequately compensated for the significant reduction in livestock income (Xiao et al., 2022). Furthermore, the strict stocking rate regulations have compelled herder households to transition from exclusive grassland grazing to a combined approach of grazing and shed feeding (Wang et al., 2019). This shift, accompanied by rising forage and labor costs, has led to a considerable exodus of herders from pastoral areas (Liu, 2016).

Within the context outlined above, ecological research rooted in grazing experiments has suggested that the spontaneously emerging multi-household management pattern (MHMP) may constitute a more efficacious approach. In the MHMP, two or more herder households unite contiguous pastures, a practice that not only augments grazing mobility, thereby fostering grassland restoration (Cao et al., 2018; Li et al., 2018; Zhang et al., 2020), but also facilitates labor savings through collaborative efforts among the households within the MHMP (Cao et al., 2011). In 2015, the Chinese central government initiated a policy aimed at promoting grassland circulation, entailing the separation of land ownership, rights consolidation, and land use rights (Yang et al., 2021). Furthermore, in 2019, it advocated for the transition from the SHMP to the MHMP, encouraging MHMP members to collectively procure and share production resources (General Office of the State Council, 2019). Despite these concerted efforts, however, the SHMP still predominates in grassland management across China, encompassing 75% of the total contracted grassland area, whereas the MHMP accounts for only 23% (Wang et al., 2020). In practical terms, widespread adoption of the MHMP has yet to materialize (Yang et al., 2021).

Given the labor-intensive nature of current livestock production methods in alpine pastoral areas (Conte & Tilt, 2014), coupled with the primary objective of laborers engaged in agricultural and pastoral practices to obtain tradable agricultural and pastoral products (Fang et al., 2010), it is pertinent to recognize that while the mutual cooperation advocated within the MHMP may yield labor savings, the relationship between labor inputs and outputs warrants careful consideration. In essence, a reduction in labor input contributes positively to production only if, under *ceteris paribus* conditions (assuming other production factors remain constant), the marginal product of labor—*i.e.*, the additional output produced per unit of labor—either remains steady or increases as a consequence of the reduced labor input (Mankiw, 2014). In simpler terms, a decrease in labor input benefits production only if the quantity of products produced per unit of time does not decrease by the same proportion as the reduction in labor input. However, it is worth noting that much of the existing research has predominantly centered on assessing the ecological aspects of grasslands in the context of the SHMP and the MHMP. These studies, often conducted through grazing experiments, have demonstrated that the MHMP exhibits a higher degree of resilience in terms of vegetation and soil characteristics (Cao et al., 2018; Li et al., 2018; Zhang et al., 2020). Additionally, some research efforts have explored the factors contributing to the formation of the MHMP, the associated property rights systems, and the composition of household income. Through a combination of qualitative and quantitative analyses, these studies have revealed that the spontaneous emergence of large-scale MHMP among herder households in the context of land transfer has effectively augmented herders' non-farm income (Cao et al., 2017; Yang et al., 2020; Zhou et al., 2021). Nevertheless, there is a notable absence of analysis concerning the labor productivity of herder households in different grassland management patterns. Therefore, this study aims to analyze labor productivity in both single (SHMP) and multi-household management patterns (MHMP), with the goal of providing new insights for policymakers to further enhance measures related to the expansion of the multi-household management pattern from the perspective of labor inputs and outputs.

2. Materials and Methods

2.1 Study Site

Maqu County, situated in Gansu Province in northwest China (coordinates 35°58'N, 101°53'E, at an elevation of 3500 m above sea level), constitutes a significant pastoral region within the area. It serves as a pivotal hub for livestock production in the region, characterized by an annual rainfall ranging from 450 to 780 mm and an average annual temperature of 1.8 °C. The expansive grassland terrain encompasses approximately 87×10^4 ha, with alpine meadows occupying the majority at 59%. As of the year 2020, Maqu County boasted a total population of approximately 57,000 inhabitants, of which herders accounted for a substantial 75%. The primary source of income for these herders is derived from livestock trading, constituting approximately 89% of their total income (Du et al., 2022). The remaining income is generated through the sale of livestock by-products (Li et al., 2022).

