Asian Journal of Applied Science and Technology
Volume 7, Issue 4, Pages 143-155, October-December 2023

Demonstration of Improved Baler in Selected Kebeles of Kafta Humera Wereda of Western Zone of Tigray

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DOI: https://doi.org/10.38177/ajast.2023.7415

Article Received: 24 October 2023 *Article Accepted: 27 December 2023* *Article Published: 30 December 2023*

ABSTRACT

The study aimed to demonstrate baler in four farmers' research groups in selected kebeles of Kafta Humera district, Tigray, Ethiopia. Each kebele had one farmers' group, resulting in four groups of 15 members each. Farmers and development agents received practical training on baler operation before the experiment. Data on time, manpower, transport and storage space, lubricant consumption, and loaded weight per trip of both grass hays and hay losses for unbaled hay were recorded for three consecutive years, from 2020 to 2022. In 2022, farmers' attitudes were assessed using a checklist. Results showed that baled hay had a significantly higher loaded weight per trip (12.50±0.23 ton/trip) than unbaled grass hay (7.24±0.24 ton/trip), with a comparative advantage of 5.26±0.28 ton per ton more weights of baled hay being transported. Baling also significantly reduced the space required for transportation and storage of grass hay from 9.20±0.66 m^3/ton (unbaled) to 7.20±0.14 m^3/ton (baled), with a space savings of 2.00±0.66 m^3/ton. Balers also significantly decreased the time and labor required for baling, loading, and uploading of grass hay from 5.0±0.29 hours and 4.52±0.34 labor per ton (unbaled) to 4.39±0.36 hours and 3.72±0.10 labor per ton (baled), with savings of time (1.08±0.35 hours/ton) and labor (0.80±0.38 labor/ton). Baled grass hay had lower lubricant consumption (11.14±0.42 liters/ton) than unbaled grass hay (12.63±0.43 liters/ton), with a comparative fuel savings of 1.48±0.16 liters per ton. There was a hay loss of 0.002±0.001 ton per a single trip from loading up to uploading of unbaled hay. Farmers perceived that the baler improves hay lifespan, reduces costs, labor, and time, minimizes wastage, enhances zero grazing, and creates income opportunities. Farmers expressed a strong desire to own balers individually or in groups. Therefore, wider introduction of balers is recommended for further popularization and expansion of the technology.

Keywords: Demonstration; Baler; Farmers' research group; Hay lifespan; Transportation; Wastage; Comparative advantage; Loading; Space saving.

1. Introduction

The western zone of Tigray has vast rangeland areas, primarily savannahs and bush land savannahs, which offer potential feed resources for grazing and browsing. Field observations and secondary data indicate that Kafta Humera wereda has an excess of feed availability beyond the current livestock consumption. However, despite the abundance of feed resources, they are not efficiently utilized due to misuse and mismanagement.

There is a feed shortage during the dry season from January to May. However, there are no existing forage conservation practices, such as haymaking, in the farming system. The grasses in the rangelands and along roadsides are not harvested or grazed at the appropriate time before flowering. Instead, most farmers burn the dried grasses, causing excessive damage

Had there been an appropriate management, the grass potential would have further been properly conserved for dry season and utilized. If properly handled, the excessively produced grasses could also be purchased by the neighboring weredas and could serve as a source of alternative income for farmers.

Baling is a common method for handling roughage feeds, particularly when it is to be sold or transported some distances for storage (Aichi, 2013). Baler is commonly used by large-scale commercial farmers for making hay, forage cultivated forages, and managing crop residue under commercial farming systems (Sergeant, 1956 and Balehegn *et al*., 2022). Additionally, Zawada *et al*. (2023) reported that balers, particularly baler-wrappers, are machines specifically designed to produce superior-quality forages, aligning with the demands of sustainable

