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THE BALANCE OF CALCIUM IN THE GRASS ECOSYSTEMS OF THE TEREK-KUMA LOWLAND

G.N. GASANOV[1, 2], T.A. ASVAROVA[1], K.M. HAJIYEV[1], R.R. BASHIROV[1], Z.N. AKHMEDOVA[1], A.S. ABDULAEVA[1], Sh.K. SALIKHOV[1], N.I. RAMAZANOVA[1], A.Sh. GIMBATOV[2], M.R. MUSAEV[2], N.R. MAGOMEDOV[2, 3], R.Z. USMANOV[1]

[1]*Precaspian Institute of Biological Resources, Dagestan Federal Research Center RAS,* 45, ul. M. Gadjieva, Makhachkala, Republic of Dagestan, Russia 367000, e-mail nikuevich@mail.ru (✉ corresponding author), tatacvar@mail.ru, kamil5555372@mail.ru, pakduik100@mail.ru, zaira-1945@mail.ru, aischat55@mail.ru, salichov72@mail.ru, nurjagan@yandex.ru, pibrdncran@mail.ru;
[2]*Dzhambulatov Dagestan State Agricultural University,* 180, ul. M. Gadzhieva, Makhachkala, Republic of Dagestan, Russia 367000, e-mail daggau@list.ru, zaremka_76@mail.ru, musiska2014@mail.ru;
[3]*Federal Agrarian Research Center of the Republic of Dagestan,* 30, ul. A. Shahbanova, Makhachkala, Republic of Dagestan, Russia 367014, e-mail musiska2014@mail.ru
ORCID:
Gasanov G.N. orcid.org/0000-0002-6181-5196
Asvarova T.A. orcid.org/0000-0002-5285-9250
Hajiyev K.M. orcid.org/0000-0003-1150-9593
Bashirov R.R. orcid.org/0000-0002-6331-2592
Akhmedova Z.N. orcid.org/0000-0002-7141-939X
Abdulaeva A.S. orcid.org/0000-0001-9056-1909
Salikhov Sh.K. orcid.org/0000-0001-5531-3045
Ramazanova N.I. orcid.org/0000-0001-9525-6292
Gimbatov A.Sh. orcid.org/0000-0003-2801-2276
Musaev M.R. orcid.org/0000-0002-3170-2086
Magomedov N.R. orcid.org/0000-0003-3871-0932
Usmanov R.Z. orcid.org/0000-0002-4046-5991
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Abstract

Terek-Kuma lowland occupies the North-Western part of the Precaspian lowland. The soil-plant cover of the territory is determined by the aridity of the climate with frequent winds, light granulometric and saline soils, high pasture load. In this study, for the first time in the Terek-Kuma semidesert conditions, the productivity of structural parts of grass ecosystems and calcium reserves during the most favorable (April) and arid (August) periods are determined for the main soil types. The work aimed to determine the accumulation, distribution and reserves of calcium in the structure of phytomass with regard to a soil type. The research was performed at the Kochubey Biosphere Station, Precaspian Institute of Biological Resources of the Dagestan Scientific Center RAS in 2011-2016 on grass phytocenoses of light chestnut and meadow-chestnut soils and saline typical automorphic soils. Assessment of plant matter and Ca accumulation in green mass, rags, steppe felt, and roots, and calculation of the Ca budget of the ecosystems were carried out according to A.A. Titlyanova et al. (1988). The content of Ca in plants was determined by capillary electrophoresis (a Drops-105M system, Lumex, Russia) with special software Elforan (Lumex, Russia). The greatest amount of phytomass accumulated on light-chestnut soil. On meadow-chestnut soil photosynthesizing parts, rags, steppe felt and roots accumulated 2.3, 1.5, 2.3 and 2.2 times less, respectively, and on typical saline soil 2.6, 1.7, 2.5 and 2.7 times less than on light-chestnut soil. This was likely caused by a decrease in projective coverage from 77.0 % on light chestnut soil to 48.5 % on meadow-chestnut soil and 43.5 % on typical saline soil. In the species patterns the dominants were *Poaceae* (51 % for light-chestnut soil) and *Asteraceae* (30 % and 17 % for meadow-chestnut soil and saline soil, respectively). The root weight for meadow-chestnut soil and typical saline soil was 2.2 and 2.9 times less than for light-chestnut soil. Their share in the total phytomass depending on soil types ranged from 85.0 to 87.2 %. In green parts, the concentration of Ca, depending on the season and the soil type, was in the range of 0.40-0.48 %, in rags it was 0.50-0.54 %, in felt 1.00-1.31 %, and in underground parts 1.14-1.38 %. By soil types, it decreased as light chestnut soil > meadow-chestnut soil > saline soil due to pH changes (8.6 > 8.2 > 8.0), an increase in the degree of salinity and the shift of salinity from the sulfate type to the sulfate-chloride type. Reserves of Ca in the above-ground parts during the growing season on light-chestnut soil amounted to 2.32 kg/ha per year and exceeded 2.7- and 3.1-fold, respectively, similar indicators for meadow-chestnut soil and typical saline soil. Ca reserves in the root mass for all types of soils were 12.6 times more than in the aboveground parts. After plant matter decomposition, steppe felt and underground organs contribute to light- chestnut soil 42.0 and 58.0 % of the calcium consumed from the soil, to meadow-chestnut soil 36.0 and 64.0 %, respectively; for the typical saline soil these amounts are 1.1- and 2.3-fold, respectively. It was revealed that the difference in the dynamics of Ca accumulation in components of a semi-desert plant community (green mass, rags, steppe felt, and roots) depends on the plant species composition, soil type and season.

