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OPERATIONAL AND TECHNICAL TESTING OF TWO TYPES OF TRACTOR RAKES IN MOUNTAINOUS AREAS

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ABSTRACT

The paper presents the results of testing two types of the most common rakes in hilly and mountainous conditions (chain finger side delivery rake and finger-wheel side delivery rake). The average yield of green mass is 38.14 t/ha, ranging from 23.50 to 46.50 t/ha. At the time of hay windrowing, the average moisture content was 31.65%. The average width of the formed windrow by the rakes is 1.25 m. The aim of the study was to measure the basic operational parameters (surface productivity, working width utilization coefficient, losses made), as well as fuel consumption and the engaged power of the tested rakes. For the two types of rakes tested, the working width utilization coefficient was in the range of 0.87-0.80 for chain finger side delivery rake, and 0.82-0.73 for finger-wheel side delivery rake, at travel speeds of 5.15 - 7.02 km h^{-1} and 4.86 - 9.97 km h^{-1}, respectively. The performance of the rakes varied from 0.81-1.01 ha h^{-1} for chain finger side rakes and 0.72-1.31 ha h^{-1} for finger-wheel side rake. The total losses for chain finger rakes averaged 1.45-2.92% of DM yield. Finger-wheel side rakes achieved slightly lower loss values of 1.29-2.21% DM. Otherwise, as the moisture content of the hay decreased, its total dry matter losses increased. The hourly fuel consumption for chain finger rakes was 2.42-4.17 l h^{-1}, and 2.25-2.95 l h^{-1} for finger-wheel rakes, while the specific consumption was on average 3.60 l ha^{-1} and 2.82 l ha^{-1}, respectively.

Keywords: *chain finger side delivery rake, finger-wheel side delivery rake, productivity, losses, fuel consumption.*

INTRODUCTION

At the moment of mowing, the grass mass contains about 80% moisture. For high-quality implementation of hay preparation, it is necessary to reduce this moisture below 20%. The reduction of its content is usually carried out naturally on the surface of the stubble. That procedure can be improved by using appropriate devices to increase the convective surface of the plant mass and the surrounding air, i.e. its easier flow through the plant mass. By correctly choosing and using the device, drying in the field can quickly bring the humidity to the level of efficient storage. The mowed mass is treated mechanically immediately after mowing. This treatment is based on loosening the swath, then turning it over, with the aim of releasing moisture more quickly. Various types of devices can be used to perform one or three of the mentioned operations for scattering, turning and collecting the mentioned mass of hay.

Machines for mowing and turning hay significantly affect the drying speed of hay. Koprivica et al. (2011) pointed out that in the process of preparing alfalfa hay in the field, the main problem was uneven drying of the plant mass in layers. After mowing, it is recommended to manipulate the mowed alfalfa, up to a humidity of 50%, with the use of rotary tedder. The decision to apply tedding must be made on the basis of a comparison of potential losses due to prolonged lying in the field against known losses due to shedding of leaves (Rotz, 1991). The operations of scattering and collection into a bundle are necessary in the process of drying the treated hay cut and its preparation for collection by presses or forage harvesters.

Rotz, (1993), in the examination of three different types of rakes (parallel bar, finger-wheel and rotary) monitored their productivity, necessary labor, fuel consumption, as well as dry mass losses. Ülger & Bastaban (1982) compared primitive manual rakes, horse-drawn cross rakes, finger-wheel, chain-type and cylindrical-drum side delivery rakes, while observing the basic exploitation elements: working width, speed of movement, fuel consumption and productivity.

Baling losses are greatly influenced by the moisture concentration in the hay. Alfalfa raking losses increase rapidly when hay moisture drops below 40%. Raking excessively wet hay will delay drying, and leaf losses can reach levels above 20% of dry matter if raking is done immediately before baling (Collins, 1995). Scattering is also done due to the increase in the exchange surface of the mowed plant mass with the local air-convection (milder compaction) and for more intensive air flow through the mass (Vranić et al., 2005). Hay tedders perform volume expansion from swaths, without changing their working width, making them loose and lifted from the stubble, and are designed for use in the early drying process, when the crop is less susceptible to breakage (Macdonald & Clark, 1987). A narrow swath can be formed with a mower and conditioner unit, without raking and other manipulations with the mass during its drying in the field. This slows drying and requires the swath to lie longer in the field for two days, resulting in potential losses due to weather conditions and rain (Rotz, 1991). Losses of hay during baling can significantly reduce the nutritional value of forage, especially legumes, due to the higher proportion of leaves, which are incomparably more sensitive to crushing than stems in the swath (Rotz & Abrams, 1988), (Buckmaster, 1990).

