Original article

Impact of raking and baling patterns on alfalfa hay dry matter and quality losses

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A B S T R A C T

A field study was conducted to investigate the impact of different patterns of raking and baling operations on the dry matter (DM) and quality losses of the produced alfalfa (Medicago sativa) hay. The experimental work was carried out on a 50 ha center pivot irrigated alfalfa field in a commercial farm located in the Eastern Region of Saudi Arabia. Raking operation was performed following two patterns corresponding to the direction of mowing operation, namely, Raking-I in the same direction of mowing (Mowing→ and Raking→) and Raking-II opposite to the direction of mowing (Mowing→ and Raking←). The baling operation; however, was performed following four patterns corresponding to the directions of both mowing and raking operations, namely, Baling-I (Mowing→, Raking→ and Baling→), Baling-II (Mowing→, Raking← and Baling←), Baling-III (Mowing←, Raking→ and Baling→) and Baling-IV (Mowing←, Raking← and Baling←). Results showed that cumulative DM losses in alfalfa hay yield of 30.93% occurred during the harvesting operations. Out of which, raking induced the most DM losses of 985.22 kg ha–1 (39.66% of the total DM losses and 17.35% of the total hay yield). However, the least DM losses were observed during the baling operation and were estimated at 175.81 kg ha–1 (10.22% of the total DM losses and 3.10% of the total hay yield). Raking opposite to the direction of mowing reduced the DM losses by 130.17 kg ha–1 (7.88% of the total DM losses and 2.29% of the total hay yield) compared to that with the direction of mowing. Results also indicated that out of the 21.04% losses in the total crude protein (CP) content of the produced alfalfa hay, 10.91% occurred during the raking operation. However, the baling operation induced the least amount of CP losses (only 2.32% of the total CP). Overall, the best results in terms of alfalfa hay quality and quantity losses were achieved with Baling-III, where the lowest DM losses (2.01% of the total hay yield) and the lowest CP losses (1.44% of the total CP) were recorded.

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1. Introduction

Alfalfa (Medicago sativa) is one of the most important forage crops cultivated worldwide in more than 80 countries covering an area of more than 35 million ha (Radovic et al., 2009). The total area in Saudi Arabia cultivated with Alfalfa crop was estimated at 123,837 ha in the year 2011, with a total alfalfa hay production of 2,550,789 tons. The importance of alfalfa, as a forage for dairy and livestock animals originates from its high nutritive value and high digestibility, particularly for ruminants (Deshpande et al., 2002). Alfalfa is commonly used for livestock nutrition in different forms, such as hay, silage, dehydrated in form of briquettes and as pastures open for grazing (Radovic et al., 2009).

There are great differences between hay-making practices conducted in humid and arid regions. In humid regions, hay producers and researchers tend to improve hay drying rates under field conditions, enhance hay bale ventilation and to use preservatives, such as propionic acid, to preserve the product for a longer time period under the wet conditions. In arid regions; however, hay baling is practiced only after the dew is accumulated on soft plant tissues to reduce losses of leaves. For the same reason, researchers developed new systems to apply fine mist water on plant tissues while baling (Shinners et al., 2006). However, during the harvesting process, losses increase as the dry matter content of the crop increases (Rotz and Muck, 1994).

The quality of forage has a direct effect on animal performance, forage value and profits. Forage species, leaf to stem ratio, stage of
maturity at harvest and storage methods are all factors that significantly affect forage quality (Rohweder et al., 1978; Ball et al., 2001). Crude Protein (CP) in alfalfa leaves is about 24% compared with less than 10% in stems, and younger portion of alfalfa stem tissue is higher in quality than older stem tissue (Ball et al., 2001). Increased maturity of alfalfa declines digestibility and CP of stems at a faster rate than that of leaves (Radovic et al., 2009). The American forage and grassland council developed an index to describe hay quality, which was defined as being the relative feed value (RFV). This index was developed using values of both forage acid detergent fiber (ADF) and neutral detergent fiber (NDF) (Rohweder et al., 1978). RFV is a widely accepted forage quality index in the USA, and is commonly used by hay producers to evaluate hay quality for pricing (Kiraz, 2011; Undersander, 2001).

