

MACHINE AND MANUAL WORKING ACTIONS FOR DIFFERENT MANURE REMOVING TECHNOLOGIES

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Abstract

Technologies for the removal of manure from cowsheds and paddocks have been investigated by video recording with the following timing and estimation of absolute and specific costs of working actions, time and resources. The comparative estimation of different technologies for manure removing was performed: by delta-scraper equipment from a manure passage; by wheeled tractor with a bulldozer attachment from a manure passage; by bulldozer from a cowshed for housing on deep litter; by wheeled tractor with frontal loader attachment from a cowshed for housing on deep litter; by perimeter gutter cleaner in tie-stall cowshed; by bulldozer from the big paddock outdoor; manually from small paddock with replaceable litter in a cowshed on a pile near the feed passage. It was established that the influences of the method of manure removing on the specific costs of working actions, time and resources per 1 centner of removed manure are significant ($p < 0.001$ for the vast majority of these final characteristics) The measures of influence η^2 are within the range from 0.279 to 0.789. The mechanized removing of manure from the manure passage using a delta-scraper in the cowshed with free-stall housing is the most ergonomical among the methods studied. This equipment works at least semi-automatic and performs on average only 0.92 working actions with a duration of 155.1 s for the removing of 1 centner of manure, which worth around 1.08 UAH. Its functioning is characterized by a complete lack of working actions of adaptive type, while the remaining methods of manure removing require at least a quarter of such hard-to-perform and long actions. The accompanying manual labor actions of the personnel for cleaning of boxes from manure at manure removing by a delta scraper or a tractor with a bulldozer attachment are 10.33 labor actions with a total duration of 12.44 s per 1 cow per day. The removal of manure by the perimeter gutter cleaner has the worst (except the fully manual method) ratio between the number of mechanized and manual working actions – 558 manual actions per each machine action.

Keywords

cattle housing, manure removing, ergonomics, labor productivity, resource costs.

INTRODUCTION

Now production is based on the use of different machines and technological techniques at various animal husbandry farms in Ukraine. Each of the technologies of cattle housing provides different efficiency of the use of fixed assets, different costs of feed, working time, energy resources. Different technologies (including when various technologies take place in different seasons of the year) provide different quantities and quality of products (RUBAN et al., 2018).

In particular, this also applies to the removal of manure from cowsheds and paddocks. So, the volume of manure obtained, its physical and mechanical properties, and total costs depend on the machines and technologies used on the farm (SINDHÖJ and RODHE, 2013).

A well-designed and efficient manure removal system contributes to the creation of an optimal

microclimate in livestock farms. In particular, it lowers the concentration of microorganisms, ammonia, which manure secretes into the air (MANYI-LOH, 2016). And this allows you to maintain the health of animals, to receive high milk yields of high quality.

It should also be noted that there are now many technical and technological solutions (both domestic and foreign), the implementation of which does not fully correspond to the environmental aspects as well as biological characteristics of cattle in terms of the disclosure of the potential of productivity, adaptability, health and productive longevity (MOUDRY JR. and MOUDRY, 2014).

At the same time, in our country cleaning of cowsheds and paddocks from manure and its removing is one of the most labor-intensive and costly processes in the industrial livestock production. This technological element consumes till 30-50% of the total labor costs when caring for animals (PISKUN, 2007). This is due to the fact that the volume of manure is usually higher than the output of the main products and the amount of feed used for it. On average, one cow per day excrete 55 kg of manure with humidity of 86%, including 35 kg of feces with humidity of 83% and 20 kg of urine with humidity of 94%. 11-85% of animal excrements falls on the surface of the stalls. Often, the lion's share of work on the removal of manure from the premises falls on the manual labor of a cattleman or milker.

The choice of the method of manure removing and the means of its implementation depends on the species of animals, their direction of productivity. It depends also on the technologies of housing, feeding, bedding, quantity of animals, location of cowshed and other factors (LENDELOVÁ, 2016). Manure removing technology consists of technological processes, which include the following operations: manure removing from the stall and livestock facilities, as well as its transportation to the storage place (MALOMO, 2018). All these processes usually is carried out partly by hand, and partly by machines.

