Original paper

COMBINES WORK QUALITY IN MAIZE SILAGE PRODUCTION

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Abstract

The paper presents testing results of three silage combines employed in maize silage preparation in Toplica region. It is focused on determination of technical working parameters of tested machines. Achieved results verified the superiority of silage combine John Deere 5820, which produced the chopped mass having particle lengths of the smallest deviation with respect to the preset cutting length. In this case, the average length of chopped mass was 9.9 mm, having 69 % mass in the range up to 8 mm. The other two silage combines produced lower mass percentage of this fraction and larger variations of particle lengths with respect to the preset length. Minimum mass flow rate was evidenced for the silage combine Fortschrit E-286: 7.3 kg s^{-1} (26.3 t h^{-1}) and the surface productivity of 0.83 ha h^{-1}, at the average speed of 4.0 km h^{-1}. Maximum production rate was achieved with silage combine John Deere 5820: 10.9 kg s^{-1} (39.1 t h^{-1}) at average working velocity of 4.7 km h^{-1} and surface efficiency of 1.21 ha h^{-1}.

Key words: *combine, mass flow rate, operational productivity, silage, work quality*

Introduction

Maize silage is popular forage, mainly used in ruminant nutrition to substitute expensive concentrated food. Many factors affect the quality of prepared fodder, including climatic conditions during the season, temperature during preparation, as well as the state of the crop used for silage production (Ball et al., 2001). Nowadays, a variety of different types of silage combines exists, Petrović et al., 2012. Depending on particular circumstances, like crop yield and species, terrain conditions, etc., specific harvester system can be used: a tractor-powered machine, self-propelled combine or a self-loading forage wagon system. To make an optimal choice of applied system, relevant and reliable information is necessary (Marsh, 2011).

Relying on the adequate value of preset cutting length, forage harvester John Deere 5830 can provide high-quality chopped material (Jonhson et al., 2002). Preparation of high-quality silage demands application of adequate machines that ensure proper mass distribution of specific fractions with respect to chopping length of ensiled plants (Ott, 2000; Lisowski, 2006; Van and Heinrichs, 2008). Srivastava et al. (2006) claimed that proper selection and definition of governing parameters and choice of silage combine type should result in reaching the upper limit of the possible machine mass flow rate.
Koprivica et al. (2007) reported that silage combine Fortschritt E-281C at working speed of 2.2 km h^{-1} has achieved a mass flow rate of 6.6 t h^{-1} and surface productivity of 0.76 ha

h^{-1}. Increasing the operational velocity to 2.8 km h^{-1} gave higher capacity (9.0 t h^{-1}) and surface productivity of 0.95 ha h^{-1}. Calvin (2007) reported that silage combines are designed for easy and efficient harvest of silage crop, which reduces share of human labor in time and allow optimal mass distribution of silage particles chopping lengths. Stanimirović et al. (2008), found that forage harvester Fortschrit E-286, with preset chopping length of 8 mm and operating speed of 4.1 km h^{-1}, achieved average mass flow rate of 7.2 kg s^{-1} (26.1 t h^{-1}) and surface productivity of 0.86 ha h^{-1}. According to Koprivica et al. (2009) harvester John Deere 5820 reached average daily performance of 7.25 ha. At average operating speed of 3.5 km h^{-1} combine achieved mass flow rate of 30.9 t h^{-1}. As it was expected, increasing the working speed to the maximum (4.5 km h^{-1}) resulted in higher productivity - 37.4 t h^{-1}.

Four different factors can limit machine capacity depending on field conditions and operation: power, mass flow capacity, speed and traction (Buckmaster, 2009). Potkonjak et al. (2010) reported that silage combine Krone Big X V8 achieves surface productivity of 2.79 ha h^{-1}, while the harvester John Deere 6810 reached only 1.4 ha h^{-1}. With preset cut length of 8 mm, combine Krone gave the average cut length of 9.8 mm, while the combine John Deere 6810 provided the cut length of 12.3 mm (preset value was 11 mm).

