907. Maize and grass mixture silage compaction with centrifugal direct-action vibrator

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(Received 10 October 2012; accepted 4 December 2012)

Abstract. The efficiency of silage compaction of the chopped mass of maize and grass mixtures by means of centrifugal direct-action vibrators was experimentally evaluated in the reported study. The results indicate that the layer of grass plant chaff undergoes intensive compaction for the duration of 5-10 min. The dependences of the density variation of maize and grass plant mixture mass on compaction duration were determined. After 20 min of maize compaction, both silage layers of 510 kg m^{-3} density (the density of the dry matter – 143 kg m^{-3}) were achieved. Moreover, while mixture of maize and fodder goat's rue (3:1) was compacted, a high mixture density was reached as well. After 10 min of compaction, 474 kg m^{-3} (166 kg m^{-3} DM) density was obtained. Analysis of silage quality indicates that maize mixtures (fodder goat's rue (3:1) and maize - red clover (1:1) silage), which were compacted with centrifugal direct-action vibrator, meet the requirements for the high quality silage.

Keywords: maize, goat's rue, red clover, mixture, compaction, container, centrifugal direct-action vibrator, density, pressure, silage, quality.

Introduction

Farmers of many European countries use hay and silage for cattle feeding. The silage is predominant raw forage for cattle and other animal feeding. It can be used in various silage production technologies, e.g. in trenches, clamps, bales, containers, etc. [1, 2, 3]. New method of mechanical treatment of herbaceous plants can be used in order to prevent the silage from an intense wilting, i.e. maceration and pressing them into a thin mat. However, this method is not used widely, and usually is used for research only [4, 5].

The quality of the silage depends on the filling time of the trenches and containers, mass compacting method and technical means. In small farms, the silage is recommended to be produced in small section type trenches and in container storages, since container production does not require huge capital investments. Moreover, for silage production, farmers can use a variety of containers (e.g. the ones which are brought together with building materials, equipment and other materials). Therefore, metal, wooden, and plastic containers [6, 7, 8] are used for this purpose in different European countries. Silage compaction in the container store can be performed manually (by hand), using the additionally weight or a special press. However, the vibratory method is one of the most effective methods for silage mass compaction in containers [7, 8, 9].

The necessary condition for the production of high quality silage is a proper plant mass compaction. Taking into account the fact that grass mass surface is unstable, a tractor driver can be injured or even killed, if a tractor turns over when the mass is compacted. Several researchers carried out investigations by using vibratory grass mass compacting method as an alternative to grass mass compacting by tractors [3, 4, 7]. Such investigations are crucial to oversee the problems in advance, before applying this method in practice. In the meantime, farmers in Lithuania and other countries do not use this vibratory grass mass compacting method in practice. However, according to research results, recommendations for using these vibrators for silage compaction in the container stores in small farms can be prepared. In order to evaluate the efficiency of such methods, physical characteristics of the compacted mass should be properly analyzed, since they determine the type of vibrators and operational parameters to be selected.

The analysis of available literature sources revealed that vibratory method for grass mass compacting in the container stores was not thoroughly analyzed [3, 10, 11]. A vibratory silage mass compaction method was used several years ago. The investigations of vibratory crop compaction, while using vibrating rollers were carried out. The investigations demonstrated that the vibrating rollers can be used only for grass mass compaction in clamps and trenches, but not in the container stores [12].

A number of investigations were carried out at the Institute of Agricultural Engineering of Aleksandras Stulginskis University (IAE ASU) (the reformed Lithuanian University of Agriculture), which were based on applying vibratory grass mass compacting method for silage compacting in the container stores in small farms. In order to evaluate this method, physical characteristics of the compacted chopped grass mass should be analyzed, the types of vibrators used, as well as, their operational parameters should be presented [3, 9].

The investigations carried out at the Institute of Agricultural Engineering indicate that for silage compaction in a container inertia directional vibrators of both, indirect and direct action, are suitable. While using such equipment for herbaceous plant compaction, traditional compaction by a tractor, which contaminates grass with dirt and gasoline products should no be used. Such method of silage production gives an opportunity to use environmentally-friendly containers. Moreover, sectional and other types of enclosures can be used as well. Finally, the work with inertia directional vibrators does not have a negative effect on human health [13].