In many countries, significant results have been achieved in ergonomic design, use and maintenance of livestock equipment, safety, professional training of personnel (NIU and KOGI, 2014).

Recently, ergonomic studies of manure removal processes in livestock farms in Ukraine have practically not been carried out. Therefore, it was necessary to examine this issue from the point of view of a comparative evaluation of the effectiveness of various methods and machines for manure removing.

Nowadays there are many ways to remove manure from cowsheds. In Ukraine, the most common are mechanical methods with the partial use of scraper conveyors, delta-scrappers, loaders, or tractors with bulldozer attachments. One of the methods for saving resources is using the method of prolonged grazing of cattle (LÄPPLE, 2012), which saves

the cost of labor and energy, in particular, for cleaning manure.

Delta-scrapers or tractors with bulldozer attachments are usually used for cowsheds with free-stall housing. For tied keeping of cows, the removal of manure from tie-stall cowsheds by perimeter gutter cleaners are widespread. Loose housing of cattle on deep litter bedding are also widely used (SMOLYAR, 2013; PISKUN, 2007), especially during the winter. In this case, manure from the cowsheds is removed 1-2 times per year by bulldozers or loaders with dump trucks.

The goal of the research is to compare the various manure removing methods. The evaluation of these methods was performed on the basis of absolute and specific costs of the working actions, time and resources for the implementation of the main (mechanized) and accompanying (manual) operations in the removal of manure from the cowsheds, as well as on the basis of the ratio between the main and accompanying technological operations.

MATERIALS AND METHODS

The research was carried out on 18 farms with different variants of technology for the removal of manure from cowsheds and paddocks. Moreover, in some farms in different animal spaces various technologies and machines for removal of manure were used.

For evaluation of methods of manure removing, we used the approaches developed for ergonomic estimation of feed preparation and distribution technologies (SHABLIA, 2018). Ergonomic studies have been conducted taking into account the means of production in the workplace, management bodies, ergonomic parameters of the workplace, which are subject to measurement and further analysis, according to methodological recommendations (SHABLIA, 2014).

The following types of manure removing technologies were examined:

1. By the way of manure removing:

- mechanized;
- manually;
- combined.

2. By used equipment:

- using mobile machines;
- using stationary equipment;
- using hand tools and means of small mechanization;
- combined options.

3. At the place of manure removing:

- indoor;
- outdoor.

Finally, methods of manure removing were divided into the following gradations:

- by delta-scraper equipment from a manure passage;
- by wheeled tractor with a bulldozer attachment from a manure passage;
- by bulldozer from a cowshed for housing on deep litter;
- by wheeled tractor with frontal loader attachment from a cowshed for housing on deep litter;
- by perimeter gutter cleaner in tie-stall cowshed;
- by bulldozer from the big paddock outdoor;
- manually from small paddock with replaceable litter in a cowshed on a pile near the feed passage.

In the presented study, the process of manure removing were investigated in the narrow sense. That is, only those actions were involved in analysis that were touched actual manure removing from cowsheds and paddocks in which the animals were located. Technological operations for loading of manure onto vehicles and their transportation to storage places in these study have not been taken into account.

Technological processes of manure removing were studied by video recording in cattle farms. On the basis of video materials, timekeeping studies was carried out. Ergonomic evaluation of working actions of technical means and cattlemen were performed. The quantity and duration of elementary working actions in these processes were defined in accordance with the principles described in "Ergonomics and Manual Handling on Farms. Number 6" and articles of Shablia (2013, 2014).

Using the above methodological approaches, sets of working actions for various objects involved in the processes of manure moving, raking, removal and loading have been developed. The names, descriptions, identification and characteristics of these working actions, as well as the methodology and criteria for their evaluation were regulated.

So, each technological process were divided into constituent elements: technological cycles, operations and elementary working actions. Then the timekeeping of each elementary working action was performed. At the timekeeping,

the affiliation of working actions to technological cycles, operations and processes of a higher level were defined.