agriculture. Balers help improve the quality of hay by preventing leaf shattering (fragmentation) during transport. Grasses available in the wet season can be processed and stored for dry season through baling reducing storage space and transportation costs. Mechanical balers are critical agricultural equipment for managing crop residue and conserving grass hay. They play a crucial role in improving soil health, providing animal feed, and reducing spoilage and losses. Mechanical balers are essential for the efficient use of resources and sustainable agriculture (Coblentz and Hoffman, 2016, Kallenbach and Kerley, 2015, Lal, 2015 and Manjunatha *et al*., 2015). Additionally, mechanical balers also play a crucial role in saving labor and transport costs, as well as time, when it comes to baled hay compared to unbaled hay (Smith, 2018 and Hay Baling Equipment, 2019). Baling also helps avoid overgrazing. Thus, introducing, disseminating and demonstrating the use of balers in Kafta Humera district, with the full participation of interested Farmers' group members, can enhance the efficient and effective use of range grasses. Specific objectives of this study include introducing and demonstrating the technology, assessing farmers' response to the new technology, and providing an alternative source of income for farmers.

2. Materials and Methods

2.1. Description of the Study Areas

The baler demonstration took place in four selected lowland kebeles of Kafta Humera Wereda in the western zone of Tigray: Adebay, Rawian, Maykadra, and Bereket. This district is located 585 km away from Mekelle, the capital city of Tigray region, Ethiopia. Kafta Humera covers 49.13% of the total area in the Western zone of Tigray. The Wereda consists of two agro-ecological zones: midland and lowland. The lowland area, known as Kolla, accounts for 85.7% of the district's land coverage, while the midland area, called Weynadega, makes up the remaining 14.3%.