2.2 Data Collection

In this study, surveys were conducted using telephone and face-to-face questionnaires between November 2021 and March 2022. These surveys were administered in randomly selected villages around Maqu County. Respondent selection was carried out in a randomized manner, ensuring representation from each chosen village. Prior to commencing the survey, a preliminary assessment was undertaken to ensure the clarity and uniformity of the questionnaire. This questionnaire included fundamental inquiries about the herders' households, their management of animal husbandry, and their household gross income.

To ensure the precision of responses and mitigate potential language barriers, we enlisted the assistance of six local Tibetans to administer the questionnaires. This team consisted of five college students and one civil servant, all proficient in the local dialect and customs. Additionally, all enumerators underwent standardized training to minimize potential biases resulting from variations in the interpretation of questionnaire questions. Prior to commencing each questionnaire, we provided a comprehensive explanation of the study's objectives to each participant and obtained their consent. With the invaluable assistance of the local enumerators, we successfully collected a total of 165 questionnaires, resulting in an effective response rate of 94.55%. Within this dataset, 121 questionnaires were obtained from single-household management patterns (SHMP), including 83 from continuous grazing systems (CGS) and 38 from rotational grazing systems (RGS). The remaining 35 questionnaires were associated with multi-household management patterns (MHMP), all of which belonged to RGS. It's worth noting that nine questionnaires were excluded from the analysis due to invalid or missing data.

2.3 Research Methods

The choice of productivity measurement methods depends on the specific objectives of the measurement and the accessibility of relevant data. Labor productivity is a commonly assessed metric, typically quantified by the ratio of output to labor input, with either gross output or value added used as a surrogate for output (OECD, 2001). Output can be quantified in either monetary or in-kind units, while labor input can be represented by various metrics, including the number of hours worked, the number of days worked, the number of shifts worked, or the average size of the labor force (Kubáľková, 2009).

As livestock production encompasses both meat and milk production (Food and Agriculture Organization of the United Nations, 2018), the labor productivity assessment in this study was divided into two components: meat production and milk and dairy production. The selection of measurement units was determined based on prevailing herder practices within the study area and data availability. Experienced herders typically possess a keen understanding of livestock weights at various stages of growth. Consequently, this study quantified meat production in terms of live animal weights. In addition, milk and dairy production were evaluated using monetary units since herders typically did not record the weights of milk and dairy products but rather tracked their income from livestock by-products. Labor inputs were measured in terms of the number of days worked. To standardize labor input, a full day of labor (comprising 24 hours daily and 365 days annually) was converted into working days, accounting for 10 hours daily and 364 days yearly. The conversion rate for monetary units was pegged to the exchange rate set by the People's Bank of China for December 2021, with 6.5 RMB equating to 1 USD. The labor productivity models for meat production (LP_m) and milk and dairy production (LP_d) were therefore defined as follows:

$$LP_m = \frac{\sum_{i=1}^n E_i - B_i}{\sum_{i=1}^n T_i} \quad (1)$$

$$LP_d = \frac{\sum_{i=1}^n C_i}{\sum_{i=1}^n D_i} \quad (2)$$

where, E_i represents the total weight of livestock at the end of the year (including livestock sold, stocked, and self-consumed) for the i^{th} household, B_i represents the total weight of livestock at the beginning of the year for the i^{th} household, T_i represents the total input of working days corresponding to meat production for the i^{th} household; C_i represents the cash income from milk and dairy production obtained by the i^{th} household in selling units, D_i represents the total input of working days corresponding to milk and dairy production for the i^{th} household, and n represents the total number of households corresponding to each management pattern.

Given the potential influence of continuous grazing systems (CGS) and rotational grazing systems (RGS) on labor inputs (Windh et al., 2019), this study conducted separate analyses for the grazing systems under both the single-household management pattern (SHMP) and the multi-household management pattern (MHMP).