MATERIAL AND METHOD

Operational and technical tests of the two types of rakes most commonly used in hilly and mountainous areas were carried out during 2019-2020, on the family farm Jugović, Mokro, near Pale (43º52'39"; 18º36'24"). A plot of 1.5 ha, at 900 m above sea level, with a slightly inclined exposure in the northeast-southwest direction, was chosen as the terrain for the application of the tested machines. The moisture content of the grass mass was determined by a laboratory method, a moisture meter for biomass, i.e. by determining the content of dry matter and its calculation per hectare.

Measurement of exploitation parameters and engaged energy was carried out to test four speed intervals per plot. The surface effect of the subsequent operations was determined by measuring their speeds and the coefficient of utilization of the working area. Losses during work operations were measured manually, after each pass during loosening and collection of mass into bundles, per meter due to the working width of the machines, on the part where the swath did not lie. During the operation of gathering into a bundle, the measurement of the working width of the rake was performed in one pass, from the edge of the untreated part to the formed windrow. In order to determine the production performance, the following were determined: movement speed ($\boldsymbol{V_t}$), working width ($\boldsymbol{B_r}$) and coefficient of utilization of production working time ($\boldsymbol{\eta_{pr}}$). The pure productivity ($\boldsymbol{W_{pr}}$) of the tested rakes was determined by the chronometric method, i.e. by measuring the working time, at appropriate movement speeds, using a form:

$$W_{pr}=0,1*V_t*B_r*\eta_{pr},\ ha\ h^{-1} \quad (1)$$

Fuel consumption was determined by the volume method with the instrument "Pirburg", type 116, and the engaged power to drive the machine with a rotary dynamometer, type DMN 10, category III (for the type with tractor PTO drive). Both types of rakes were powered by the same LTZ T40AS tractor unit.

RESULTS AND DISCUSSIONS

In hilly and mountainous conditions, chain finger side delivery rake (SIP FAVORIT 220) and finger-wheel side delivery rake are the most common. The first type gets its drive from PTO shaft of the tractor, while the second type has ideal resistance from the moved plant mass, with the condition that the supporting springs of the wheels are well adjusted. Recommended descriptive contact is "just off the surface of the soil".

Table 1. Technical characteristics of the rake SIP FAVORIT 220

Parameter	Unit	Value
Category of suspension points	-	I + II
Working width	m	2,2
Number of rows of elastic fingers	-	3
Required power	kW	12
Productivity	ha h^{-1}	up to 1,5
Length	m	1,3
Width	m	2,4
Weight	kg	215

Picture 1 chain finger side delivery rake

Picture 2 finger-wheel side delivery rake

A good construction of the rake, in interaction with adequate technical settings, is a significant factor in reducing total losses of hay, partially extreme in the mowing operation. For the quality work of chain finger side delivery rake, the subjective factor should meet two basic prerequisites: avoiding work in dried mass < 50-55% and avoiding direct contact between the tip of the fingers and the soil surface.
The average yield of green mass in the test of the mentioned types of rakes is 38.14 t/ha, ranging from 23.50 to 46.50 t/ha. At the time of collecting the loose mass of hay, its average humidity was 31.65%. The average width of the windrow formed by the rake is 1.25 m.

Table 2. Technical characteristics of finger-wheel side delivery rake

Parameter	Unit	Value
Category of suspension points	-	I + II
Working width	m	2,4
Number of wheels/number of fingers	-	4/40
Required power	kW	18
Productivity	ha h^{-1}	up to 3,6
Length	m	-
Width	m	2
Weight	kg	175

Working width and productivity of tested rakes

The finger-wheel rake achieved a maximum working width of 1.98 m at a speed of 4.86 km h^{-1}, and a minimum of 1.75 m at a speed of 9.97 km h^{-1}. Chain finger rake also achieved similar values of the working capacity, however, the test was not performed in the fourth gear, due to increased losses and sticking of the grass mass. The coefficient of utilization of the working width-τG, depending on the speed of movement, was in the interval 0.87-0.80 for chain finger rake, or 0.82-0.73 for finger-wheel rake. From the mentioned data, a significant dispersion of τG is evident, with a fairly high correlation coefficient R^2=0.9921 and R^2=0.8716 (Chart 1). According to the theoretical working width of the tested machines, chain finger rake achieved slightly higher values, due to easier and more precise guidance on slopes, unlike finger-wheel rake. In both cases, the joint was formed in two passes.