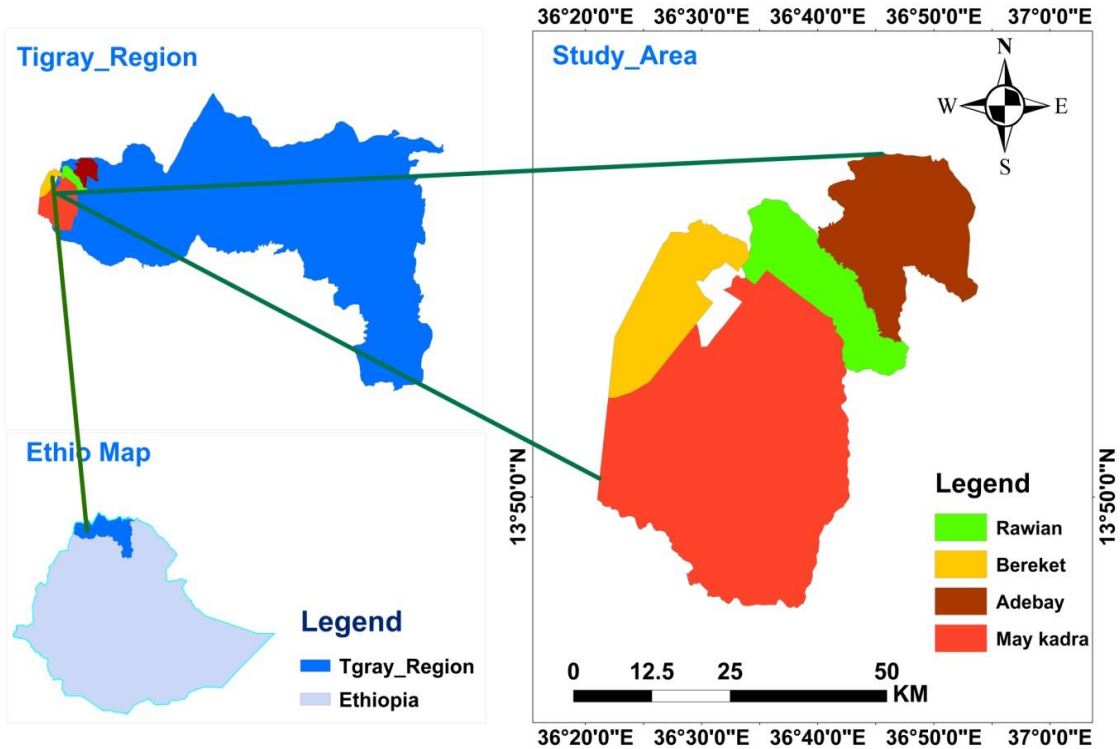

Figure 1. Map of study kebeles

The district is situated between 13^0 40'- 14^0 27' north latitude and 36^0 27'-37^0 32' east longitude. The agro-ecology of the zone is characterized by hot to warm semi-arid lowland plains, with high temperatures, unpredictable rainfall, and vast areas suitable for large-scale and subsistence agriculture, including crops and livestock. The region experiences a unimodal rainfall pattern, with an annual average of 448.8.5 mm. The mean annual temperature ranges from 25°C to 27.5°C (EARO, 2002). The district's altitude varies from 500 to 1850 meters above sea level. It shares borders with Tsegede in the south, Sudan in the west, the Tekeze River (which separates Kafta Humera from Eritrea) in the north and Sheraro in the east, as well as Welkait in the southeast. The study area represents a remote tropical climate where extensive agriculture is predominantly carried out manually by a large number of migrant laborers.

2.2. Design of the study

A total of four farmers' groups were established in four priority-selected kebeles of the Kafta Humera wereda in the Western zone of Tigray. Four kebeles were chosen based on their potential for natural grass forage production. Each selected kebele had one farmers' group consisting of 15 interested members, with one member elected as the team leader to facilitate effective communication between researchers and farmers' group members. Prior to the execution of the demonstrational experiment, all farmers' group members and development agents from the selected kebeles of the wereda underwent a two-day training to improve their baler operation skills. The farmers' attitude towards the technology was assessed through a prepared checklist at the end of the demonstration.

A total of sixteen trips for baled grass hay and twenty-three trips for unbaled hay were made by the same hay-transporting 6 x 4 truck. The truck has dimensions of 12 meters in length, 2.5 meters in width, and 3 meters in height, with a carrying capacity of 1000-1500 quintals. These trips were recorded for three consecutive years, from 2020 to 2022, in order to compare time, manpower, transport and storage space, lubricant consumption, and loaded weight per trip. Additionally, hay loss during the transportation of unbaled grass hay per each trip was recorded.

2.3. Data Collection

2.3.1. Farmers' attitude

The farmers' attitude towards the baler technology was assessed using a prepared checklist at the end of the demonstration

2.3.2. Measuring resource savings of baled versus unbaled grass hay

(i) Weighing unbaled and baled grass hay

The grass was harvested at 50% flowering, and the harvested grass hay was turned for four consecutive days until it completely dried before being made into a circular heap. After the grass completely dried, it was collected and made into a circular heap with a diameter of 6 meters and a height of 4 meters. The weight of the unbaled grass hay was estimated by determining the volume of the heap (stack) (π (diameter/2)2 x height = 3.14* 3*3*4=113.04m^3). Then the weight of the grass hay per heap (stack) was estimated based on 250 cubic feet (7.08 cubic meters) of storage space per ton of hay (USDA, 2019). Accordingly, a heap with a volume of 113.04 m^3 contained 15,966.1 kilograms (16 tons) of grass hay. Before storage, immediately after unloading, the weights of the unbaled grass hay were measured using a hanging balance with a capacity of 100 kilograms.

During both loading and unloading, the weights of the baled grass hay were determined by counting the number of bales and multiplying it by the weight of a single bale, which has dimensions of 0.4 meters in width, 0.5 meters in height, and 0.9 meters in length, weighing 20 kilograms.

(ii) Measuring time and lubricants

The time required to load the same amount of grass hay (both baled and unbaled) onto a 6 x 4 truck, which has a length of 12 meters, width of 2.5 meters, and height of 3 meters, with a carrying capacity of 1000-1500 quintals, and during unloading for storage, was measured using a stopwatch.

In terms of lubricant consumption, the amount of lubricant used by a truck to transport the same quantity of both baled and unbaled grass was calculated by multiplying the amount of lubricant used per single trip by the number of trips made by the truck to transport the same amount of both types of grass hay. Additionally, the lubricant consumed by the tractor for operating the mechanical baler, and the time required for baling the grass hay, were recorded by both the tractor and baler operators.

(iii) Wasted grass hay during transportation to storage

The amount of wasted grass hay from transportation to storage was calculated as the difference between the weight of the hay uploaded prior to storage and the original weight of the hay loaded prior to transportation.