Stanimirović et al. (2009) analysed maize ensiling by silo-combine Zmaj 350. At average harvester speed of 5.1 km h^{-1}, they found surface productivity of 1.09 ha h^{-1} and mass flow rate of 9.1 kg s^{-1} or 32.9 h t^{-1}. However, at smaller velocity of 4.5 km h^{-1} the mass flow rate was only 7.2 kg s^{-1} (25.8 t h^{-1}). Mohammad et al. (2013) proposed the application of sensors to monitor the flow rate of harvested mass and reported that their accuracy was about 95%.

Materials and methods

Testing the work quality of silage combines Fortschritt E-286, Zmaj 350 and John Deere 5820 has been conducted in the Toplica region during 2013. All three self-propelled harvesters have been employed in maize silage preparation in the vicinity of village Zitoradja (43°11'14 "N, 21°42'28" E).

Primarily, test plots were planted by maize hybrid ZP-704. In all analysed cases, experimental data were obtained through 5 repetitions. Necessary adjustments of silage combines and presetting of the chopping length to 8 mm were carried out within the second phase of experiment. The length distributions of the chopped mass were determined by subsequent measurement and classification in the appropriate length fractions of the 5 kg of chopped mass taken from the transport trailer.

Mass flow rate was measured by capturing chopped mass after leaving combines within the specified time interval. The mean operating speed was determined by measuring the time of combine traveling between the two fixed points having mutual distance of 100 m. Final values were calculated by averaging five replicates. The aim of this study was to determine the work quality of tested silo-combines in the agro-ecological region of Toplica.

Results and discussion

Data presented in Table 1 show that silage combines were tested in similar conditions. The average yields were in the range between 23.91 t ha^{-1} and 24.49 t ha^{-1}, and the average heights of corn stalks were in the range from 2,560 to 2,732 mm. Numbers of plants per

hectare were in the range from 58,940 to 59,210. Moisture of the maize biomass during the ensiling process ranged between 69.9 % and 71.4 %.

Table 1. *Technical characteristics of silage harvesters and experimental conditions*

Parameters		Type of silage harvesters		
		Fortschritt E-286	Zmaj 350	John Deer 5820
Number of rows	/	/	3	4
Length	[m]	7.97	5.73	7.62
Width	[m]	3.14	2.51	3.30
Mass	[kg]	5,260	4,800	7,711
Chopping device type	/	Cylinder with knives	Cylinder with knives	Cilinder with knives
Drum rotation rate	[min^{-1}]	914	1,100	1,200
Maximal capacity	[t h^{-1}]	80	80	100
Cutting length	[mm]	3.3-15	4.8 -19	3-20
Operating speed	[km h^{-1}]	up to 8.7	up to 10	up to 10
Transport speed	[km h^{-1}]	20	20	20
Engine power	[kW]	110	125	206
The average plant height	[mm]	2,560	2,732	2,693
The average height set on ear	[mm]	726	730	717
Stem diameter	[mm]	22.6	23.2	23.4
Number of plants per hectare	[plant ha^{-1}]	58,940	59,210	59,143
Yield of maize	[t ha^{-1}]	24.49	23.91	24.14
Moisture	[%]	71.4	69.9	72.3
The average length of a clip	[mm]	233	240	215

Table 2 presents average values of chopped lengths of sillage mass, as well as mass participations of three particular fractions (< 8 mm, 8 – 19 mm and > 19 mm).

Based on these results, it can be noted that the silage combine Fortschritt E-286 achieved an average length of chopped mass of 9.4 mm with standard deviation of 0.8 mm and variation coefficient of 7.4 %. Most of chopped mass was in the shortest fraction having length of up to 8 mm (68.9%). The middle-length fraction having lengths between 8 mm and 19 mm comprehended mass participation of 29.4%, and the least mass percentage (1.7 %) was found for the largest fraction having lengths of chopped mass over 19 mm.

The average length ($\overline{X}$) of maize mass chopped by harvester Zmaj 350 was 11.7 mm, with a standard deviation (S_d) of 1.0 mm and variation coefficient (C_V) 4.1 %. Percentage of the fraction of chopped particles having lengths smaller than 8 mm took the value of 58.8 %, 39.4 % for the fraction between 8 mm and 19 mm, and 1.8 % for the largest fraction having particles over 19 mm in length.