2.4 Input and Output Variables Description

Meat production involves various key activities, including livestock release and gathering, vaccinations, fence repairs, forage sowing and harvesting, pasture transfers, and livestock sales, as delineated in Table 1. The average full-year labor input for meat production varied among herder households within different management patterns and grazing systems. In SHMP-RGS, herder households worked an average of 113.87 days per year for meat production, while in SHMP-CGS, they worked 103.09 days. Both of these exceeded the overall study household average of 100.79 working days. In contrast, herder households within MHMP-RGS expended an average of 81.12 working days, which was lower than the overall study household average. Specifically, herder households in MHMP-RGS devoted 77.31 working days throughout the year to livestock management, which was lower than the 95.3 working days spent by the overall study households. Conversely, herder households in SHMP-CGS and SHMP-RGS invested an average of 98.9 and 104.02 working days throughout the year, respectively, exceeding the overall study household average. For livestock vaccinations, which took place between June and July each year, the average full-year labor input of herder households in MHMP-RGS was less than the 0.49 working days of the overall study households. Conversely, herder households in SHMP-CGS and SHMP-RGS expended 0.52 and 0.61 working days throughout the year, respectively, exceeding the overall study household average. Regarding fence repairs, herder households in both SHMP-CGS and MHMP-RGS contributed a lower average full-year labor input than the 3.12 working days of the overall study households. However, herder households in SHMP-RGS allocated an average of 4.60 working days throughout the year, surpassing the overall study household average. For forage sowing and harvesting, activities occurring between June and July and September and October each year, herder households in both SHMP-CGS and MHMP-RGS devoted an average full-year labor input lower than the 0.56 working days of the overall study households. Conversely, the average full-year labor input for herder households in SHMP-RGS exceeded the overall study household average. Regarding pasture transfers, a practice undertaken by herders in both SHMP-RGS and MHMP-RGS from winter to summer pastures at the end of April or the beginning of May each year and again to winter pastures at the end of September or the beginning of October, the average full-year labor input of herder households in SHMP-RGS was higher than the 1.08 working days of the overall study households. In contrast, herder households in MHMP-RGS spent 0.65 working days throughout the year, which was lower than the overall study household average. Lastly, herders transported their available livestock to the local sole trade center at the end of the production cycle in October for trading based on market prices and livestock weights. Herder households in SHMP-RGS expended an average full-year labor input exceeding the 0.82 working days of the overall study households. Conversely, herder households in both SHMP-CGS and MHMP-RGS allocated 0.76 and 0.48 working days throughout the year, respectively, which were less than the overall study household average.

Milk and dairy production activities encompass milking, as well as the production of ghee and cheese, which typically occur between May and September. In terms of labor input, herder households in both SHMP-CGS and MHMP-RGS dedicated fewer working days compared to the overall study households, which averaged 64.92 working days for these activities. However, herder households in SHMP-RGS allocated more time to milk and dairy production, averaging 78.26 working days. Specifically, the average labor inputs for milking, ghee making, and cheese making in SHMP-RGS were 42.80, 26.14, and 9.32 working days, respectively, surpassing the corresponding figures for the overall study households. In the case of herder households in SHMP-CGS, they expended 42.20 working days on milking, which exceeded the overall average. However, their average labor

input for ghee and cheese making was 21.39 and 0 working days, respectively, lower than the overall study household averages. Within MHMP-RGS, the average labor input for milking and ghee making was lower than the figures for the overall study households. Nonetheless, the average labor input for cheese making was 3.2 working days, which exceeded the corresponding value for the overall study households.

Table 2 displays meat production by herder households from yaks and Tibetan sheep. In SHMP-RGS, herder households exhibited higher average initial weights, end weights, and growth weights for the total number of yaks they raised, recording 26,204.89 kg, 34,015.13 kg, and 7,810.24 kg, respectively. This contrasts with the overall study households, which reported 13,461.78 kg, 17,509.71 kg, and 4,047.93 kg, respectively. Conversely, the average initial weights, end weights, and growth weights of the total number of Tibetan sheep raised in SHMP-RGS were lower than those observed in the overall study households. For SHMP-CGS and MHMP-RGS, the average initial and end weights of the total number of yaks raised by herder households were lower than those reported for the overall study households. However, the average initial and end weights of the total number of Tibetan sheep raised were higher than those of the overall study households. In SHMP-CGS, the growth weight of the total number of yaks raised by herder households was lower than that recorded for the overall study households. In contrast, the growth weight of the total number of Tibetan sheep raised was higher in SHMP-CGS. Within MHMP-RGS, the growth weight of the total number of yaks raised by herder households exceeded that observed in the overall study households, whereas the growth weight of the total number of Tibetan sheep raised was lower in MHMP-RGS compared to the overall study households.