(iv) Labor needed for baling, transportation, and storage

The labor required for baling the harvested grass hay was recorded by the baler and tractor operators, in collaboration with the animal forage researcher of the center. Additionally, the labor needed for transporting and storing the same quantity of both unbaled and baled grass hays was recorded by both the truck driver and the animal forage researcher of the center. The total labor required for transportation and storage of the same quantity of both grass types was then calculated by multiplying the labor required per single trip by the number of trips made by the truck to transport and store the same amount of both grass hays.

(v) Space saved by baled grass as compared unbaled grass

The space saved during transportation of baled grass hay, compared to the same amount of unbaled grass hay, was calculated by measuring the difference in space occupied on the truck. Similarly, the space saved by baled grass hay during storage, compared to the same amount of unbaled grass hay, was calculated by comparing the space occupied in the animal feed store**.** The animal feed store has dimensions of 100 meters in length, 50 meters in width, and 6 meters in height.

2.4. Data analysis

The labor, time, and lubricants consumed for the same amount of baled and unbaled grass hay from baling up to uploading, transported using the same truck, were compared using a paired t-test with SPSS version 22 (2013). The analysis included the change in space occupied by both grass hays from loading to unloading, the wasted grass hay during transportation to storage, and the change in the transported weight of both types of hay per single trip. Additionally, simple descriptive analysis of SPSS 22 was used to analyze the perception data.

3. Results and Discussion

3.1. Weight and space requirements for unbaled and baled grass hay during transport and storage

Table 1 shows the average loading weights of baled and unbaled grass hay during transportation using the same truck from the field to the feed site, located 120 kilometers southwest of the research center. The mean weight of loaded baled grass hay per a single trip is significantly higher than that of loaded unbaled grass hay. Additionally, the average space area required for baled grass hay during transportation and storage (7.20±0.14 m^3/ton) is significantly lower than that of the space occupied by unbaled grass hay (9.20 ±0.66 m^3/ton). These results indicate that baled hay has a comparative advantage of 2.00±0.66 m^3/ton over unbaled grass, using less area for a greater mass of hay. This is due to baled grass hay being more compacted and requiring less space than unbaled grass hay. This result is consistent with the findings of Coblentz and Hoffman (2016), Kallenbach and Kerley (2015), Lal (2015), Ball *et al*. (1998), Donald *et al*. (1996), Teffera *et al*. (2012), and Guerrieri *et al*. (2019) who reported that baling grass hay allows for efficient use of storage space, reducing the need for additional storage facilities.

Table 1. Weight of un-baled and baled grass hay per single trip using the same truck, as well as the space they occupy during transportation and storage (m^3/ton)

No. of trips made	Weight of un-baled and baled grass hay per trip (ton/trip)				Space occupied by un-baled and baled grass hays (m^3/ton)			
	Wt of un-baled	Wt of baled	Difference		Un-baled	Baled	Difference	
1	6.87	12.5	5.63	P-value	10.9	7.2	3.7	P-value
1	7.47	12.45	4.98		8.82	7.23	1.59	
1	7.08	12.64	5.56		10.11	7.12	2.99	
1	7.16	12.35	5.19		9.47	7.29	2.18	
1	7.20	12	4.80		9.28	7.5	1.78	
1	6.99	12.6	5.61		9.18	7.14	2.04	
1	7.59	12.65	5.06		8.33	7.11	1.22	
1	7.11	11.95	4.84		9	7.53	1.47	
1	7.11	12.59	5.48		8.82	7.15	1.67	
1	7.43	12.7	5.27		8.65	7.09	1.56	
1	7.61	12.69	5.08		8.41	7.09	1.32	
1	7.27	12.64	5.37		9.09	7.12	1.97	
1	7.50	12.5	5.00		9	7.2	1.8	

1	7.37	12.7	5.33		9.78	7.09	2.69	
1	6.81	12.39	5.58		9.57	7.26	2.31	
1	7.24	12.7	5.46		8.82	7.09	1.73	
Mean± SD	**7.24±0.24**	**12.50±023**	**5.26±0.28**	**0.001**	**9.20±0.66**	**7.20±0.14**	**2.00±0.66**	**0.001**