In the latter case, the application of silage combine John Deere 5820 resulted in the average length of chopped mass of 9.9 mm, with a standard deviation from 0.5 mm and variation coefficient of 7.4 %.

Comparing the work quality of these three combines gave the following conclusion: the smallest deviation of actual average length of chopped mass in relation to the preset value was achieved by combine John Deere 5820. In that case, the average length of chopped mass was 9.86 mm, while 69.45 % of the chopped mass was shorter than 8 mm. These results are consistent with findings of other researchers: Ott, 2000; Jonhson et al., 2002;

Lisowski, 2006; Calvin, 2007; Stanimirović et al., 2008; Van and Heinrich, 2008; Potkonjak et al., 2010, among the thers.

Table 2. *Achieved chopped lengths of maize mass and presence of different fractions*

Type of silage combine	Average cut length and mass percentage of different chopped mass fractions	$\overline{X}$ (mm)	S_d (mm)	C_V (%)	Xmin (mm)	Xmax (mm)
Fortschritt E-286	Average cut length (mm)	9.4	0.8	7.4	4.9	21.0
	Fraction up to 8 mm	68.9	5.5	7.9	58.3	78.4
	Fraction 8 - 19 mm	29.4	4.6	16.0	21.1	39.0
	Fraction > 19 mm	1.7	1.7	107.2	1.0	5.0
Zmaj 350	Average cut length (mm)	11.7	1.0	4.1	5.0	22.1
	Fraction up to 8 mm	58.8	9.7	17.2	45.0	77.8
	Fraction 8 - 19 mm	39.4	11.0	26.4	18.3	57.0
	Fraction > 19 mm	1.8	1.5	86.4	1.0	5.0
John Deere 5820	Average cut length (mm)	9.9	0.5	7.4	5.4	21.6
	Fraction up to 8 mm	69.5	5.8	8.1	52.4	79.0
	Fraction 8 - 19 mm	29.1	4.9	17.2	20.6	39.0
	Fraction > 19 mm	1.4	2.0	108.1	1.0	6.8

Basic statistical parameters of working speed, mass flow rate and productivity of tested combines are listed in Table 3. Presented data show that traveling velocity of silage harvester Fortschritt E-286 varied between 3.0 km h^{-1} and 5.0 km h^{-1}, with average value of 4.0 km h^{-1}. Chopped mass flow rate was recorded in the range between 5.31 kg s^{-1} (19.33 t h^{-1}) and 9.46 kg s^{-1} (34.15 t h^{-1}), having the mean value of 7.30 kg s^{-1} (26.3 t h^{-1}). It follows that, under testing conditions, this machine reached mean capacity of only about 33 % with respect to declared value. Simultaneosly, the surface productivity varied between 0.61 ha h^{-1} and 1.13 ha h^{-1}, with average value of 0.83 ha h^{-1}.

Table 3. *Working speed, flow rate of chopped mass and productivity of tested combines*

Type of ensilage harvesters	Statistical property	Operating speed [km h^{-1}]	Mass flow rate		Surface productivity [ha h^{-1}]
			[kg s^{-1}]	[t h^{-1}]	
Fortschritt E-286	$\overline{X}$	4.0	7.30	26.3	0.83
	Sd	0.5	0.97	3.3	0.14
	Cv (%)	11.0	0.18	14.2	13.48
	min.	3.0	5.31	19.3	0.61
	max	5.0	9.46	34.2	1.13
Zmaj 350	$\overline{X}$	5.0	8.60	31.0	0.98
	Sd	0.4	0.98	4.1	0.14
	Cv (%)	7.8	10.38	11.4	10.36
	min.	4.4	6.93	25.0	0.87
	max	5.7	10.67	38.4	1.15
John Deere 5820	$\overline{X}$	4.7	10.87	39.1	1.21
	Sd	0.6	0.83	4.5	0.32
	Cv (%)	8.1	11.45	16.8	11.87
	min.	4.2	8.92	32.1	0.98
	max	5.7	11.76	42.3	1.39