Keywords: phytocoenosis, phytomass accumulation, plant matter translocation, Ca accumulation, Ca reserves, calcium budget

The Terek-Kuma lowland (the northwestern part of the Caspian lowland) is characterized by light grain size and saline soils, arid climate, high pasture load, and degraded soil and vegetation cover. Soils with a low content of humus and the main nutrients of plants in combination with an unfavorable water-salt regime have low productivity [1]. However, these estimates were obtained only for the photosynthesizing part of the phytomass, while the structure of the phytocenosis also contains other elements, the rags, steppe felt, and roots.

The elemental composition of phytocenoses in the Terek-Kuma lowland was studied by many rsearchers. In particular, there are data on the relative content of calcium in the vegetating air-dry mass (hay) [2, 3], but there is no similar information regarding the structure of the vegetation cover (green mass, rags, felt, and roots). The lack of these data hinders estimation of the reserves of biophilic elements, including Ca, and its balance in herbal ecosystems, including differentiated by the main types of soils.

On the territory of the Terek-Kuma lowland, the content of Ca in plants is higher than in the adjacent Prisulakskaya lowland, 2.014±0.02 vs. 1.623±0.25 g/kg [4]. A gradual decrease in its accumulation is regularly noted from November to April next year. Gireev et al. [4] explain this by the transformation of meadow-wormwood communities into ephemeral-wormwood and wormwood ones. It can be assumed that such a decrease in the amount of Ca in phytocenoses has another reason and is associated with the translocation of substances between the elements of the phytocenosis structure across the stages of plant development.

Moisture is noted to have a decisive effect on the accumulation of chemical elements in plants, in particular, the Ca content increases with increasing precipitation [5, 6]. It was also revealed that favorable hydrothermal conditions during the growing season contribute to an increase in Ca content in soil [7].

In this study, productivity of herbal ecosystems and Ca reserves in the Terek-Kuma semi-desert was differentiated with regard to components of phytomass structure for the main soil types during climatically most favorable (April) and dry (August) seasons, and the Ca balance in ecosystems was calculated

The work aimed to study calcium accumulation in plant matter, taking into account its structure, and the prevalence of this element in herbal ecosystems on the main types of soils of the Terek-Kuma lowland.