The sets of elementary working actions for a loader, a tractor with a bulldozer attachment, a scraper conveyor, a delta scraper and a cattleman has been developed. In this case, the methods for classifying and timekeeping of elementary working actions of manure loader are similar to those described by Shablia (2018) for forage loader. But, for example, the classification of working actions of delta-scraper was designed freshly. So, the process of manure removing by delta-scraper was divided into the following actions:

- Moving without cargo (manure) at working position forward;
- Moving without cargo at idle position backward;
- Moving of partially loaded delta scraper in the download process forward;
- Moving the fully loaded delta scraper (with overflow manure through top) forward;
- Moving the partially loaded delta scraper without touching the floor forward;
- Moving the fully loaded delta scraper without touching the floor forward;
- Moving without cargo at idle position without touching the floor backward;
- Moving of partially loaded delta scraper with the help of a person forward;
- Moving of fully loaded delta scraper with the help of a person forward;
- Moving without cargo at working position with the help of a person forward;
- Moving without cargo at idle position with the help of a person backward;
- Waiting in the middle of the manure loading process;
- Waiting in the middle of the moving at idle position;
- Waiting during preparatory operations before turning on the delta scraper;
- Waiting during final operations after turning off the delta scraper;
- Waiting during repairs;
- Waiting outside the manure removing process.

The classifications of elementary working actions for a wheeled tractor with a bulldozer attachment, a bulldozer and a perimeter gutter cleaner were based on similar approaches.

In addition, working actions were divided on types on resoluteness. Each working action was appertained to one of two types:

1. Resolute – a working action that is carried out resolutely and quickly, without interruptions and stopovers, and also does not require special caution;
2. Adaptive – a working action that is performed slowly, with a slowdown, in order to prepare for the execution of resolute actions, or to provide a comfortable and safe working situation. The adaptive actions provide the exact positioning of the object in space or the exact position in relation to it.

The final characteristics of manure removing processes were evaluated:

- quantity and duration of processes, cycles, operations and elementary working actions;
- the number of animals served by the object of the work process during one technological process and per unit of time;
- costs of time, working actions and money to ensure the implementation of the process, operation, cycle, working action per cow and per 1 centner of treated manure;
- percentage share of working actions of adaptive type.

In addition, the ratios between the number, duration and costs of the main (mechanized) and accompanying (manual) working actions for the various variants of managing for manure removing process was estimated.

Based on the research carried out, databases were created. They included the characteristics of working action ($n = 17263$) carried out with the use of machines ($n = 4340$) and technical means of small mechanization and manually ($n = 12923$). Working actions were divided into 223 technological processes. For each process, the main ergonomic characteristics were determined.

Analysis of variance were used for evaluation of influence of main characteristics of manure removing technologies on their final ergonomic and effective indicators. In particular, the influences of the method of removal of manure on the costs of working actions, time and means necessary for the implementation of this technological process was clarified.

The SPSS-20 statistical analysis package was used for statistical analysis. "General Linear Model" procedure were used for analysis of variance. The correlation analysis between different numerical characteristics of manure removal processes was performed using the procedure "Correlation".

RESULTS AND DISCUSSION

At the process of manure removing, different technologies and methods are used, as well as various configurations of joint mechanisms, equipment and people (Fig. 1, 2, [Table 1](#)).



Figure 1 - Manure removing methods: by bulldozer from the big paddock outdoor without the use of manual labor ("a") and manually from small paddock with replaceable litter in a cowshed on a pile near the feed passage ("b").



Figure 2. Manure removing methods: by delta-scraper from a manure passage at standalone mode ("a") and by perimeter gutter cleaner with the help of cattlemen ("b")

The method of manure removing by wheeled tractor with frontal loader attachment from a cowshed for housing on deep litter was excluded from the list of comparable methods, since its organization was extremely inefficient.

The rest of the above methods were compared with each other.