During testing the silo-combine Zmaj 350, traveling velocity was in the range from 4.4 km h^{-1} to 5.7 km h^{-1}, with average value of 5.0 km h^{-1}. Mass flow rate took values between 6.93 kg s^{-1} (24.95 t h^{-1}) and 10.67 kg s^{-1} (38.41 t h^{-1}), while the average rate was 8.60 kg s^{-1} (30.96 t h^{-1}). Thus, measured value of mean flow rate of the combine was 38.75% of the value declared by manufacturer. Under specified testing conditions, silage harvester Zmaj 350 achieved surface productivity from 0.87 ha h^{-1} to 1.15 ha h^{-1}, while the average productivity was 0.98 ha h^{-1}.

Results of testing the combine John Deere 5820 also show its deficiency with respect to mass flow rate – real flow rate was only 39.13% of those declared by manufacturer. Testing speed varied in the range between 4.2 km h^{-1} and 5.7 km h^{-1}, while the mean velocity was 4.7 km h^{-1}. Average flow of chopped mass was 10.87 kg s^{-1} (39.13 t h^{-1}) and mass flow rate variations were from 8.92 kg s^{-1} (32.11 t h^{-1}) and 11.76 kg s^{-1} (42.34 t h^{-1}). Minimum, maximum and average registered surface efficiencies were 0.98 h ha^{-1}, 1.39 ha h^{-1} and 1.21 h ha^{-1}, respectively.

Experimental results show increase of the mass flow rate and surface productivity of all three combines with increasing the operating speeds. Analogue results have been also reported by: Harigan, 2003; Srivastava et al., 2006; Koprivica et al., 2007, 2009; Stanimirović et al., 2008; Potkonjak et al., 2010; Buckmaster, 2009; Barwicki et al., 2011.

Presented results of testing different combines show that forage harvester Fortschrit E-286 achieved much lower average speed in relation to other two silo-harvesters, Zmaj 350 and John Deere 5820, while the speeds of the two latter combines were similar. Silage combine John Deere 5820 achieved the highest mass flow rate, much over the combines Fortschrit E-286 and Zmaj 350, while the mass flow rates of these two combines can be rated as similar. Similar differences between the silo-combines were determined with respect to surface productivities.

Conclusion

Following the common practice, all three forage harvesters have been tested under fairly similar operational conditions. Among others, it can be noted that yields of maize crops collected and chopped by these harvesters at the experimental plot were close by values - between 23.91 t ha^{-1} and 24.49 t ha^{-1}.

However, the smallest deviation of actual cut length of chopped mass with respect to the preset cutting value was recorded when silo combine John Deere 5820 was used. In this case, the average length of chopped mass was 9.86 mm, and 69.45% chopped mass was in fraction having length of up to 8 mm. In opposite to this machine, the other two silo-combines expressed smaller participations of chopped particles of this fraction, as well as larger discrepancies of real (measured) chopped lengths from their preset values.

When compared to the other two harvesters, silo combine John Deere 5820 reached the highest average mass flow rate (10.87 kg s^{-1} or 39.13 t h^{-1}) and surface productivity (1.21 ha h^{-1}) at average working speed of 4.7 km h^{-1}.

Measured values of the average mass flow rate (7.30 kg s^{-1} or 26.28 t h^{-1}) and surface productivity (0.83 ha h^{-1}) of the combine Fortschritt E-286 were smallest. It should be noted that this harvester operated at smallest working velocity - only 4 km h^{-1}.

Finally, testing the silo combine Zmaj 350, which was performed at average operational velocity of 5.0 km h^{-1}, resulted in average mass flow rate of 8.60 kg s^{-1} (30.96 t h^{-1}) and surface productivity of 0.98 ha h^{-1}.

Results of present experiment clearly show that, under real agro-ecological conditions of Toplica region, all three forage harvesters were characterized by lower mass flow rate in comparison to values declared by manufacturers. Attempts of experimentators to increase the mass flow rates of tested combines failed at preset cutting lengths and testing conditions, because the speed increasing over the applied testing values resulted in congestion of combines during the work.

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