3.2. Time and labor requirements for unbaled and baled grass hay during baling, transportation and storage

Table 2 displays the average time and labor required for the preparation of tightening rope, bale formation, and double tightening of the pressed square bale for baled grass hay, as well as the loading for transportation and uploading for storage for both unbaled and baled natural grass hays. The average time and labor required for baled grass during baling, transportation, and storage are significantly lower than those for unbaled grass hay. This results in a comparative time savings of 1.08±0.35 hours/ton and a labor savings of 0.80±0.38 labor/ton for baled grass hay. This is due to baled grass hay is more compact and easier to transport than unbaled hay, resulting in quicker collection, compression, and baling, loading and uploading . This ultimately saves time for farmers and agricultural workers. This finding is supported by previous research studies conducted in different areas of the world (Teffera *et al*., 2012, Smith, 2018, Hay Baling Equipment, 2019 and Guerrieri *et al*., 2019) which indicated that baling hay with a mechanical baler is a faster process than handling unbaled hay. This allows for time and labor savings, as well as transport cost savings by transporting more hay in a single trip through reducing the number of trips required and ultimately cutting down on transport costs.

Table 2. Average time and labor required for unbaled and baled grass hay during baling, transportation and storage

No. of trips made	**Time taken by unbaled and baled grass hay (Time/ton) in hours**				**Labor required for unbaled and baled grass hay (labor/ton)**			
	Unbaled	**Baled**	**Difference**		**Unbaled**	**Baled**	**Difference**	
1	5.06	4.1	0.56	P-value	4.91	3.52	1.39	P-value
1	5.22	3.59	1.23		4.95	3.60	1.35	
1	5.14	4.15	0.59		4.39	3.80	0.59	
1	5.35	4.05	1.30		4.07	3.78	0.29	
1	5.06	4.24	0.42		4.78	3.75	1.03	
1	5.33	4.43	0.50		4.43	3.65	0.78	
1	5.16	3.59	1.17		4.16	3.74	0.42	

1	4.55	3.59	0.56		4.09	3.59	0.50	
1	4.58	3.57	1.01		4.38	3.75	0.64	
1	5.03	4.48	0.15		4.23	3.80	0.43	
1	5.07	4.24	0.43		4.42	3.90	0.52	
1	4.48	3.55	0.53		4.30	3.80	0.50	
1	5.27	4.28	0.59		4.93	3.68	1.25	
1	4.56	3.49	1.07		4.99	3.80	1.19	
1	5.08	4.36	0.32		4.94	3.67	1.27	
1	5.06	4.15	0.51		4.31	3.73	0.58	
Mean± SD	**5.0±0.29**	**4.39±0.36**	**1.08±0.35**	**0.0001**	**4.52±0.34**	**3.72±0.10**	**0.80±0.38**	**0.0001**

3.3. Lubricant requirements of unbaled and baled grass hay during baling and transportation

The average amount of lubricant consumed by unbaled and baled grass hay during transportation of the same quantity of grass hays using the same truck and lubricant required for baling hay is shown in **Table 3**. The average lubricant required for baled grass hay is lower than that required for unbaled grass hay. Baled grass hay shows a comparative lubricant savings of 1.48±0.16 liters per ton. This is because baled hay is typically more compact and denser, allowing for more efficient use of space and potentially reducing the number of trips required for transport. Additionally, the weight distribution and aerodynamics of the bales may also contribute to lower lubricant consumption**.**

