Multifunctional unit and methods for improvement of mountain agricultural landscapes

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Abstract. Mountain fodder land, which is a reliable source of high-quality and cheap feed production for the development of the main industry of the northern Caucasus mountain zone - animal husbandry, sometimes up to 60% of the area is littered with stones that must be removed from meadows and pastures to increase their productivity. Therefore, it became necessary to create a small multifunctional maneuvering unit to remove stones from the slopes. A new resource-saving way of improvement and unit for raking and recycling of stones from the slopes of meadows and pastures with an exposition slope of up to 12° were developed. The unit implements the shuttle traffic starting from the summit grassland of the slope, the paddocks across the slope, raking the stones by comb, and, as required, disposing them to the channel that is simultaneously cut with the help of a single-bottom plow. Tests of the unit were carried out in a station on the southern slope of the Dargavskaya basin of republic of North Ossetia - Alania (left Bank of the Gizeldon river) at an altitude of 1650 m below sea level (b.s.l.), with a slope of 10°. Width of capture of the unit – 2000 mm; speed - 8-10 km/h, depth of the cut channel 120-130 mm; width of the channel – 350 mm; angle of rotation of the comb from 0 to 30°; overall dimensions of the unit -2000x2500x1200 mm. The use of a multifunctional unit allows enriching the soil with organic nutrients that stimulate increased productivity of forage lands, reducing erosion and other degradation processes of soil cover, creating favorable conditions for the use of mechanization in meadows and pastures, increasing the environmental and economic importance of natural forage lands.

1. Relevance of the topic

Nowadays, mountain forage lands, primarily pastures, are characterized by unsatisfactory cultural and technical condition, large areas of which are clogged with stones. The presence of stones in the mountains is associated with the constant destruction of rocks and knocking by hooves of animals.

In terms of topography, landscape and soil and climatic conditions (steep slopes, sharp change of temperature of air and soil, as the seasons and during the day; low power of humus horizon, strong stony, etc.) the problem of improvement of the mountain slopes is the difficulty of use of means of mechanization [1, 3].

To carry out mechanized works on hay harvesting, increase productivity and increase the useful area of pastures, the actual event is the cleaning of stones. The degree of stony is considered weak if up to 10 % of the area of pastures covered with stones; medium from 10 to 20 %; strong from 20 to 60 % and over 60% are very strong.
It is well known that grass mowing should be carried out at a height of 60-70 mm from the soil surface [2]. Stones, protruding above the soil above 60 mm, prevent the use of tractor mowers on hayfields and contribute to injury of animals on pastures.

Due to the peculiarities of the relief of mountain agro-landscapes, the use of serial means of mechanization for cleaning stones is impossible. More than 200 inventions on the mechanized cleaning of stones which are generally intended are recently patented: for assembly and export of stones; uprooting of stones from the soil, loading and export; crushing of stones and the subsequent export. These include stone harvesters Jympa model: model MYM-185, MYM 205 AM, MYM 205 DX; kivipekka; stone cleaning machine (SCM)-0.6; 7200 SignatureTM Kongskilde “Stonebear”, Schulte, Tamerlan -1800, mobile launcher (ML) -6 etc.

Stone harvester kivipekka reliably cleans the soil from stones of different diameters and prepares the soil for sowing. The principles of this technique: the shaft of the pick-up collect gems by movement in the opposite direction from the car. The depth of the collection – up to 15 cm. Double cube hopper receives the stones, moving towards him in the sieve, while the land perceives through the cell, back out into the field.

Manufacturer country of kivipekka is Finland. This machine is widely used for the treatment of soil with a high percentage of contamination with stones. The performance of the stone harvesting unit – 1200 kg per minute – is an excellent performance, putting kivipekka on one of the first places among similar equipment.

There are also machines for the assembly of stones from the surface of the field and construction sites - Kongskilde “Stonebear”. However, these machines are a great option for companies with the main field of activity - cleaning of golf courses, beaches, sports facilities, lawns, industrial areas and construction sites.