Agricultural practices have improved since the industrial revolution as a result of using large machinery and agrochemicals. These improvements supported the increasing needs for food and fibers of the rapidly growing human population (Liaghat and Balasundram, 2010). Forage is an essential part in fulfilling the needs for human food by providing nutritious feed, like alfalfa hay, to animals that can be used for human consumption.

Hay baling is characterized as one of the essential hay production operations, where it involves hay handling, transporting and storing. In addition, hay baling is a high-capacity one-man operation with low harvest losses (Kepner et al., 1982). Hay baling machines are specific agricultural equipment designed for gathering the harvested hay from windrows and compressing it in round or square-shaped bales. Baling process is accomplished after three previous operations, namely: (i) forage cutting using mowing machines, which cut the forage and discharge it in rows, (ii) windrowning process using a windrower, which gathers the cut forage into larger windrows of 1.0–1.5 m width and (iii) raking process using a rake machine that stirs the hay and turns it over to ensure a complete hay drying process.

Haymaking and ensiling have been traditional practices to preserve forage crops. However, losses in hay yield and quality during the harvesting and packing operations were estimated at 30 to 70% of the potential alfalfa crop (Glover and Melton, 1996) are still not given the consideration they deserve. Therefore, more research efforts are needed in this particular subject in order to minimize losses; particularly during raking and baling processes (Shinners et al., 2006; Roman and Hensel, 2014), improve quality and to safely store forage crops. It was observed that various haymaking practices resulted in significant yield and quality losses when not correctly managed (Orloff, 1997). Losses in hay yield and quality, as a result of various alfalfa harvesting practices, were investigated by Rotz and Abrams (1988), who reported yield losses of 3.5%, 0.8%, 1.8% and 1.1% in raking, windrowing, baler pickup and in the baler chamber, respectively. Stichler and Bade (1997) reported that raking losses could amount to 5–15% and poor baling practices could result in additional losses of 1–15%.

Investigations have been conducted to reveal the effect of the direction of raking and baling, with respect to the direction of the preceding cutting operation, on the quality of the produced hay. However, no definite patterns have been recommended to hay producers; moreover, contradictory results have been reported. For example, the research conducted in the last century by Kieseilbach and Anderson (1931) on the effect of raking alfalfa at various directions with respect to the mower swath, which reported that there were no differences in hay quality factors when it was raked against the heads (following the mower), or with the heads (opposite to the mower) or across the swath. Wills and Bledsoe (2015); however, recommended raking plants in the same direction of cutting to allow the rake teeth to contact the leafy part of the plant for better plant movement, so as to roll the leafy part to the center of the windrow. They also reported that raking in the opposite direction of cutting would result in placing the leafy part on the outside of the windrow, which could lead to more damage to the plant during any further mechanical action. It was recommended by Hunt and Wilson (2015) to rake plants in the same direction of the preceding mowing operation, taking into consideration to complete the whole raking process before moisture content dropped below 40%, especially for leafy plants, such as alfalfa.

The ultimate goal of haymaking machines is to maintain the nutritive quality of the hay as high as possible; therefore, understanding the influence of harvesting practices on the quantity and quality of the harvested hay is essential. Practically, there is no mechanical action that can be done to forage crops to improve the nutritive value of the produced hay; however, using the right machine in a correct manner and at the best time can save a significant amount of the original forage feed value (Buchs, 2010). Therefore, the main goal of this study was to investigate the impact of different patterns of raking and baling operations on the dry matter and quality losses of alfalfa hay under the hyper-arid climatic conditions of Saudi Arabia.

2. Materials and methods

2.1. Study site

The field work related to this study was conducted in the Todhia Arable Farm (TAF) located between Al-Kharj and Haradh cities in the Eastern Region of Saudi Arabia between the latitudes of 24°10’22.77” and 24°12’37.25”N and the longitudes of 47°56’14.60” and 48°05’08.56”E. A 50 ha center pivot irrigated field (ID: TE-8), cultivated with alfalfa crop (variety: Super-Fast), was designated as the study field (Fig. 1). The study was carried out for the alfalfa cut/harvest number 2 made on April 18th, 2016 on the west half of the field within its three middle spans (number 4, 5 and 6) covering an area of 12 ha.