The results of the research of vibrator showed that during vibratory thickening, grass layer thickens intensively for 5-10 min and such vibrator is recommended for thickening the grass layers of 0.5-0.6 m thickness. It was determined that vibrator works most effectively at 43.96 s^{-1} frequency or close to it [13]. Such vibrator is recommended for the thickening of the plants with huge stems, such as maize and its mixture with red clover. On the other hand, such vibrator is much more efficient in thickening maize, since it reaches a larger mass density – 730 kg m^{-3} and 223 kg m^{-3} of the dry matter. However, the experimental indirect-action vibrator does not meet all the desirable requirements, since its operation is unstable, an undesirable ‘swimming’ effect appears leading to reduced pressing efficiency [13]. Therefore, it has to be improved and turned into a direction-type vibrator with two unbalances, rotating at different directions at the same angular speed, and in this way, increasing its inducing force and amplitude of fluctuations. Furthermore, major performance parameters of such direct-action vibrator should be tested, optimal working regimes should be identified and its major design parameters validated. Finally, vibrator performance parameters must be estimated and its effect on the density and quality of the ensiled forage should be determined.

The aim of the research is to evaluate the technology of maize and grass mixture silage compaction by means of centrifugal direct-action vibrator, to determine the dependences of density variation of maize and grass plant mixture mass on compaction duration, on duration of thickening and to determine vibrator efficiency on the basis of silage quality.

Research methods

One of the most important indicators characterizing the compaction of fiber-plant mass is its density. Analyzing fiber-plant mass compaction process, the majority of researchers make the following assumptions [10, 14]:

– the amount of the static load force does not depend on grass deformation speed;

– the fluxion of the pressure in terms of the mass density is a function of the added pressure.

These assumptions are used to describe the simplified models of grass mass compaction [3, 10]. Grass mass deformation and relaxation of elements forming a model are defined by differential equations [15, 16]. These equations are complicated, since the elements of compacted mass form the systems which have many degrees of freedom and a number of resonance frequencies. When a model can be analyzed as a vibratory system having one degree of freedom, this task is not as complicated. It is considered that the analyzed system is influenced by sinusoidal excitation force, and in this case, was written as the equation of vibration velocity, which establishes the dependence between vibration velocity and the excitation force amplitude [17, 18]:

$$v_m = \frac{F_m}{\sqrt{\mu^2 + \left(m\omega - q/\omega\right)^2}}, \tag{1}$$

where v_m is the vibration velocity, F_m is the amplitude of excitation force, μ is the constant of mechanical resistance (internal friction), m is the system mass, ω is the frequency of excitation force, q is the spring resilience equal to the force required to affect the spring in order to cause its deformation.

If mechanical resistance of grass mass is known and vibration velocity is measured (1), then, by this equation, the values of excitation force F_m may be established and these values can be compared with the calculated ones.

The efficiency of silage compaction by centrifugal direct-action vibrators was evaluated using experimental trials. The research object was the chopped mass of maize and grass forage mixtures, compacted with centrifugal direct-action vibrator:

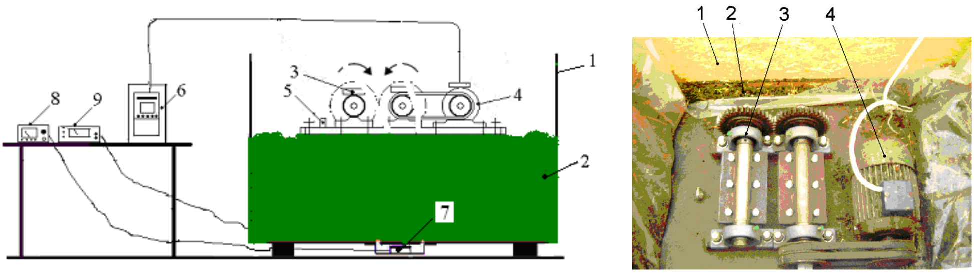
- chopped mass of maize (experiment variant I);
- chopped mass of maize and red clover mixture (ratio 1:1) (experiment variant II);
- chopped mass of maize and fodder goat's rue mixture (ratio 1:1) (experiment variant III);
- chopped mass of maize and fodder goat's rue mixture (ratio 3:1) (experiment variant IV).