Table 2 also presents the cash income generated by herder households through milk, ghee, and cheese production. In SHMP-CGS, the average cash income derived from milk and ghee exceeded that of the overall study households. Specifically, herder households garnered an average of \$825.61 from milk and \$463.08 from ghee, in contrast to \$684.31 and \$346.76 for the overall study households, respectively. However, the average cash income from cheese was lower in SHMP-CGS, with herder households earning an average of less than \$16.06, compared to the overall study households. In SHMP-RGS, the average cash income from milk and cheese surpassed that of the overall study households, with herder households earning an average of \$716.45 and \$33.60, respectively. Nonetheless, the average cash income from ghee was lower, with herder households earning \$293.47, compared to the overall study households. Within MHMP-RGS, the average cash income from milk and ghee was inferior to that of the overall study households, while the average cash income from cheese was higher.

Table 1. Labor inputs of herder households in livestock production in each management pattern

| Item | SHMP-CGS ¹ (n = 83) | | SHMP-RGS ² (n = 38) | | MHMP-RGS ³ (n = 35) | | Overall (N = 156) | |
|--|-----------------------------------|-------|-----------------------------------|-------|-----------------------------------|-------|----------------------|-------|
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| <i>Meat production (man-day⁴)</i> | | | | | | | | |
| Release of livestock | 40.35* | 9.87 | 43.11 | 20.48 | 21.51* | 7.52 | 36.79 | 15.27 |
| Gathering of livestock | 58.55 | 9.87 | 60.91 | 20.75 | 55.80 | 10.35 | 58.51 | 13.45 |
| Livestock vaccinations | 0.52 | 0.40 | 0.61* | 0.14 | 0.29* | 0.20 | 0.49 | 0.33 |
| Fence repairs | 2.86 | 1.95 | 4.60* | 3.04 | 2.12* | 0.90 | 3.12 | 2.28 |
| Forage sowing | 0.01* | 0.08 | 0.62* | 0.40 | 0.10* | 0.05 | 0.18 | 0.32 |
| Forage harvesting | 0.04* | 0.19 | 1.31* | 0.76 | 0.18* | 0.06 | 0.38 | 0.67 |
| Pasture transfer ⁵ | - | - | 1.47* | 0.79 | 0.65* | 0.18 | 1.08 | 0.71 |
| Livestock sales | 0.76* | 0.18 | 1.25* | 0.62 | 0.48* | 0.23 | 0.82 | 0.44 |
| Total | 103.09 | 21.45 | 113.87 | 40.94 | 81.12* | 17.47 | 100.79 | 29.03 |
| <i>Milk and dairy production (man-day)</i> | | | | | | | | |
| Milking | 42.20 | 12.05 | 42.80 | 15.79 | 33.00* | 11.69 | 40.28 | 13.48 |
| Ghee making | 21.39 | 5.87 | 26.14* | 6.86 | 17.40* | 5.73 | 21.65 | 6.76 |
| Cheese making | 0.00 | 0.00 | 9.32* | 15.45 | 3.20 | 0.98 | 2.99 | 8.47 |
| Total | 63.59 | 14.04 | 78.26* | 24.93 | 53.60* | 15.67 | 64.92 | 19.49 |

Note. * denotes the significance level of 0.05 for the difference in means of the corresponding indicator between herder households in each grassland management pattern and the overall study households. SD denotes the standard deviation of the mean. ¹ SHMP-CGS = single household management pattern-continuous grazing system. ² SHMP-RGS = single household management pattern-rotational grazing system. ³ MHMP-RGS = multi household management pattern-rotational grazing system. ⁴ Man-day denotes the amount of work done by one person in one day (10 hours daily × 364 days yearly). ⁵ Pasture transfer denotes the transfer of livestock between summer and winter pastures.

Source: Authors' calculations from field study data.