It was established that the method of manure removing influences significantly on absolute and specific quantity and duration of working actions, as well as the costs that take place while doing so ([Table 2](#)).

Table 1. The ratio between machine and manual working actions at different methods of manure removing

Technological operations	Number of working actions (units) per:			Duration of working actions (seconds) per:			Costs (UAH) for manure removing per:	
	200 cows per day	1 cow per day	1 centner of treated manure	200 cows per day	1 cow per day	1 centner of treated manure	1 cow per day	1 centner of treated manure
Manure removing method by perimeter gutter cleaner in tie-stall cowshed								
Machine operations, total	78	0.39	3.06	9946	49.73	279.57	0.324	2.07
Manual operations for servicing the gutter cleaner, total:	43486	217.43	562.08	31322	156.61	399.34	0.605	1.66
including raking of manure in gutter by milker	12436	62.18	431.13	10050	50.25	352.51	0.197	1.47
including raking of manure in gutter by cattleman	16670	83.35	1018.77	11532	57.66	661.44	0.205	2.76
including the final clearing of the passage by cattleman	6700	33.50	837.50	3978	19.89	497.16	0.083	2.07
including cleaning scrapers from manure into sloping conveyor by cattleman	7680	38.40	337.50	5764	28.82	261.35	0.120	1.09
Manure removing method manually from small paddock with replaceable litter in a cowshed on a pile								
Manual operations – clearing the floor from the manure by pitchfork	21266	106.33	797.50	17556	87.78	658.34	0.366	2.74
Methods of manure removing from a manure passage at stand-alone mode								
Machine operations, total	312	1.56	3.17	8108	40.54	69.07	0.825	1.63
Manual operation for servicing manure passage, total:	2066	10.33	449.71	2488	12.44	510.93	0.052	2.13
including raking of manure residue from the passage by cattleman	920	4.60	230.25	1364	6.82	365.58	0.028	1.52
including raking of manure residue from the boxes by cattleman	1148	5.74	669.17	1126	5.63	656.28	0.023	2.73
Manure removing method by bulldozer from a cowshed with big paddock outdoor at housing on deep litter								
Machine operations, total	46	0.23	0.66	564	2.82	8.18	0.110	0.31
including manure removing by bulldozer from the big paddock outdoor	40	0.20	0.60	490	2.45	7.36	0.086	0.26
including manure removing by bulldozer from a cowshed	6	0.03	1.73	74	0.37	24.36	0.024	1.43

Table 2. Influence of manure removing methods on their final characteristics

Final characteristics of methods, units of their measurement	Measures of influence η^2	Significance level p
Number of working actions per 1 cow per day, units	0.789	<0.000
Duration of working actions per 1 cow per day, seconds	0.779	<0.000
Number of working actions per 1 centner of treated manure, units	0.520	<0.000
Duration of working actions per 1 centner of treated manure, seconds	0.769	<0.000
Average duration of 1 working action, seconds	0.279	0.021
Costs for manure removing per 1 cow per day, UAH	0.728	<0.000
Costs for manure removing per 1 centner of treated manure, UAH	0.769	<0.000

In particular, the types of mechanisms and equipment involved in the manure removing process are important. The levels of their influence on the final characteristics are in the range from $\eta^2 = 0.164$ ($p = 0.053$) for the specific duration of the working actions per cow per day up to $\eta^2 = 0.712$ ($p < 0.000$) for the specific costs of the resources (UAH per cow per day).

Golub, G. et al. (2018) demonstrated the difference between 2 types of compared

machines for manure removing by specific resource consumption too. For example, they established different specific energy consumption of these machines.

The areas from which the manure is removed (from the manure passage in cowshed / from a cowshed for housing on deep litter / from the big paddock outdoor / from the tie-stall cowshed with perimeter gutter / from small paddock with replaceable litter in a cowshed) also affect the final characteristics of this process (Table 3).