3.4. Wasted amount of unbaled grass hay during transportation

The amount of wasted hay (hay loss) due to dropping on the track during the transportation of unbaled grass hay from the field (120 kilometers) to the feed site of the research center is indicated in **Table 3**. The average amount of unbaled grass hay loaded per single trip by the same truck is 7.24±0.24 tons per trip, while the average amount of unbaled grass hay uploaded in the same trip is 7.236±0.243 tons per trip. This indicates an average hay loss of 0.002±0.001 tons per trip. This elaborates the importance of mechanical balers for baling grass hays through proving convenient loading conditions during transporting time in order to avoid hay loss during transportation and transport it safety to anywhere. This finding is supported by previous research findings conducted in different areas of the world (Ball *et al*., 1998, Teffera *et al*., 2012, Kallenbach and Kerley, 2015, Lal, 2015, Coblentz and Hoffman, 2016, John, J. 2017, John, P. 2017 and Abayineh *et al*., 2020),which showed that mechanical balers helps to compress the hay into bales, which can be stored for extended periods without spoilage, reducing the amount of hay lost due to weather conditions, pests, and other factors. They also added that baling also helps to reduce losses during transportation, ensuring that the material is available when needed.

Table 3. Average lubricant usage for unbaled and baled grass hay during baling and transportation, as well as wasted unbaled grass hay from transportation to storage

No. of trips made	Lubricant consumed by unbaled and baled grass hay (liters/ton)				Wasted unbaled grass hay (ton/trip)			
	unbaled	baled	Difference		During loading	During uploading	Difference	
1	12.64	10.99	1.65	P-value	6.87	6.868	0.002	P -value
1	12.38	10.71	1.67		7.47	7.468	0.002	
1	12.58	11.23	1.35		7.08	7.079	0.001	
1	12.24	10.89	1.35		7.16	7.157	0.003	
1	12.32	10.97	1.35		7.20	7.198	0.002	
1	13.16	11.87	1.29		6.99	6.989	0.001	
1	12.33	10.74	1.59		7.59	7.589	0.001	
1	13.66	11.88	1.78		7.11	7.107	0.003	
1	13.10	11.60	1.50		7.11	7.109	0.001	
1	12.37	10.97	1.40		7.43	7.428	0.002	
1	12.37	10.78	1.59		7.61	7.609	0.001	
1	12.69	11.21	1.48		7.27	7.268	0.002	
1	12.00	10.60	1.40		7.50	7.497	0.003	
1	12.40	11.06	1.34		7.37	7.368	0.002	
1	13.04	11.75	1.29		6.81	6.807	0.003	
1	12.74	11.05	1.69		7.24	7.238	0.002	
Mean± SD	**12.63± 0.43**	**11.14± 0.42**	**1.48± 0.16**	**0.0001**	**7.24± 0.24**	**7.236± 0.243**	**0.002± 0.001**	**0.001**

3.5. Farmers' perception

The perception of farmers towards mechanical baler technology is displayed in **Table 4**. The analysis of farmers' perception indicated that the baler improves the lifespan of hay without spoilage, reduces transportation and storage spaces, costs, labor and time, and minimizes wastage during feeding. This result is in agreement with the findings of Teffera *et al*. (2012), who reported that baling hay helps feed animals with minimal wastage, preserves its nutrients for a longer period, simplifies transport and storage conditions, and facilitates the preparation of feed rations. The

same authors also reported that baled hay is more compact and requires less space compared to un baled hay, making it easier to load and transport over long distances. Farmers in the Dejjen and Bahir Dar Zuria districts of the Amhara region appreciated and preferred the baler for its ability to minimize hay loss during transportation. Manjunatha *et al.* (2015) also highlighted the importance of the baler in handling crop residues for animal feeding, fuel, and fiber production for paper manufacturing. In Sudan, the use of balers for hay production and conservation is beneficial in reducing the weed seed bank and managing herbicide-resistant weeds **(**Grain Research and Development Corporation, 2018). Similarly, John *et al*. (2013) reported that the best way to preserve hay is by baling it at the appropriate moisture content and storing it in a hay barn in Mexico. The balers also enhance the cut and carry feeding system and create opportunities for unemployed youths and farmers to bale grasses harvested at the appropriate growth stage as a source of income generation. These findings align with the reports of Teffera *et al*. (2012), Balehegn *et al* (2022), Finner (1973), Manjunatha *et al.* (2015), and the Grain Research and Development Corporation (2018), who emphasized that baled hay serves as an income source for households. Moreover, Tripathi *et al*. (1995) reported that baling hay reduces the costs and labor involved in transportation, storage, and handling. Guerrieri *et al*. (2019) observed that balers have gained significant attention in the agricultural industry because of their ability to mechanize the production process, their ease of use and transportation, their minimal storage requirements and flexibility, and their low demand for manpower. Overall, farmers appreciate the technology and are eager to own or purchase mechanical balers, either individually (investors) or in groups (cooperatives), due to its economic importance. They only need a supply of improved mechanical balers, such as balers from Mayweini Ranch Begait Livestock Breed Multiplication and Conservation.