Table 2. Output of herder households in livestock production in each management pattern

| Item | SHMP-CGS (n = 83) | | SHMP-RGS (n = 38) | | MHMP-RGS (n = 35) | | Overall (N = 156) | |
|----------------------------------|------------------------|--------------------|-------------------------|---------------------|------------------------|---------------------|------------------------|--------------------|
| | Yak | Sheep | Yak | Sheep | Yak | Sheep | Yak | Sheep |
| <i>Meat production</i> | | | | | | | | |
| Kg | | | | | | | | |
| Initial weight | 8855.34* (5606.29) | 378.84 (473.85) | 26204.89* (15233.56) | 135.26* (611.45) | 10550.23* (7779.43) | 493.49 (1435.47) | 13461.78 (11763.76) | 345.23 (822.44) |
| End weight | 11093.31* (6036.72) | 467.54 (556.70) | 34015.13* (17793.81) | 151.55* (680.15) | 14805.54 (9908.85) | 532.94 (1529.76) | 17509.71 (14383.42) | 405.24 (899.58) |
| Growth weight | 2237.98* (1421.13) | 88.70* (107.15) | 7810.24* (3057.96) | 16.29* (70.31) | 4255.31 (2429.24) | 39.46 (133.41) | 4047.93 (3135.17) | 60.01 (110.28) |
| <i>Milk and dairy production</i> | | | | | | | | |
| \$ ¹ | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Milk | 825.61* | 472.07 | 716.45 | 451.45 | 314.35* | 273.70 | 684.31 | 474.16 |
| Ghee | 463.08* | 264.78 | 293.47 | 184.92 | 128.76* | 112.11 | 346.76 | 258.23 |
| Cheese | 00.00 | 00.00 | 33.60 | 117.21 | 64.18* | 90.29 | 16.06 | 81.96 |
| Total | 1288.69* | 736.85 | 1043.52 | 642.33 | 507.29* | 472.46 | 1053.65 | 729.18 |

Note. * denotes the significance level of 0.05 for the difference in means of the corresponding indicator between herder households in each grassland management pattern and the overall study households. Values denote the average with the standard deviation in parenthesis. SD denotes the standard deviation of the mean. ¹ Based on the exchange rate of the People's Bank of China in December 2021, 1\$ = 6.5 RMB.

Source: Authors' calculations from field study data.

3. Results and Discussion

3.1 Descriptive Analysis of the Sample Households

Table 3 illustrates that family members constituted the primary labor force in the research area, with young adults predominantly comprising the available workforce across all management patterns. The average available labor force within herder households in SHMP-CGS and SHMP-RGS consisted of two individuals, which was consistent with the overall study household figures. However, in MHMP-RGS, the average available labor force was three individuals. Despite having an average of over 22 years of engagement in production, the available labor force within herder households had limited educational backgrounds, typically receiving only 2-3 years of formal education across different management patterns.

The principal livestock reared by herder households were yaks and Tibetan sheep. The average pasture area owned increased progressively from SHMP-CGS (58.20 ha) to MHMP-RGS (103.81 ha) and SHMP-RGS (186.24 ha). The average numbers of yaks and Tibetan sheep reared in the respective management patterns were as follows: 36 and 9, 45 and 10, and 80 and 3. Specifically, 31, 31, and 36 households exclusively reared yaks in the three respective management patterns, while mixed rearing was conducted by 52, 4, and 2 households, respectively. Production practices also varied among the management patterns. Herders in both SHMP-RGS (33.74 km) and MHMP-RGS (17.34 km) engaged in livestock transfers between summer and winter pastures according to seasonal shifts, adapted grazing routes to accommodate livestock foraging, and utilized superior animals for breeding purposes. Forage seeding was performed by all households in SHMP-RGS and MHMP-RGS, but only by three households in SHMP-CGS. Notably, across all three management patterns, herder households were situated at varying distances from the local market center, spanning from 9.01 to 25.69 km. Consequently, ownership of motorbikes was a common occurrence.