Chopped plants of 67-72 % moisture content (chop length – 15-20 mm) were used for the trials. The research was carried out in laboratory trial facilities of Institute of Agricultural Engineering, Aleksandras Stulginskis University (IAE ASU).

The study was carried out in a laboratory stand (Fig. 1). The grass mass was compacted in a container storage (0.75×1.20×0.95 m), at the bottom of which - an opening was made and a sensitive pressure plate of 0.25×0.25 m size was fitted. The centrifugal direct-action vibrator was used for grass compaction. This vibrator was rotated by an asynchronous engine of 1.1 kW at 1500 min^{-1}. The weights of 7.0 kg mass were fitted to rollers in the vibrator, and their mass centers were 40 mm away from the axis. The total mass of this vibrator was 125 kg.

The velocity and acceleration of a flat vibrator vibrations were measured by a vibrometer 2511 with a band adjustable filter 1621, manufactured by a Danish company "Bruel & Kjaer", according to the established methods [9].

In order to measure pressure force on grass mass at the bottom of the container, a tensometric sensor was used. The pressure on the surface of the grass mass, as well as, at the bottom of the container was exerted by the vibrator static and dynamic forces. Operational parameters of the vibrator, grass mass density variation and other parameters were recorded using the above described methods. The pressure on the tensometric sensor 7 was measured by a pressure measuring device B&K Type 1526. All pressure measuring equipment was calibrated, and schedules of meter calibration were made. The tensometric sensor was calibrated after taking it out of the tenso-block body and fitting it on a specially manufactured calibration stand.



a) Scheme of centrifugal direct-action vibratory device

b) Centrifugal direct-action vibrator

Fig. 1. The scheme of grass thickening in container storage using centrifugal direct-action vibratory device: 1 – container storage (0.75×1.20×0.95 m); 2 – mass of compacted grass plants; 3 – centrifugal direct-action vibrator; 4 – electrical engine; 5 – vibration sensor; 6 – electric current frequency converter; 7 – tensometric sensor; 8 – pressure measurement device; 9 – vibration measurement device

The efficiency of the vibratory compaction in this study was assessed in terms of variation of density ρ. Moreover, the amount of the dry matter (DM) in the thickened grass was established and the density for dry matter was calculated as well. The volume of grass mass was calculated using a ruler (accuracy ± 0.001 m), for measuring the filling up of the container at 4 points. The grass mass in the container was weighed by the scales with a weighing range of 20-500 kg and accuracy of ± 0.5 kg. After putting two silage layers of 200 kg each into the container and pressing both layers, the silage was wrapped in polyethylene film and pressed by using the gravity force of the centrifugal direct-action vibrator.

After two months of storage under the similar ambient weather conditions, silage samples were taken and the quality of feed was evaluated by using standard methods [3]. Each experiment had three replications and the trial data was processed using mathematical-statistical methods by calculating arithmetic mean, average square deviation and selecting Student's coefficient – errors at 0.95 reliability. All calculated meanings of research results in the tables are placed without deviations (only average meanings).

Results

The excitation force F_e of directed action vibrator may be estimated by nomogram (Fig. 2) and calculated by the formula:

$$F_e = F_d r \left(\frac{\pi n}{30} \right)^2 , \tag{2}$$

where F_e is the excitation force, F_d is the disbalance gravity, r is the rotation radius of disbalance centre, n is the disbalance rotation frequency.

Vibrator pressure σ directly depends on the total excitation and gravity forces F, as well as, pressure increase coefficient k, and inversely depends on pressed surface area s (Fig. 3). In order to assess the efficiency of the vibrator we have to calculate contact pressure generated under the flat surface:

$$\sigma = \frac{k\left(F_e + F_g\right)}{s}, \tag{3}$$

where σ is the vibrator pressure, F_g is the vibrator gravity force, k is the pressure increase coefficient, s is the pressed surface area.