The reported values are slightly lower compared to those reported by Öztürk and Çelik, (2003), 112.0% for chain finger rake and 95.77% for finger-wheel rake. The higher values of the constructive engagement of the machine in the first case are the consequence of the distance between the part of the slope formed in the first and return stroke. The productivity of the rake was directly influenced by two basic factors: speed of movement and working width. The surface performance of the rakes, depending on the speed of their movement, varied in the range of 0,81-1,01 ha h^{-1} for chain finger rake, or 0,72-1,31 ha h^{-1} for finger-wheel rake (Chart 2), which is partially in agreement with the results of Öztürk and Çelik, (2003): 1,40 ha h^{-1} for chain finger and 1,52 ha h^{-1} for finger-wheel. Similar data were reported by Ülger & Bastaban (1982), 1,57 ha h^{-1} and 1,45 ha h^{-1}, respectively. Furthermore, Arin, (1982) reports effects of 1,03 ha h^{-1} for finger-wheel and 1,3 ha h^{-1}, for cylindrical side delivery rake, which is in agreement with research. According to the above, the productivity of the tested rakes was lower by 30-40% than the theoretical one, which was lower than results, reported by Öztürk et al., (2003) of 20-30%, at a movement speed of 7 km h^{-1}. They also stated the values of the surface productivity per unit of working area of 0.64 ha/h/m for chain finger rake and 0.61 ha/h/m for finger-wheel rake. The average values in the conducted research, depending on the speed of movement, were in the interval 0.42-0.66 ha/h/m for chain finger rake and 0.36-0.75 ha/h/m for finger-wheel rake.

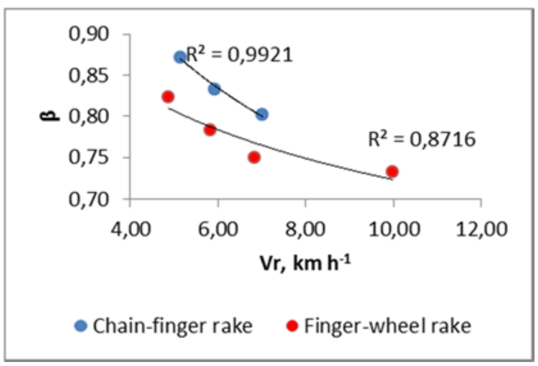

Chart 1 coefficient of utilization of the working width of the examined rake

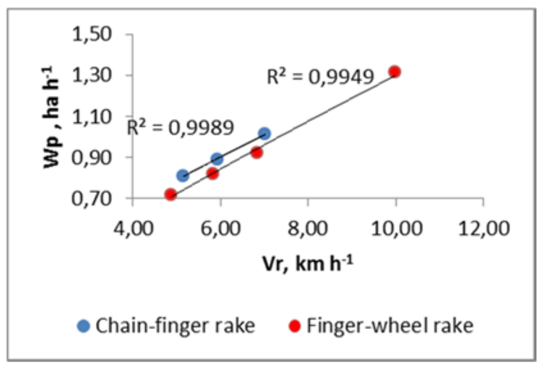

Chart 2 Production performance of the tested rakes

Rake losses, % of DM yield

When evaluating the quality of the rake work, the main factor is the amount of leaf mass loss, especially when handling dried material. Losses of hay during the operation of raking into a windrow represent all the unaffected plant mass, and for the most part, they are the result of the process of shredding the plants during mowing to a length of <10 cm. Depending on the type of rake, the degree of their general adjustment, the user's intuition, the condition of the grass mass, losses can vary in a wide range. Depending on the type of rake, the aforementioned losses depend on the way the hay is moved. During the shorter journey of moving the hay, due to the reduction of its friction against the stubble, especially in the initial time interval, as well as the internal friction of the stalk against the stalk, leaf losses are significantly reduced.

