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Original article

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

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ABSTRACT

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} (59.66% 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.

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

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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) windrowing 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, windrow turning, 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 Kiesselbach 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 nutritious 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