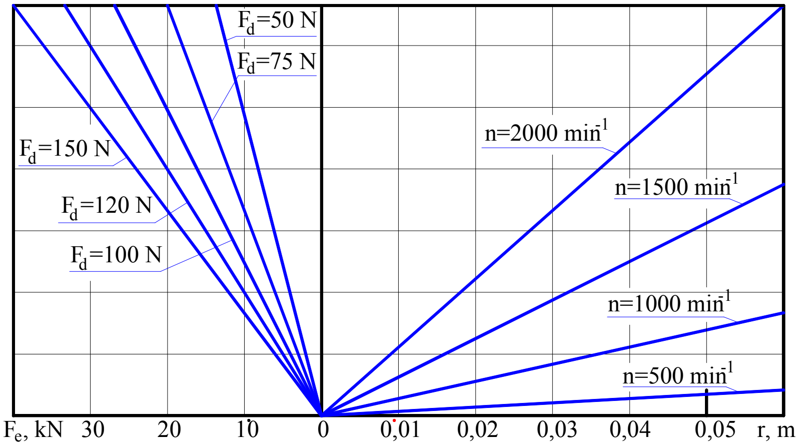


Fig. 2. Dependences of vibratory excitation force F_m variation on rotation radius of disbalance centre r, disbalance rotation frequency n and disbalance gravity F_d

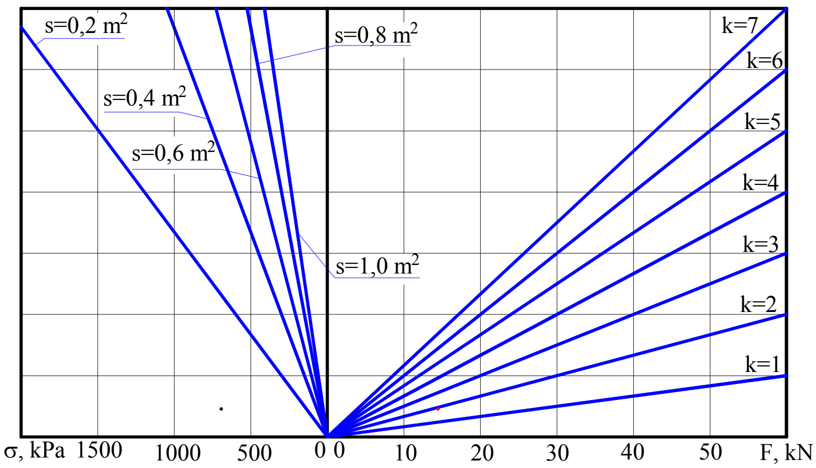


Fig. 3. Dependences of vibrator pressure σ on the total vibratory excitation and gravity forces F, pressed surface area s and pressure increase coefficient k

The results of experimental research of chopped maize and grass mixture silage compaction technology evaluation, while using centrifugal direct-action vibrator, indicate that the layer of the grass plant chaff compacts intensively for 5-10 min. Further grass layer compaction is inexpedient, since there was no significant compaction of comparative pressure increase. The dependences of density variation of maize and grass plant mixture mass on compaction duration (Figs. 4-6) have been determined. Maize mass density variation in the container storage is provided in Fig. 4.

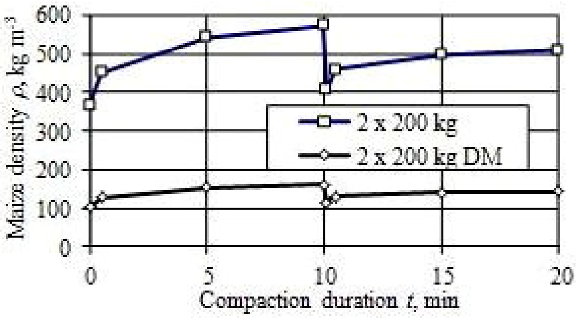


Fig. 4. Dependences of maize mass density ρ variation on compaction duration t, while compacting the mass with centrifugal direct-action vibrator

Moisture content of maize mass was 71.9 ± 0.6 %. The first 200 kg load corresponds to 10 min compaction duration, whereas the second additional 200 kg load corresponds to additional 10 min compaction duration. After 20 min of compaction, both silage layers of 510 kg m^{-3} density were achieved and, while compacting the first mixture layer of 200 kg mass, 571 kg m^{-3} density was achieved after 10 minutes. Densities of dry matter were 143 and 160 kg m^{-3} respectively.