Using the machine Kongskilde “Stonebear” with a working width of 4 and 5 meters, stones with a diameter from 3 to 30 centimeters are easily removed. High efficiency is due to the fact that only one person can operate and maintain the machine. To avoid compaction of the soil, the designers of this rock skimmer supplied it with wide tires with low pressure. Due to this, the collection of stones is possible even just before sowing crops.

High-tech duo Schulte, consisting of a roller and a stone skimmer – a complex of machines that can clear any field of small, medium and large stones.

Separate cleaning allows for much more thorough cleaning of fields. Swather collects stones in rolls – furrow at the middle or the edges of the field. Rolls can be a lot – it depends on the contamination of the territory. Further, the stone skimmer rakes the rolls with special blades, and the stones fall into the hopper.

A method for removing stones is also known [4], [5], including removing stones from the surface of the field with their sampling from the soil, moving to the untidy site and loading into the vehicle. The disadvantage of this method is that it is designed to work on arable land and is not suitable for slope areas of mountain and foothill zones.

Studies have shown that all of the above units and methods of removing stones are intended for arable flat agricultural land, and their use is associated with a significant violation of the turf cover, which is unacceptable on natural forage lands, especially on small-scale slope lands [6].

The purpose of the study is a new method of improvement and a prototype of a mounted stone harvesting unit, technical expertise and justification of its effective use on slope, natural forage lands, with the utilization of small and medium-sized stones in simultaneously cut channels.

The tasks of the research were the following:
- develop a new method and unit for the disposal of stones;
- choose the grazing land littered with loosely scattered small and medium-sized stones;
- determine the degree of contamination by counting the area of contact of stones on the site (1 m²);
- calculate the volume weight of stones per unit area is 1 m2 by the method of displacement of liquid;
- multi-function assembly testing;
2. Results of scientific research
A group of mechanization, together with the laboratory of mountainous grassland farming North-Caucasus Scientific Research Institute of Mountain and Foothill Agriculture of the Vladikavkaz Scientific Center of the Russian Academy of Sciences, has been developed a method for improving forage land and constructed a prototype of a hinged stone harvesting assembly to remove stones by diameter more than 30 mm on the steep slopes up to 12°, aggregated with tractors “Belarus” mountain modification.

The method and the main components of the developed unit [7], [8], are shown in (figure 1).

The proposed method is carried out with the shuttle movement of the unit, starting from the top of meadows and pastures by corrals across the slope, raking the stones with a comb, and, as necessary, utilizing them in a simultaneously cut channel with a single-hull plow mounted on a fixed frame of the unit. The soil by plough body falls off down the slope, forming a parapet along the bottom of the treated area.

The depth of the cut channel cannot be more than 20 cm, because in the mountainous area close to the surface of the rocky ledges of the soil. Channel width (35 cm) is selected as the most suitable value of the width of the commercially available housings of the plow, and the frequency cut on the field of channels is set depending on the degree of contamination of by stones. It is known that the remaining stones on the field of less than 30 mm do not have a negative impact on the work of hay harvesting equipment.

The unit is pivotally connected to the fixed frame (6) by means of a hinged device (6) and hung on the Minskiy tractor factory (MTF) -82 tractor (11).

The rotating device (5), controlled by a hydraulic cylinder (9) from the tractor cab, serves to establish the angle of attack of the comb from 0 to 30°, which changes relative to the direction of movement of the unit, stimulating the rolling of stones down the slope.

Spring struts (2) press the comb to the soil surface, which provides a constant gap between the field surface and the ploughshare equal to 50 mm. Single-body plough (7), as stones accumulate, cuts a channel for disposal. It is equipped with a mechanism for sinking into the soil, as well as a protection mechanism at a meeting with a hidden under the soil cobblestone or rock ledge.

The width of the grip, the angle of rotation of the comb, the depth of the channel, the width of the channel, the height of the comb, as well as the number of tiered pens are adjustable depending on the debris and the size of the stones before the unit [9].
Figure 1. Principal scheme of the unit, where: 1 - comb, 2-spring struts, 3 - movable frame, 4-support wheels of the comb, 5-rotary device, 6 - fixed frame, 7 - plow, 8 - hinged device, 9-hydraulic cylinder, 10-support wheels of the plow, 11-tractor MTF-82.