Table 3. Descriptive statistics of each management pattern

| Variable | SHMP-CGS (n = 83) | SHMP-RGS (n = 38) | MHMP-RGS (n = 35) | Overall (N = 156) |
|--|----------------------|----------------------|----------------------|----------------------|
| <i>Demographic characteristics</i> | | | | |
| Age of the labor force per household (years) | 37.42 (6.26) | 38.87 (7.08) | 42.06 (6.96) | 38.81 (6.84) |
| Time in education of the labor force per household (years) | 1.76 (2.66) | 2.98 (4.00) | 2.26 (2.28) | 2.17 (2.99) |
| Production experience of the labor force per household (years) | 22.77 (6.09) | 24.36 (8.48) | 25.82 (8.89) | 23.84 (7.46) |
| Available labor force per household ¹ (people) | 2.37 (0.91) | 2.29 (0.93) | 2.80 (0.87) | 2.45 (0.92) |
| <i>Management characteristics</i> | | | | |
| Yak rearing (households) | 31.00 | 36.00 | 31.00 | 98.00 |
| Mixed rearing ² (households) | 52.00 | 2.00 | 4.00 | 58.00 |
| Sowing of forage seed (households) | 3.00 | 38.00 | 35.00 | 76.00 |
| Ownership of motor vehicle (households) | 62.00 | 27.00 | 20.00 | 109.00 |
| No. of yaks reared (households) | 36.00 | 80.00 | 45.00 | 49.00 |
| No. of Tibetan sheep reared (households) | 9.00 | 3.00 | 10.00 | 7.00 |
| Area of pasture per household (ha) ³ | 58.20 (31.66) | 186.24 (119.38) | 103.81 (52.47) | 99.62 (85.43) |
| Distance between pastures ⁴ (km) | - | 33.74 (29.46) | 17.34 (7.03) | 25.88 (23.18) |
| Distance of households to market (km) | 9.01 (6.25) | 25.19 (15.04) | 25.69 (13.42) | 16.92 (13.62) |

Note. Values denote the average with the standard deviation in parenthesis. ¹ Available labor denotes labor force that normally participates in production all year round. ² Mixed rearing includes yaks and Tibetan sheep. ³ 1ha = 15mu. ⁴ Distance between pastures denotes the distance between summer and winter pastures.

Source: Authors' calculations from field study data.

3.2 Labor Productivity for Livestock Production in Each Management Pattern

3.2.1 Labor Productivity in SHMP-CGS

Table 4 displays the labor productivity for meat production among herder households in SHMP-CGS. The range of labor productivity in this pattern varied from 4.71 Kg/man-day to 70.73 Kg/man-day, with a mean of 23.04 Kg/man-day, which was lower than that of the overall study households (40.89 Kg/man-day). Notably, the majority of herder households (63.85%) demonstrated labor productivity between 10 Kg/man-day and 30

Kg/man-day. It is important to note that in SHMP-CGS, livestock are confined to a single pasture throughout the year, limiting their mobility. Studies have shown that limited mobility can increase pasture trampling (Yeh et al., 2014), resulting in higher soil bulk density and lower vegetation cover and aboveground biomass (Klimeš et al., 2013). Consequently, this may restrict livestock growth by limiting their access to fresh and adequate native grasses (Kerven et al., 2016).

In Table 5, the labor productivity for milk and dairy production among herder households is shown. The range of labor productivity varied from \$5.92/man-day to \$39.74/man-day, with a mean of \$19.74/man-day, which was higher than that of the overall study households (\$15.44/man-day). Furthermore, the majority of herder households (68.68%) demonstrated labor productivity between \$10/man-day and \$30/man-day. Herder households in SHMP-CGS had an advantage in terms of market access, with a distance of only 9.01 km to the market center, enabling same-day delivery of milk and dairy products via motorcycle. Consequently, the average labor time spent by herder households on milking and dairy production activities between May and September was approximately 63.59 working days, resulting in an average annual income from the sale of milk and dairy products of \$1,288.69. This finding aligns with previous observations that the milk sales of herder households are influenced by market distance, as reported by Hussen (2007).

3.2.2 Labor Productivity in SHMP-RGS

In SHMP-RGS (Table 4), the labor productivity for meat production among herder households ranged from 29.13 Kg/man-day to 125.68 Kg/man-day, with a mean of 70.36 Kg/man-day, surpassing that of the overall study households (40.89 Kg/man-day). Additionally, the majority of herder households (50.00%) achieved labor productivity levels between 60.00 Kg/man-day and 80.00 Kg/man-day. Previous research has underscored the significance of rotational grazing in improving livestock production. The practice of transferring livestock between summer and winter pastures enhances pasture recovery periods, native grass utilization efficiency, and livestock mobility, thereby benefiting livestock growth (Zhang et al., 2020; Kerven et al., 2016).