Table 3. Influence of areas from which manure is removed on the final characteristics of manure removing

Final characteristics of methods, units of their measurement	Measures of influence η^2	Significance level p
Number of working actions per 1 cow per day, units	0.788	<0.000
Duration of working actions per 1 cow per day, seconds	0.779	<0.000
Number of working actions per 1 centner of treated manure, units	0.211	0.060
Duration of working actions per 1 centner of treated manure, seconds	0.754	<0.000
Average duration of 1 working action, seconds	0.232	0.036
Costs for manure removing per 1 cow per day, UAH	0.405	<0.000
Costs for manure removing per 1 centner of treated manure, UAH	0.317	0.004

Groborz and Juliszewski (2013) compared farmers workload by manual and mechanical tasks on family farms. They noted that even mechanized work contains in themselves a higher or lower share of manual activities. As a result of the analysis, the authors concluded that it is necessary to specify the criteria for the division into manual and mechanical work.

We did this by dividing each technological operation into working actions performed by means of machines and manually. It was established different ratio between the main (mechanized) and accompanying (manual) operations for different methods of manure removing (Table 1). It should be noted that the columns "per 1 centner of treated manure" in the table refer to manure as a subject of labor. In this case for machines the amount of removed manure is usually equal to the amount of manure treated. But for accompanying manual operations, these two indicators can be different, because the cattlemen at some methods treated only a small portion of the total amount of manure removed.

It has been demonstrated that there are variants of methods for manure removing, which use either exclusively manual labor, or exclusively machine removal. This is the manually manure removing from small paddock with replaceable litter in a cowshed on a pile near the feed passage and machine manure removing by bulldozer from a cowshed with big paddock outdoor at housing on deep litter, respectively.

The last option is the cheapest both as a costs per 1 cow, and per 1 centner of removed manure. However, this result was a consequence of the use of somewhat modified technology, in which about 90% of the total amount of manure was removed from the paddock, and only a

small proportion of manure – from the cowshed.

Completely manual removing of manure is characterized by an intermediate level of costs of funds. However, by the number and total duration of labor actions per 1 centner of treated manure, this method is an absolute leader. Considering the usual for an average farm loading equal to 200 cows per cattleman, only the execution of this operation 1 time per day requires costs 5.9 hours. In addition, it is necessary to load manure manually (unlike the remaining methods) on a vehicle. This is also a very labor-intensive operation: its costs per 1 cow only 18.7% less than for removing manure from the paddock. It should also be emphasized that manure removing in this case occurs only once a day, which increases the risks about microclimate and biosecurity of the technology and products in comparison with variants of higher manure removing frequency.

The perimeter gutter cleaners are intended mostly for removing of manure from the tie-stall cowsheds [2]. The use of gutter cleaners are due to its suitability for manure removing at farms of any size. The gutter cleaner is easy to install and operate. Its installation is possible at the reconstruction of the old cowsheds with narrow passageways for manure.

However, the manure removing by perimeter gutter cleaner were characterized mostly by maximum specific costs of working actions and time among the methods of manure removing.

Besides, the removal of manure by the perimeter gutter cleaner has the worst (except for the fully manual method) ratio between the number of mechanized and manual working actions – 558 manual actions per each machine actions.

It has been established that time and recourse costs for manure removing depend on the number of involved aggregates and workers. So, on the one hand, *ceteris paribus*, increasing of number of aggregates and workers, which execute a technological operation, leads to reducing of its duration. On the other hand, the specific costs of time and resources per cow or per 1 centner of removed manure can increase or decrease, depending on the particulars of the work being performed.

For example, at manure removing by bulldozer from a cowshed for housing on deep litter, there were no significant differences between the time costs on removing of 1 centner of manure using one and two bulldozers. At the same time, the correlation coefficient between the number of bulldozers and the cost of removing 1 centner of manure $r = 0.87$ ($p = 0.05$) was established. At the simultaneous operation of two bulldozers, the cost of removing 1 centner of manure was 2.02 UAH, while the independent work of one bulldozer cost 1.03 UAH/centner.