3. Calculation of the height of the comb

One of the important structural parameters that affect the quality of the unit and its structural weight is the height of the comb. At low altitude combs the stones that are stacked in front of comb, unable to waddle through the brush and clog already cleared the field. And the increase in the height of the comb will lead to the weighting of the unit and increase the specific pressure of the support wheels on the grass cover. Therefore, it is proposed to determine the height of the comb depending on the width of its grip and the degree of clogging of the field surface with stones [10].

At the same time, a pile of stones raked by a comb down the slope into a channel simultaneously cut by a plow can be represented with some approximation in the form of a pyramid ((о, с, о₁, d) (Fig.2), at the base of which there is a rectangular equilateral triangle (с, о₁, d), one leg of which is the height of the comb (h), and the other — the value of the departure of stones on the lower slope of the field edge of the comb (b). Take h=b. The height of the pyramid H is determined by the segment о₁, о₂, and is equal to the constructive width of the comb B₁.

The height of the comb is chosen from the condition of the maximum clogging of the field with stones (Smax), and the utilization of stones in the channel begins in case that the volume of the abstracted pyramid is filled with stones, i.e. \( V_{\text{stones}} = V_{\text{pyramid}} \).

The volume of stones collected from the surface of the field required to fill the volume of the pyramid can be expressed as (1):

\[
V_{\text{stones}} = \frac{P_{\text{stones}}}{\rho_{\text{stones}}} = \frac{S_{\text{max}} \cdot S_{\text{field}}}{\rho_{\text{stones}}} = \frac{S_{\text{max}} \cdot B_1 \cdot L}{\rho_{\text{stones}}} \tag{1}
\]

where:

- \( V_{\text{stones}} \) - the volume of stones required to fill the volume of the pyramid (m³).
- \( P_{\text{stones}} \) - weight of stones collected by the comb when passing the path L (kg).
- \( \rho_{\text{stones}} \) - specific gravity of stones of fraction 60...200mm, for the collection of which the unit is designed, (kg/m³).
$S_{\text{max}}$ - the maximum value of the degree of contamination of the field surface with stones ($\text{kg/m}^2$).

$S_{\text{field}}$ - area of cleared field where the condition $V_{\text{stones}} = V_{\text{pyramid}}$ is available ($\text{m}^2$).

$B$ - width of the comb (m).

$L$ - the path passed by the comb to collect stones, the volume of which is equal to the volume of the pyramid, (m).

Figure 2. Comb.

It is known the equation of the pyramid volume ($V_{\text{pyramid}}$)

$$V_{\text{pyramid}} = \frac{S_{\text{basement}} \cdot H}{3} \quad (2)$$

where:

$S_{\text{basement}}$ – area of pyramid basement (m),

$H$ – the high of the pyramid (m).

For the figure 1 we can see that pyramid volume $V_{\text{pyramid}}$ can be expressed as

$$V_{\text{pyramid}} = \frac{0.5 h^2 B_1}{3} \quad (3)$$

where: $B_1$ – structural width of the comb (m)

Assimilating the right parts of equations (1) and (3) and making transformations with respect to $h$, we obtain equation (4) to determine the height of the comb, $h$:

$$h = \frac{6 S_{\text{max}} B L}{B_{\text{pyramid}}^3} \quad (4)$$
The combination of cleaning stones with their utilization in the cut channels will provide not only an increase in the useful pasture area, but also improve the water-air regime of the soil, the ecological situation in the mountain zone, stimulating an additional increase in yield [11].

4. Manufacture testing of the unit

Pilot production assembly testing was conducted on the southern slope of the Dargavskaya basin of republic of north Ossetia - Alania (left Bank of the Gizeldon river) at an altitude of 1650 m below sea level (b.s.l.), with a slope of 10°, where stationary test for unit assembly for simultaneous removal and disposal of stones was executed.