The labor productivity for milk and dairy production among herder households in SHMP-RGS ranged from \$3.76/man-day to \$26.95/man-day, with a mean of \$12.63/man-day. This was slightly lower than the labor productivity of the overall study households, which averaged \$15.44/man-day (Table 5). The majority of herder households in SHMP-RGS (84.21%) demonstrated labor productivity levels between \$0/man-day and \$20/man-day. The larger livestock scale owned by herder households in SHMP-RGS resulted in increased labor time spent on milking and dairy production activities (80 yaks/household; 78.26 man-days/household). However, due to the distance from the market center (25.19 km) and the requirement for fresh high-quality milk at the collection point, herders couldn't deliver milk collected at dusk on the same day. Consequently, the average annual income earned by herder households, excluding milk and dairy products used for self-consumption and donations to monasteries, amounted to approximately \$1043.52.

3.2.3 Labor Productivity in MHMP-RGS

In MHMP-RGS (Table 4), the labor productivity for meat production among herder households ranged from 18.28 Kg/man-day to 108.62 Kg/man-day, with a mean of 51.21 Kg/man-day. This was higher than the labor productivity of the overall study households, which averaged 40.89 Kg/man-day. Additionally, the majority of herder households in MHMP-RGS (51.43%) demonstrated labor productivity levels between 30.00 Kg/man-day and 60.00 Kg/man-day. The MHMP-RGS pattern allows member households to combine adjacent pastures, providing better opportunities for livestock to access high-quality, abundant native grasses and drinkable water (Klimeš et al., 2013). Furthermore, member households monitor and control the number of livestock reared by each other, enabling livestock to choose more palatable plants. This results in prolonged rumination time and a greater nutrient supply to the rumen, facilitating livestock weight gain (Askar et al., 2013).

The labor productivity for milk and dairy production among herder households ranged from \$2.37/man-day to \$22.56/man-day, with a mean of \$8.30/man-day. This labor productivity was concentrated between \$0/man-day and \$30/man-day, which was lower than that of the overall study households (\$15.44/man-day) (Table 5). Furthermore, the majority of herder households (77.14%) exhibited labor productivity levels between \$0/man-day and \$10/man-day. In the multi-household management pattern, the number of livestock reared by each member household was strictly controlled, leading to a reduction in the average labor time spent by herder households on milking and dairy production activities (45 yak/household; 53.60 man-day/household). Additionally, due to the relative distance of these households from the market center (25.69 km) and their collective living arrangement, opportunities for bartering between members of the multi-household management pattern with livestock by-products were available. Ultimately, the average annual income obtained by member households from the sale of milk and dairy products was \$507.29.

Table 4. Labor productivity for meat production in each management pattern

| Productivity (Kg/man-day) | SHMP-CGS | | SHMP-RGS | | MHMP-RGS | | Overall | |
|---------------------------|----------|---------|----------|---------|----------|---------|---------|---------|
| | Freq | % | Freq | % | Freq | % | Freq | % |
| (1.00, 10.00] | 11 | 13.25 | 0 | 0 | 0 | 0 | 11 | 7.05 |
| (10.00, 20.00] | 34 | 40.96 | 0 | 0 | 1 | 2.86 | 35 | 22.44 |
| (20.00, 30.00] | 19 | 22.89 | 1 | 2.63 | 6 | 17.14 | 26 | 16.67 |
| (30.00, 40.00] | 9 | 10.84 | 1 | 2.63 | 5 | 14.29 | 15 | 9.62 |
| (40.00, 50.00] | 4 | 4.82 | 1 | 2.63 | 6 | 17.14 | 11 | 7.05 |
| (50.00, 60.00] | 2 | 2.41 | 7 | 18.42 | 7 | 20.00 | 16 | 10.26 |
| (60.00, 70.00] | 3 | 3.61 | 10 | 26.32 | 5 | 14.29 | 18 | 11.54 |
| (70.00, 80.00] | 1 | 1.20 | 9 | 23.68 | 2 | 5.71 | 12 | 7.69 |
| (80.00, 90.00] | 0 | 0 | 5 | 13.16 | 1 | 2.86 | 6 | 3.85 |
| (90.00, 100.00] | 0 | 0 | 1 | 2.63 | 0 | 0 | 1 | 0.64 |
| (100.00, 110.00] | 0 | 0 | 1 | 2.63 | 2 | 5.71 | 3 | 1.92 |
| (110.00, 120.00] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| (120.00, 130.00] | 0 | 0 | 2 | 5.26 | 0 | 0 | 2 | 1.28 |
| Total | 83 | 100 | 38 | 100 | 35 | 100 | 156 | 100 |
| Min | 4.71 | | 29.13 | | 18.28 | | 4.71 | |
| Max | 70.73 | | 125.68 | | 108.62 | | 125.68 | |
| Mean | 23.04* | (14.55) | 70.36* | (19.42) | 51.21* | (21.25) | 40.89 | (26.62) |

Note. * denotes the significance level of 0.05 for the difference in means of the corresponding indicator between herder households in each grassland management pattern and the overall study households. Freq is the abbreviation for frequency.