Comparative estimation of different methods of manure removing showed that the most ergonomic variant is the use of a delta-scraper equipment in the cowshed with free-stall

housing. This equipment is intended for manure removing from open passages, in which the manure accumulates. It works at least semi-automatic and it makes possible to clean cowsheds from liquid and solid manure. The installation is safe for cows as the delta-scraper moves at a low speed.

Delta-scraper performs on average only 0.92 working actions with a duration of 155.1 s for the removing of 1 centner of manure. The cost of removing 1 centner of manure is around 1.08 UAH.

Functioning of delta-scraper equipment is characterized by a complete lack of working actions of adaptive type (Table 4), while the remaining methods of manure removing require at least a quarter of such hard-to-perform and long actions.

Table 4. Percentage share of working actions of adaptive type at carrying out operations of mechanized removal of manure by different methods

Manure removing methods	Percentage share of working actions of adaptive type, %
By wheeled tractor with a bulldozer attachment from a manure passage	35.85
By bulldozer from a cowshed for housing on deep litter	45.32
By wheeled tractor with frontal loader attachment from a cowshed for housing on deep litter	25.73
By perimeter gutter cleaner in tie-stall cowshed	70.46
By bulldozer from the big paddock outdoor	38.95

The accompanying manual labor actions of the personnel for this method are minimal: to clean up the remains of manure on the manure passage, it is necessary 2.55 actions (3.8 s) for each centner removed manure. For cleaning of boxes from manure at manure removing by a delta scraper needs 10.33 labor actions with a total duration of 12.44 s per 1 cow per day.

The removing of manure by bulldozer from the big paddock outdoor is the method, the closest to considered version by ergonomics and specific number and duration of working actions. But it is the four times cheaper.

The manure removing by wheeled tractor with a bulldozer attachment from a manure passage in the cowshed with free-stall housing requires the same additional manual labor actions and costs of recourses to clean the boxes, as at the use of a delta scraper. But this method differ from previous one by the specific costs of main (mechanized) technological operation. So, a wheeled tractor spends 5.88 working action with a total duration of 60.59 seconds to remove 1 centner of manure. The cost of removing 1 centner of manure at this method is 2.72 UAH (about 34 cents) or 1.32 UAH (about 16 cents) per cow per day.

At this case the cost of removing 1 centner of manure corresponds with data of

Bentley and Tranel (2015). For example, in their researches handling manure from the time cow dropped it until the time the manure was in storage was investigated. The costs of this variant of manure removing was 53 cents per 1 centner of manure. But in these studies, transportation of manure from the building to the storage was taken into account, but not in ours.

CONCLUSIONS

It was established that the influences of the method of manure removing on the specific costs of working actions, time and resources per 1 centner of removed manure are significant ($p < 0.001$ for the vast majority of these final characteristics) The measures of influence η^2 are within the range from 0.279 to 0.789 for different final characteristics of manure removing.

The mechanized removing of manure from the manure passage using a delta-scraper from the cowshed with free-stall housing is the most ergonomic among the methods studied. This equipment works at least semi-automatic and performs on average only 0.92 working actions with a duration of 155.1 s for the removing of 1 centner of manure, which worth around 1.08 UAH. Its functioning is characterized by a complete lack of working actions of adaptive type, while the remaining methods of manure removing require at least a quarter of such hard-to-perform and long actions.

The accompanying manual labor actions of the personnel for cleaning of boxes from manure at manure removing by a delta scraper or a tractor with a bulldozer attachment are 10.33 labor actions with a total duration of 12.44 s per 1 cow per day.

The mechanized manure removing by wheeled tractor with a bulldozer attachment from a manure passage in the cowshed with free-stall housing requires 5.88 working action with a total duration of 60.59 seconds to remove 1 centner of manure. The cost of removing 1 centner of manure at this method is 2.72 UAH or 1.32 UAH per cow per day.

Total costs of means for the manure removing by the perimeter gutter cleaner are about 0.93 UAH per a cow per day. But this method has the worst (except the fully manual method) ratio between the number of mechanized and manual working actions – 558 manual actions per each machine action.

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