To accomplish the tasks, the degraded pasture, covered with small and medium stones, with a total area of 8760m², was divided into three equal areas, 2920m², each of which was a repeat. In turn, each section was divided into three experimental allotments (options) of 973m², between which the dividing strips of 2m width were allocated. The total number of options - 9 (three in each repetition), each second option - control (2, 5, 8). The unit moves through the experimental field in three segments, changing the direction shown in the scheme of experience (figure 3). At the beginning of the third segment, the plow falls to a predetermined depth, forming a recycling channel width of 35 cm, which enters the stone mass directed by the comb.

In the spring, after complete drying of the pasture, at the beginning of the vegetation of meadow grasses, by measuring the area of contact with the soil of freely scattered small and medium-sized stones, ranging in size from 3 to 60 cm, we determined the area of clogging of the accounting allotment (1m²), which, in the amount of three pieces, are diagonally on each version of the experiment. Clogging with stones as the options are located from top to bottom, on average, amounted to: 37.2; 45.6-52% of the area of the allotment.

Increasing the level of debris as the location of the plots decreases due to the fact that for a certain time the animals in the horizontal movement of the pasture hooves knock small and medium stones, which by inertia roll down the slope.

According to the scheme of the experiment, the second allotment of the experimental site (options 2,5,8) was a control, which was not processed by the unit.

It is established that during shuttle movement of the unit from the upper variant to the lower, three-tiered segments, the comb with a width of 2.2 m rakes the stones down the slope into the cut channel of the lower part of the third segment early calculated by the depth, width and length of the corresponding volume of stones collected from the accounting allotment (the volume mass was determined by the difference between the displaced and the remaining water in the container when loading into it stones from the accounting allotment).

According to the order of the processed experimental plots (options): 1; 3; 4; 6; 7; 9, the volume of stones to be disposed of at 90-93% of purification was, according to calculations, respectively: 2.5; 3.2; 3.4; 3.7; 4.1 and 4.9m³.

According to the obtained indicators, the depth of the utilization channel was adjusted with the help of the mechanism of the plow penetration into the soil [], which amounted to the volume of stones and the length of the channel: 10cm; 12; 12.5; 13.5; 14.5; 17cm.

Depleted parapet, together with filled with stones recycling channel formed of erosion-protective and water-absorbing terraces with a width of 70-75cm.

In addition to raking stones, the unit during movement through the pasture due to the gap between the ploughshare of the comb and the surface of the mountain area, evenly distributes the remaining animal excrement, enriching the soil with organic nutrients that stimulate increased productivity of forage and animals feeding by high-quality feed.
Figure 3. Scheme of the unit movement, where: 1-movable frame with comb; 2-fixed frame with plow; 3-channel for stone recycling; 1, 2, 3 - corrals.

Observations, according to the methodical instructions, as well as the calculations [11] of nutritional value with the use of Axelson coefficients, established a positive dynamics of changes in yield and nutritional value of pasture feed after the use of the stone harvesting unit (table 1).

Table 1. Yield and nutritive value of pasture use of stone harvesting unit (for 3 years of observations).