The dependence of density ρ variation of maize and red clover mixture (1:1) mass on compaction duration t is shown in Fig. 5. It was established that the density of maize and red clover mixture (1:1) after 10 minutes was 395 kg m^{-3}, after 20 minutes – 387 kg m^{-3} and after 30 minutes – 383 kg m^{-3} (densities of the dry matter – 126 kg m^{-3}, 123 kg m^{-3} and 122 kg m^{-3} respectively) (Fig. 5).

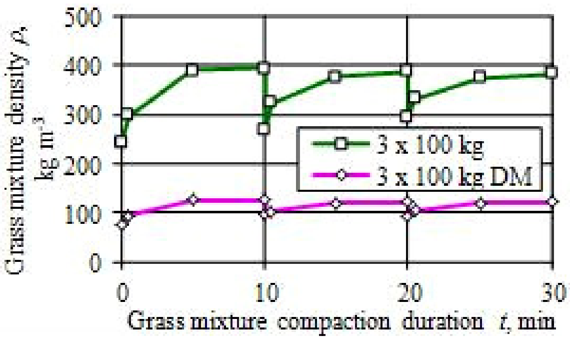


Fig. 5. Dependence of maize and red clover mixture (1:1) density ρ variation on compaction duration t, while compacting mixture by centrifugal direct-action vibrator

A similar mass density was achieved while maize and fodder goat's rue mixture (1:1) was compacted (Fig. 6). The higher density of this mixture was reached while different compositions (3:1) were compacted. After 10 min of compaction, 474 kg m^{-3} (166 kg m^{-3} DM) density was obtained. This density is not sufficient, but because of a mixture of the large quantities of maize (large sugar content and maize is classified as good ensilaging plants), the density of silage does not have a substantial negative impact on forage quality.

While evaluating the experimental technology of grass ensiling in a container store, when centrifugal direct-action vibrator was used, the attention was paid on grass mass chopping, loading into the container and compaction with the vibratory mechanism (harvesting and transporting operations were not analyzed). This technology was evaluated by means of three parameters:

- time needed to perform each operation and the complete production cycle;

- production efficiency;
- feed quality.

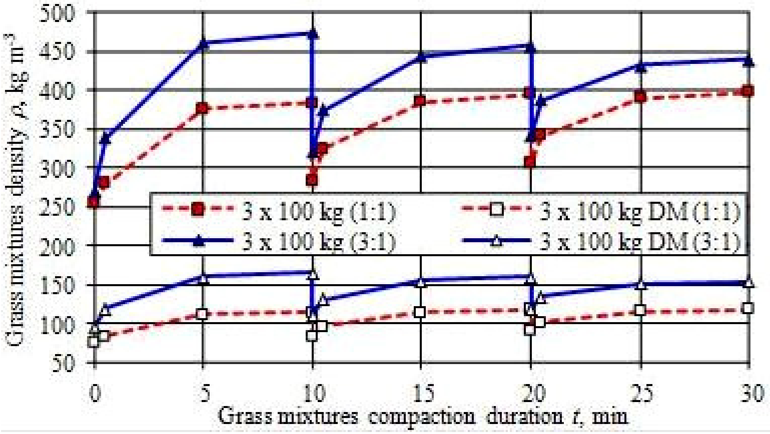


Fig. 6. Dependence of maize and fodder goat's rue mixture (1:1 and 3:1) density ρ variation on compaction duration t while compacting mixtures by centrifugal direct-action vibrator

The time required for a production cycle starting with grass chopping is equal to the sum of times (durations of technological operations) for: grass chopping, grass loading into the container, lifting up of the vibrator, grass compaction, grass sealing and pressing in a container.

All technological indicators of grass compaction are listed in Table 1.

Table 1. Technological indicators of vibratory grass compaction

Technological indicators	Technological operations					
	Grass chopping	Grass loading into container	Vibrator lifting up and down	Grass compaction	Grass sealing and pressing	Complete production cycle
Duration of technological operation, min	7.5-10	3-5	4-6	5-20	5-10	17-41
Efficiency of technological operation, t h^{-1}	1-1.5	2-3	0.4-0.9		-	-

Note: in the column of "Duration of technological operation" the time was registered when the operation was carried out with 150 kg of grass mass.