2.2. Experimental Layout

Different patterns of major alfalfa hay harvesting operations (mowing, raking and bailing), performed at an average machine forward speed of 8 km h⁻¹, were investigated. Alfalfa harvesting process was started with the mowing operation using a 5 m width of cut Self-propelled Swather (Model: New Holland HW320). The mowing operation was performed in one direction and the result was 8 swaths (each is 1.5 m in width) for each of the three spans (each span is 40 m in width) as shown in Fig. 2. However, the raking operation was performed using a raking machine (Model: New Holland 260 Rolabar rake), which covered 10 m width. The raking operation combined every two of the eight alfalfa hay swaths, in each of the three studied spans, into one swath. Hence, the raking operation resulted in four hay swaths (each is 1.5 m in width) in each span. The two patterns of raking operation investigated in this study included: raking with the direction of mowing (Raking-I) and raking opposite to the direction of mowing (Raking-II). The final operation of baling was performed, using a large square baler (Model: Class Quadrant 2200), on the four raked swaths in each span with and opposite to the direction of raking, which resulted in four bailing patterns (two bailing patterns for each of the two raking patterns). In addition to Fig. 2 and Table 1 illustrates the patterns of hay harvesting operations investigated in this study.

2.3. Alfalfa hay samples collection

Collection of alfalfa hay samples was performed following the protocols for hay sampling described by Putnam and Orloff (2002); In order to determine the total hay yield and quality, alfalfa
hay yield samples were collected from the standing crop using a steel quadrant of 0.5 m x 0.5 m immediately prior to the mowing operation. In addition, samples representing the produced alfalfa hay after mowing and raking operations were randomly collected from the hay swaths (Fig. 3-a). After the baling operation, alfalfa hay sampling process was performed using a power driven (electric drill) hay core sampler that consisted of a 5 cm in diameter and 50 cm in length stainless steel tube. Hay samples, representing the portion of the hay left on the soil surface of the field after each harvesting operation (i.e. the losses), were collected using the steel quadrant (Fig. 3-b). The collected alfalfa hay samples were analyzed for the determination of the dry matter and hay quality losses induced by the different hay harvesting operations.

2.4. Lab analysis procedure

For the determination of alfalfa hay quantity and quality parameters, the collected alfalfa hay samples were subjected to laboratory analysis to determine dry matter and quality using the near infrared reflectance spectroscopy (NIRS) method following the procedures described by Abrams (1989). The oven dried (at 70 °C for 24 h) hay samples were weighed for the determination of sample dry matter and ground using a centrifugal mill (Model: ZM200 - RETSCH) equipped with a 2-mm screen. The prepared hay samples were used for the determination of hay quality parameters using a calibrated NIR spectrometer (Model: Matrix-1 - Brucker). The steps followed, in the laboratory, for the preparation and analysis of the alfalfa hay samples are illustrated in Fig. 4. The studied parameters included the alfalfa hay dry matter (DM), crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF) and relative feed value (RFV).

2.5. Statistical analysis

The CoStat statistical software program (version 6.311) was used to perform the ANOVA statistical analysis for the collected observations. The least significant difference (LSD) test was utilized for the comparison between treatment means at significant levels of 0.05 and 0.01.

3. Results and discussion

The collected samples were analyzed for the determination of the hay harvesting machine’s induced dry matter and quality losses. Although the collected alfalfa hay samples were analyzed for various quality parameters, the comparison between the different studied alfalfa hay harvesting operations was performed mainly based on the different losses in dry matter (DM), in addition to, parameters commonly used to describe forage quality, including crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF) and relative feed value (RFV), Table 2.