| Options   | 1st Dry substance, thousand | 1st Feed unit, thousand | 1st Digestible protein, thousand | 1st Exchange energy, GJ | 2nd Dry substance, thousand | 2nd Feed unit, thousand | 2nd Digestible protein, thousand | 2nd Exchange energy, GJ | 3rd Dry substance, thousand | 3rd Feed unit, thousand | 3rd Digestible protein, thousand | 3rd Exchange energy, GJ |
|-----------|-----------------------------|-------------------------|---------------------------------|-------------------------|-----------------------------|-------------------------|---------------------------------|-------------------------|-----------------------------|-------------------------|---------------------------------|-------------------------|
| 1         | 1.45                        | 1.30                    | 0.11                            | 14.4                    | 2.36                        | 2.10                    | 0.22                            | 24.3                    | 3.08                        | 2.74                    | 0.31                            | 32.3                    |
| 2(control) | 1.29                        | 1.16                    | 0.10                            | 12.85                   | 1.31                        | 1.17                    | 0.12                            | 13.5                    | 1.50                        | 3.4                    | 0.15                            | 15.3                    |
| 3         | 1.55                        | 1.40                    | 0.12                            | 15.44                   | 2.47                        | 2.20                    | 0.23                            | 25.4                    | 3.13                        | 2.78                    | 0.32                            | 32.9                    |
| 4         | 1.53                        | 1.38                    | 0.11                            | 15.24                   | 2.60                        | 2.31                    | 0.21                            | 26.8                    | 3.36                        | 2.99                    | 0.34                            | 35.3                    |
| 5(control) | 1.14                        | 1.03                    | 0.09                            | 11.35                   | 1.30                        | 1.16                    | 0.12                            | 13.4                    | 1.54                        | 1.37                    | 0.16                            | 16.2                    |
| 6         | 1.51                        | 1.36                    | 0.11                            | 15.04                   | 2.55                        | 2.27                    | 0.23                            | 26.2                    | 3.70                        | 3.29                    | 0.38                            | 38.9                    |
| 7         | 1.42                        | 1.28                    | 0.11                            | 14.14                   | 2.63                        | 2.34                    | 0.24                            | 27.1                    | 3.80                        | 3.38                    | 0.39                            | 39.9                    |
Statistical processing of the data found that through the use of stone harvesting unit increased the area of development of grass, and the action of evenly distributed manure and moisture retention gave a significant (reliable) increase in yield compared to the control, which increased over the years from 0.33 to 1.28 - 1.93 t/ha.

It is established that the technological process of surface improvement, due to the uniform distribution of manure piles over the entire surface of the pasture area, contributed to the reduction of soil acidity from pH-4.8 to pH-5.1.

This affected the germination of fallow, native seeds of legumes, whose share in the herbage increased from 2.1-3.6% on the control to 12.2 - 16.7 % in experimental allotments, in the third year of observation. Legumes, together with cereals (whose share in the herbage also increased from 26.7 to 47.3 %) due to their biological characteristics allowed not only to increase the yield of dry mass, but also the collection of nutrients and the accumulation of feed energy. So the concentration of feed units pasture in the feed increased from an average from 1047 to 3430 from the 1 hectare; digestible protein from 0.09 to 0.40 t/ha, and the exchange energy from 11.58 to 40.5 GJ/ha.

Legumes, thanks to the symbiotic fixation of nitrogen from the air, hold a leading place in the biologization of mountain agriculture, replenishing the soil with organic substances and elements of mineral nutrition. At the same time, the change in species composition contributed to the formation of a two-tier vertical structure of natural plant communities, providing a more complete use of sunlight in the process of photosynthesis, increasing the effect of biological nitrogen accumulation from 12.8 to 21 g per 1 kg of dry weight of feed, in particular, the protein content in pasture feed.

The increase in pasture productivity due to the removal and utilization of stones allowed increasing the load on 1 ha of pastures, from 1.1 heads of feeding young cattle to 3.6 heads, and the high concentration of digestible protein and exchanged energy contributed to the accumulation of the average monthly weight of animals from 560 to 975 g. These changes allowed, for the pasture period (120 days), obtaining an additional 348 kg of live weight (421.9 - experimental, 73.9 -control), which at a purchase price of 265 rubles/kg amounted to 92.22 thousand rubles.

5. Conclusions
Application of stone harvesting unit developed by the staff of North-Caucasus Scientific Research Institute of Mountain and Foothill Agriculture of the Vladikavkaz Scientific Center of the Russian Academy of Sciences allows clearing the pastures from scattered small and medium-sized stones up to 91-93 %, evenly spreads the manure left by animals. The stones disposed in the channels, which are the filters for waste waters, providing the water saturation of underlying grassland.

Increase of useful area, improvement of water-air and nutrient regimes allowed increasing pasture productivity by more than 3 times, changing species composition (increasing bean component to 16.7 %, cereal component to 47.3 %), to improve product quality [12]. These factors contributed to the increase in the area of pastures, increase in the collection of environmentally friendly products by 5.7 times for a total of 92.22 thousand rubles/ha.

The method and small-sized multifunctional unit for removing stones from the slopes of meadows and pastures can improve the productivity of fields, reduce erosion and other degradation processes of soil cover, and create favorable conditions for the use of mechanization in meadows and pastures.

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