Source: Authors' estimations from field study data.

Table 5. Labor productivity for milk and dairy production in each management pattern

| Productivity (\$/man-day) | SHMP-CGS | | SHMP-RGS | | MHMP-RGS | | Overall | |
|---------------------------|----------|--------|----------|--------|----------|--------|---------|--------|
| | Freq | % | Freq | % | Freq | % | Freq | % |
| (00.00, 10.00] | 11 | 13.25 | 13 | 34.21 | 27 | 77.14 | 51 | 32.69 |
| (10.00, 20.00] | 35 | 42.17 | 19 | 50.00 | 7 | 20.00 | 61 | 39.10 |
| (20.00, 30.00] | 22 | 26.51 | 6 | 15.79 | 1 | 2.86 | 29 | 18.59 |
| (30.00, 40.00] | 15 | 18.07 | 0 | 0 | 0 | 0 | 15 | 9.62 |
| Total | 83 | 100 | 38 | 100 | 35 | 100 | 156 | 100 |
| Min | 5.92 | | 3.76 | | 2.37 | | 2.37 | |
| Max | 39.74 | | 26.95 | | 22.56 | | 39.74 | |
| Mean | 19.74* | (8.88) | 12.63* | (5.89) | 8.30* | (5.12) | 15.44 | (8.89) |

Note. * denotes the significance level of 0.05 for the difference in means of the corresponding indicator between herder households in each grassland management pattern and the overall study households. Freq is the abbreviation for frequency.

Source: Authors' estimations from field study data.

4. Conclusions

Based on data collected from a survey of 156 herder households in Maqu County on the Qinghai-Tibet Plateau, this study analyzed labor productivity in meat and milk/dairy production within both single and multi-household management patterns. The results revealed noteworthy differences among these patterns. In the rotational grazing system, herder households in both single and multi-household management patterns achieved higher labor productivity in meat production compared to the overall study households (40.89 Kg/man-day). They performed at 70.36 Kg/man-day and 51.21 Kg/man-day, respectively. However, herder households in the single-household management pattern within the continuous grazing system exhibited lower labor productivity for meat production, measuring only 23.04 Kg/man-day. Conversely, due to varying distances from pastures to

market centers in different management patterns, herder households in the single-household management pattern within the continuous grazing system achieved higher labor productivity in milk and dairy production compared to the overall study households (15.44 \$/man-day). Their productivity reached 19.74 \$/man-day. For herder households in the single and multi-household management patterns within the rotational grazing system, their labor productivity in milk and dairy production was 12.63 \$/man-day and 8.30 \$/man-day, respectively. These findings underscore the challenges associated with achieving high labor productivity simultaneously in both meat production and milk and dairy production within the same grassland management pattern.

The findings of this study hold significant implications for policymakers, providing valuable insights into the multi-household management pattern in terms of labor inputs and outputs. While the multi-household management pattern demonstrates potential in reducing labor inputs within herder households, it also faces challenges in achieving substantial levels of meat and milk/dairy production. Therefore, policymakers should consider implementing follow-up measures that prioritize the simultaneous increase in meat and milk/dairy production within the multi-household management pattern. This necessitates specific efforts to reduce the distance between herder households and market centers, thus facilitating the sale of milk/dairy products. Merely advocating for the broader adoption of the multi-household management pattern may not suffice without addressing these production-related challenges.

It's essential to acknowledge the limitations of this study. The ecological and socio-economic contexts in other grassland regions may differ significantly from those in the Gannan grassland. Consequently, caution should be exercised when attempting to generalize the results to other areas. To validate these findings and offer a more comprehensive understanding of grassland management practices, future research could explore similar studies in diverse pastoral regions characterized by varying environmental and socio-economic conditions.

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