Analysis of technological operation of vibratory grass compaction revealed that 17-41 min are needed to perform a production cycle with a full container (150 kg of chopped grass mass). With adequate planning and distribution of operations, a silage production cycle (without grass harvesting and transporting operations) can be shortened down to 9-26 min, i.e., down to the total time of carrying out vibrator, lifting it up and lowering down, and grass compaction operations. The efficiency of a production cycle was limited by a technological operation of the lowest efficiency. In this case it was grass compaction – 0.4-0.9 t h^{-1} (see Table 1).

Analysis of feed quality (moisture content, DM content, pH, crude protein and nitrogen content, organic matter digestibility) indicate that mixtures of maize – fodder goat's rue (3:1) and maize – red clover (1:1) silage, which were compacted with centrifugal direct-action vibrator, meet the requirements for the type of silage (Table 2). Mixture of maize and fodder goat's rue (1:1) has silage of lower quality as feed within an acidic (pH is 4.7) and has lower organic matter digestibility – 76 %.

Table 2. Results of silage quality analysis

The sort of silage	Moisture content, %	Absolutely dry matter, %	pH	Crude protein, %	Nitrogen content, %	Organic matter digestibility, %
Maize	73.7	92.6	4.2	8.5	1.3	85
Mixture of maize and red clover (1:1)	67.5	92.1	4.4	14.4	3.9	87
Mixture of maize and fodder goat's rue (3:1)	67.3	92.9	4.3	9.6	1.5	83
Mixture of maize and fodder goat's rue (1:1)	67.3	91.5	4.7	14.9	2.4	76

Therefore, considering the results of these experiments, there is possible to conclude that the centrifugal direct-action vibrator of the analyzed design would be useful for maize compaction and partly for the compaction of the maize mixture – fodder goat's rue (3:1) and maize – red clover (1:1).

Vibratory silage compaction method can be recommended for small farms, and vibratory devices are suitable for herbaceous plants with big stems (maize) and partly for the compaction of their mixtures in the container stores.

Conclusions

The results of experimental research of the chopped maize and evaluation of grass mixture silage compaction technology, while using centrifugal direct-action vibrator indicate that the layer of grass plants chaff compacts intensively for 5-10 min. However, further grass layer compaction is inexpedient, since there was no significant compaction of comparative pressure increase.

The dependences of density variation of maize and grass plant mixture mass on compaction duration, while compacting the mass with centrifugal direct-action vibrator, have been determined. After 20 min of maize compaction, both silage layers of 510 kg m^{-3} density were obtained and, when the first mixture layer of 200 kg mass was compacted – the density achieved after 10 min was 571 kg m^{-3}. Densities of dry matter were 143 and 160 kg m^{-3} respectively.

It was determined that the density of maize and red clover mixture (1:1) after 10 minutes was 395 kg m^{-3}, after 20 minutes – 387 kg m^{-3} and after 30 minutes – 383 kg m^{-3} (densities of the dry matter – 126 kg m^{-3}, 123 kg m^{-3} and 122 kg m^{-3} respectively). A similar mass density was achieved while maize and fodder goat's rue mixture (1:1) was compacted.

Higher density of the mixture was obtained when maize and fodder goat's rue mixture (3:1) was compacted. After 10 min of compaction, 474 kg m^{-3} (166 kg m^{-3} DM) density was achieved. This density is not sufficient, but because of the mixture of the large quantities of maize (large sugar content and maize are classified as good ensilaging plants), density of silage does not have a substantial negative impact on forage quality.

Analysis of technological operations of vibratory grass compaction indicates that 17-41 minutes are needed to perform a production cycle with a full container (150 kg of chopped grass mass). The efficiency of a production cycle was limited by a technological operation of the lowest efficiency. In this case it was grass compaction – 0.4-0.9 t h^{-1}.

Analysis of feed quality indicates that mixtures of maize – fodder goat's rue galega (3:1) and maize – red clover (1:1) silage, which were compacted with centrifugal direct-action vibrator, meet the requirements for the high quality silage. The mixture of maize and fodder goat's rue (1:1) has a silage of lower quality than feed within an acidic (pH is 4.7) and has lower organic matter digestibility – 76 %.

The proposed vibratory silage compaction method can be recommended for small farms, and the centrifugal direct-action vibrator of the considered design would be useful for maize compaction in the container stores and is partly applicable for compaction of maize mixtures – fodder goat's rue (3:1) and maize – red clover (1:1).

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