According to the empirical assessment of Barać (2007), of the total cycle time for preparing hay from an adequate plant species, mowers participate with 20.4%, thus representing the basic source of the mentioned types of losses. However, with inadequate operational application of the rake, respecting all other factors, those losses can become extreme.

A linear increase in losses as a function of movement speed (on average 1.45-2.92% of the DM yield) is noticeable with the chain finger rake, with a correlation coefficient of R^2=0.9678. The obtained results are partially in agreement with the results of Öztürk, (1998), who stated their range of 2.51-11.83%, depending on the moisture content of the material during raking. Furthermore, by lowering the percentage of moisture in the hay, losses of dry matter increased. Finger-wheel rake achieved somewhat lower DM loss values, 1.29-2.21%, with a correlation coefficient of R^2=0.6311, Chart 3. Similar values for this type of rake were stated by Öztürk, (1998), 1.36-10.94%. However, slightly higher values were reported by Al-Gaadi, (2018), where total alfalfa baling losses were 18.50% DM of the total yield, while Twidwell, (1998), explicitly claimed that alfalfa baling operation achieved the highest loss of dry matter, average 5-15%. Based on laboratory research, Savoie, (1988) noted that hay losses were about six times higher for alfalfa than for grass hay, increased by lowering the moisture content of plants, and could be >20% for drier types of legumes. The maximum losses of rakes, when collecting clover and meadow grasses, were achieved by rakes with forced drive of fingers from tractor PTO, Barrington, (1970), Savoie, (1982) and Rotz, (1993).

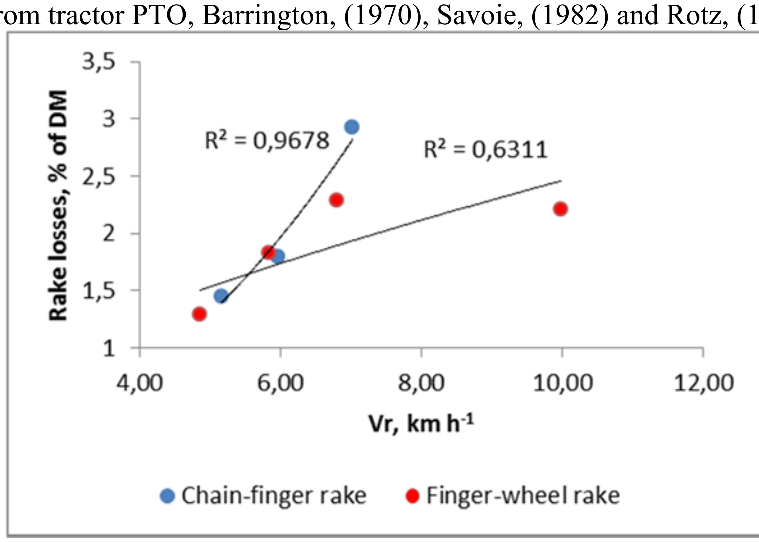

Chart 3 Losses of tested rakes, % of DM yield

Fuel consumption and engaged power of the tested rakes

Both types of tested rakes were driven by the LTZ T40AS tractor. The fuel consumption for the pure operation of the unit was 2,42-4,17 l h^{-1} for chain finger rake and 2,25-2,95 l h^{-1} for finger-wheel rake. The slightly higher consumption of chain finger rake was a consequence of the forced drive of the fingers from the tractor PTO shaft. In terms of specific fuel consumption, chain finger rake achieved 2,99-4,11 l ha^{-1}, average 3,6 l ha^{-1}, while finger-wheel rake achieved 3,13-2,24 l ha^{-1}, average 2,82 l ha^{-1}. Those values are lower than the statements of Öztürk, (1998), where the fuel consumption of chain finger rake was 9,0 l h^{-1} (6,21 l ha^{-1}), and finger-wheel rake was 8,9 l h^{-1} (5,91 l ha^{-1}). The obvious difference is probably due to the use of a higher power tractor. In the same treatment, the author states the engaged power for pulling the rake: 3.95 kW for the chain finger rake and 6.22 kW for the finger-wheel rake. The engaged power on the PTO of the examined chain finger rake, on average, was 10.33 kW, which is lower than the value of Öztürk, (1998), and was 5.99 kW of the total engaged power for propulsion and movement.