3.1. Losses in dry matter (DM)

The quantity of the portion of alfalfa hay yield left on the soil surface during each harvesting operation was investigated for the DM losses determined through the analysis of the 0.5 m x 0.5 m grid randomly collected samples. The average results of the alfalfa hay DM losses, induced by different patterns of hay harvesting operations, are presented in Fig. 5. Results indicated that the greatest losses occurred during the raking operation. The ANOVA statistical results (Table 3) showed significant differences among the
amounts of DM losses induced by various hay harvesting operations. On the average, the greatest DM losses; however, occurred during the raking operation, where for Raking-I, the loss was estimated at 1050.30 kg ha$^{-1}$ (18.50% of the total alfalfa hay yield) and for Raking-II, the loss was determined at 920.13 kg ha$^{-1}$ (16.21% of the total alfalfa hay yield). On the other hand, the various baling patterns produced the lowest DM losses (2.01–4.20% of the total hay yield).

Although the studied patterns of raking and baling operations induced different amounts of DM losses, the differences in DM losses within the patterns of the same harvesting operation were
not statistically significant. However, it was noted that raking opposite to the direction of mowing caused a reduction of the DM losses of the harvested alfalfa hay by 130.17 kg ha\(^{-1}\) (2.29% of the total alfalfa hay yield (Fig. 5)) compared to raking with the direction of mowing operation. It was also observed that baling with the direction of mowing operation reduced the DM losses in the harvested alfalfa hay, irrespective of the direction of the raking operation. This observation is clearly illustrated in Fig. 5, where Baling-III (baling with the direction of mowing operation and opposite to the direction of raking operation) resulted in the lowest DM losses of 114.38 kg ha\(^{-1}\) (2.01% of the total hay yield), followed by Baling-I (baling with the direction of both mowing and raking operations), where the DM losses were determined at 135.26 kg ha\(^{-1}\) (2.38% of the total hay yield).

In general, results of the study revealed that the total amount of DM losses of 30.93% occurred during the three major alfalfa hay harvesting operations (mowing, raking and baling). Out of which, the raking operation induced the most DM losses in alfalfa hay yield compared to mowing and baling operations (Fig. 6). The overall mean of the DM losses during the raking operation was estimated at 985.22 kg ha\(^{-1}\), which constituted 59.66% of the total DM losses induced by the three major hay harvesting operations (mowing, raking and baling) and 17.35% of the total alfalfa hay yield of the studied field. However, the least DM losses of 175.81 kg ha\(^{-1}\) were observed during the baling operation, which was equivalent to 10.22% of the total DM losses and to 3.10% of the total alfalfa hay yield. This is in agreement with the results reported by Twidwell and Kephart (1998), where the raking operation caused the greatest dry matter loss in alfalfa hay yield (5–15%).

### 3.2. Losses in crude protein (CP)

Losses in CP were estimated from the portion of the harvested alfalfa left on the soil surface following the various studied patterns of harvesting operations. Similar to losses in DM, significant differences were observed among the CP losses induced by the studied harvesting operations. Results presented in Table 3 and Figs. 7 and 8 indicated that of the total losses of 21.04% in the total CP content of alfalfa hay occurred during the studied hay harvesting operations (mowing, raking and baling); however, more than half of this loss in the CP content of alfalfa hay occurred during the raking operation. Results indicated that the overall mean of the CP losses induced by the raking operation was estimated at 197.27 kg ha\(^{-1}\) (51.87% of the total CP losses and 10.91% of the total alfalfa hay yield of the studied field).
Fig. 5. Dry matter losses in hay yield induced by different patterns of harvesting operations.

Table 3
ANOVA results for DM and quality losses data induced by various harvesting operations.

| Harvesting operation | Dry matter (DM) losses (kg ha\(^{-1}\)) | Crude protein (CP) losses (kg ha\(^{-1}\)) | Relative feed value (RFV) |
|----------------------|----------------------------------------|------------------------------------------|-------------------------|
| Mowing               | 595.19\(^a\)                          | 113.32\(^a\)                            | 117.47\(^a\)            |
| Raking-I             | 1050.30\(^b\)                         | 210.13\(^b\)                            | 145.94\(^b\)            |
| Raking-II            | 920.27\(^b\)                          | 185.18\(^b\)                            | 149.51\(^b\)            |
| Baling-I             | 155.25\(^c\)                          | 36.74\(^c\)                             | 165.61\(^b\)            |
| Baling-II            | 238.52\(^c\)                          | 55.81\(^c\)                             | 188.67\(^c\)            |
| Baling-III           | 114.38\(^c\)                          | 26.52\(^c\)                             | 172.00\(^c\)            |
| Baling-IV            | 195.07\(^c\)                          | 44.34\(^c\)                             | 171.67\(^c\)            |
| LSD                  | LSD\(_{0.01}\)                         | LSD\(_{0.01}\)                          | LSD\(_{0.01}\)          |
| CV,%                 | 64.69                                  | 65.71                                   | 16.53                   |

LSD = Least Significant Different and CV = Coefficient of Variation.