Table 4. Farmers 'Perception towards Improved Balers

Attributes	**Type of Grass**	
	Un baled	**Baled**
Ease of Transportation		
Very difficult to transport	40 (100%)	-
Very easy to transport	-	40(100%)
Transportation cost		
High	40 (100%)	-
low/cheap	-	40(100%)
Transportation Labour		
High number of labour	40 (100%)	-
Less number of labour	-	40(100%)
Transportation Time		
Huge number of Time	40 (100%)	-

Less number of Time	-	40(100%)
Ease of Storage		
Difficult to store	40 (100%)	-
Easy to store	-	40(100%)
Storage Area coverage		
Very large	40 (100%)	-
Small	-	40(100%)
Storage cost		
High	40 (100%)	-
Low /cheap	-	40(100%)
Storage labour		
Huge number	40 (100%)	-
less number	-	40(100%)
Storage time		
High	40 (100%)	-
less	-	40(100%)
Wastage while feeding		
Very high	40 (100%)	-
Very less	-	40(100%)

4. Conclusions

The study demonstrated that baled hay offers significant advantages over unbaled grass hay. This includes a higher weight per trip (12.50±0.23 ton/trip compared to 7.24±0.24 ton/trip for unbaled grass hay, resulting in a comparative advantage of 5.26±0.28 tons per ton more weight of baled hay being transported). It reduced space requirements for transportation and storage (from 9.20±0.66 m^3/ton for unbaled hay to 7.20±0.14 m^3/ton for baled hay, with a space savings of 2.00±0.66 m^3/ton). It also decreased time and labor (from 5.0±0.29 hours and 4.52±0.34 labor per ton for unbaled hay to 4.39±0.36 hours and 3.72±0.10 labor per ton for baled hay, resulting in time savings of 1.08±0.35 hours/ton and labor savings of 0.80±0.38 labor/ton). Baled grass hay had lower lubricant consumption at 11.14±0.42 liters/ton compared to unbaled grass hay at 12.63±0.43 liters/ton, with a comparative fuel savings of 1.48±0.16 liters per ton. Additionally, farmers perceived that the baler improves hay lifespan, reduces costs, labor, and time, minimizes wastage, enhances zero grazing, and creates income opportunities. Farmers expressed a strong desire to own balers individually or in groups.

5. Recommendations

Based on the positive benefits of balers in conserving hay (grasses, crop residues, etc.), it is recommended to introduce balers more widely to help farmers benefit from the advantages and to further popularize and scale up the technology. Awareness creation should be strengthened for farmers in the following areas:

• Making high-quality hay and how to conserve it for later use;

• Baling and conserving crop residues for later use;

• Factors affecting hay quality and other related topics.

6. Nomenclature/Abbreviations

EARO - Ethiopian Agricultural Research Organization.

M^3 - Meter cubic.

SPSS - Statistical Package for the Social Sciences.

USDA - United States Department of Agriculture.

Declarations

Source of Funding

The study was supported by Humera Begait Research Center of Tigray Agricultural Research Institute, Mekelle, Tigray, Ethiopia.

Competing Interests Statement

The authors declare that there are no competing interests.

Consent for Publication

The authors declare that they consented to the publication of their original research work. The manuscript has been submitted for publication with due consent of authorities of their institute.

Authors' Contributions

All authors took part in data collection, literature review, analysis and manuscript writing.

Ethical Statement and Conflict of Interest

The research work presented in this manuscript did not include any experimentation on humans or animals. The authors conducted the study independently, and consequently, there are no conflicts of interest in this paper.

Acknowledgement

The authors would like to thank to Humera Begait Research Center of Tigray Agricultural Research Institute for its support and financial supports.

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