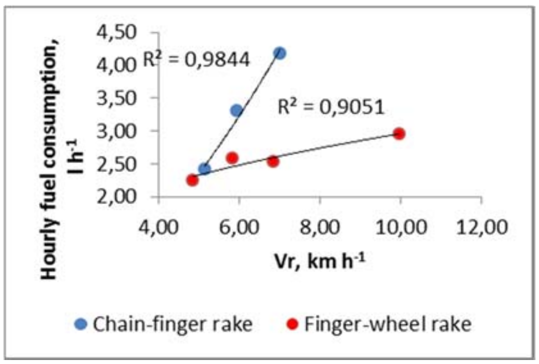

Chart 4 Hourly fuel consumption of the tested rakes, l h^{-1}

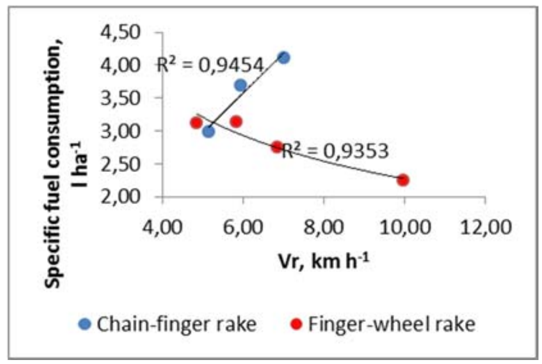

Chart 5 Specific fuel consumption of the tested rakes, l ha^{-1}

The chain finger rake achieved the maximum fuel consumption of 4,17 l h^{-1} at a movement speed of 7,02 km h^{-1}, and the finger-wheel rake had the minimum consumption of 2,25 l h^{-1} at a movement speed of 4,86 km h^{-1}. Chart 4 shows an approximate linear increase in hourly fuel consumption of chain finger rake, in contrast to finger-wheel rake, where the growth is milder, while in terms of specific fuel consumption, finger-wheel rake achieved 21.66% lower values. The reason for the increase in consumption and load was the accumulation of a larger amount of grass mass in front of the chain finger rake and its jamming between the grate hay remover from the fingers and the surface of the stubble, and for this reason they were tested in three speed modes. Unlike chain finger rake, finger-wheel rake did not have the mentioned problem, which was in favor of lower engaged power and thus fuel consumption.

CONCLUSION

With the two types of rakes tested, the maximum working width was achieved by the finger-wheel rake of 1.98 m, while chain finger rake reached 1.76 m. The coefficient of utilization of the working width, depending on the speed of movement of the rake, was in the interval 0.87-0.80 for chain finger rake, i.e. 0.82-0.73 for finger-wheel rake. Surface effects as a function of movement speed varied from 0.81-1.01 ha h^{-1} for chain finger rake or 0.72-1.31 ha h^{-1} for finger-wheel rake. Total losses with chain finger rake had a noticeable linear trend of increase as a function of increasing movement speed, on average 1.45-2.92% of DM yield. Finger-wheel rake achieved somewhat lower loss values of 1.29-2.21% DM. Also, with the reduction of hay moisture, its total losses of dry matter increased. Hourly fuel consumption for chain finger rake was 2.42-4.17 l h^{-1}, i.e. 2.25-2.95 l h^{-1} for finger-wheel rake, while the average specific consumption of chain finger rake was 3.60 l ha^{-1}, and of finger-wheel rake it was 2.82 l ha^{-1}. The engaged power on the PTO of the tractor for the chain finger rake was an average of 10.33 kW. Both types of tested rakes have been used in production practice, and the main limiting factors for the choice are performance, losses of plant mass, fuel consumption and maintenance. Chain finger rake are characterized by operational cleanliness, good maneuverability, performing work operations while driving backwards, the ability to regulate the height of the wheels and a long service life. They are suitable for working on meadow hay, and often also for working on sloping terrain, while the relatively main disadvantages are smaller effects and somewhat greater losses of leaf mass. Unlike chain finger rake, the advantages of finger-wheel rake are: stable construction, the possibility of collecting hay in one, two or more rows, depending on the amount of grass mass, low fuel consumption, no forced drive and minimal maintenance as well as the purchase price.

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