Fig. 6. Overall mean dry matter losses in hay yield induced by different harvesting operations.
total CP of the harvested alfalfa hay). On the other hand, the baling operation caused the least amount of CP losses of 41.96 kg ha\(^{-1}\) (11.03% of the total CP losses and 2.32% of the total CP of the harvested alfalfa hay).

Although the collected observations showed no significant differences among the studied two raking and four baling patterns, the different hay harvesting patterns induced different amounts of CP losses. For example, raking opposite to the direction of mowing resulted in a reduction in the CP losses of 26.09 kg ha\(^{-1}\) (12.41%) compared to raking with the direction of mowing operation. On the other hand, baling with the direction of mowing resulted in low CP losses compared to baling opposite to the direction of mowing, especially when the raking operation was performed opposite to the direction of mowing. Among the four baling patterns, Baling-III (Mowing→, Raking→ and Baling→) was found to produce, on the average, the least CP losses (26.06 kg ha\(^{-1}\)) followed by Baling-I (Mowing→, Raking→ and Baling→) with an average CP loss of 43.46 kg ha\(^{-1}\). The highest average CP loss (53.95 kg ha\(^{-1}\)) was recorded for Baling-II (Mowing→, Raking→ and Baling→).

3.3. Changes in the quality of the harvested alfalfa hay

The influence of the studied hay harvesting patterns on the quality of the produced alfalfa hay was investigated utilizing the CP, ADF, NDF and RFV quality assessment parameters. The ANOVA statistical results of the hay quality parameters for the standing alfalfa crop and the hay produced by the investigated hay harvesting patterns are presented in Table 4. Results indicated that the quality of the produced alfalfa hay decreased significantly...
compared to the standing crop determined immediately before the mowing operation. The amount of the crude protein content of the final produced hay decreased significantly (p < 0.01) by 20–23% compared to the CP content of the standing alfalfa crop (Fig. 9). Among the investigated patterns, Baling-II (Mowing →, Raking → and Baling →) induced the least CP reduction (19.65%); however, Baling-III (Mowing →, Raking → and Baling →) caused the greatest reduction (22.83%) in the CP content, with no significant difference between their reduction data.

The reduction in the RFV, as a result of different hay harvesting patterns, was found to be of high significant value (p < 0.01) and ranging from 31 to 42% compared to that prior to the mowing operation. The greatest reduction in the RFV (41.43%) of the produced hay was noticed during the harvesting pattern of Baling-III, which also resulted in the high reduction in the CP content, with no significant difference between their reduction data.

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4. Conclusions

A field study was conducted to investigate the impact of different patterns of raking and baling operations on the dry matter (DM) and quality losses of the produced alfalfa hay. The following conclusions are inferred from the study:

- On the average, the total DM losses in alfalfa hay yield of 30.93% occurred during the three major hay harvesting operations (mowing, raking and baling). Raking operation was found to induce the highest DM losses of 59.66% of the total losses (17.35% of the total alfalfa hay yield); however, raking opposite to the direction of mowing reduced the DM losses by 2.29% of the total alfalfa hay yield. On the other hand, baling operation induced the least DM losses of 10.22% of the total DM losses (3.10% of the total alfalfa hay yield).
- On the average, a total crude protein (CP) losses of 21.04% from the produced alfalfa hay occurred during the harvesting operations. More than half of these total CP losses were attributed to the raking operation. The baling operation; however, was observed to induce the least CP losses of 2.32% (11.03% of the total CP losses).
- The best results in terms of hay harvest losses were achieved with Baling-III (Mowing →, Raking → and Baling →). This harvest arrangement resulted in the lowest DM losses (2.01% of the total hay yield) and the lowest CP losses (1.44% of the total CP).

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