Materials and methods. The study was carried out at the Kochubey Biosphere Station (the Precaspian Institute of Biological Resources of the Dagestan Federal Research Center RAS, 44.40720 N, 46.24771 E) in 2011-2016. Seasonal accumulation, reserves and budget of calcium (April, August) were analyzed in detail in 2013-2015. Herbaceous phytocenoses on light-chestnut and meadow-chestnut soils and a typical automorphic solonchak of the Terek-Kuma lowland were surveyed. In the 0-30 cm layer of light-chestnut soil contained 1.12% humus, 1.11 mg/100 g P_2O_5, 20.12 mg/100 g K_2O, the density was 1.14 g/cm^3, the lowest moisture capacity was 20.6%; for meadow-chestnut, the parameters were 0.54%, 0.7 mg/100 g, 18.2 mg/100 g, 1.42 g/cm^3, and 26.7%, respectively; for a typical automorphic solonchak these were 0.48%, 0.66 mg/100 g, 16.8 mg/100 g, 1.45 g/cm^3, and 30.3%. The type of salinity varied from chloride-sulfate to chloride depending on the hydrothermal conditions of the seasons, the salinity varied from weak to very strong.

Plant matter accumulation per time unit per area unit, Ca content in green mass, rags, steppe felt and roots, and calculation of Ca balance in ecosystems were carried out according to Titlyanova [7]. The Ca content in plant matter was determined by capillary electrophoresis (Kapel-105M system equipped with Elforan software, Lumex, Russia) in the mode of determination of cations and anions [8]. A total of 150 samples were analyzed in 3 biological and analytical replicates.

The Latin names of the species are given according to Murtazaliev [9].

Statistical processing was carried out using Microsoft Excel 2010 software. The mean values (*M*) and errors of the mean (±SEM), linear regression equations, correlation coefficient (*r*), and determination coefficient (*R*) were calculated.

Results. In the conditions of the plain, phytocenoses are most productive on light chestnut soil. On average, for 2011-2016, the accumulation of air-dry phytomass here was 2.2 times higher than for meadow-chestnut soil. On typical automorphic solonchak, the productivity of the phytocenosis decreased 2.6 times as compared to that for light-chestnut soil (Table).

On meadow-chestnut soil and typical saline, the level of accumulated rags (102.8 and 100.5%, respectively) was the same as for green mass, and on light-chestnut soil it was 33.7% less, which was associated with the species composition of phytocenoses.

Air-dry weigh of above ground parts and roots accumulated structural components of vegetation cover for different soil types of the Terek-Kuma lowland (Kochubey Biosphere Station of the Precaspian Institute of Biological Resources, the Dagestan Federal Research Center RAS, 2011-2016)

Component	Soil	Phytomass, t/ha per year (*M*±SEM)	Ca	
			concentration, % (*M*±SEM)	reserves, kg/ha
Green mass	Light-chestnut	4.84±0.02	0.48±0.02	2.32
	Meadow-chestnut	2.11±0.01	0.41±0.01	0.86
	Typical saline	1.89±0.03	0.40±0.03	0.76
Rags	Light-chestnut	3.21±0.02	0.54±0.03	1.73
	Meadow-chestnut	2.17±0.01	0.50±0.01	1.08
	Typical saline	1.91±0.04	0.50±0.02	0.96
Steppe felt	Light-chestnut	4.32±0.03	1.31±0.01	5.66
	Meadow-chestnut	1.89±0.02	1.30±0.02	2.46
	Typical saline	1.71±0.02	1.00±0.01	1.71
Roots	Light-chestnut	83.71±0.03	1.38±0.02	115.52
	Meadow-chestnut	38.19±0.03	1.38±0.03	52.70
	Typical saline	31.19±0.02	1.14±0.03	35.56

On light chestnut soil, the proportion of ephemera from the bluegrass family, which were represented by *Eragrostic minor* Host., *Poa bulbosa* L., and *Eremopyrum orientale* L., was 51.4% by the number and 19.6% by weight. On the meadow-chestnut soil and saline soil, the phytomass of *Artemisia taurica* Willd and *A. lercheana* Web. ex Stechm remained rather high, 37.7% by number and 83.7% by weight), since their rags for April-August did not have time to completely turn into steppe felt.

According to some publications, the contribution of underground organs to the total mass of herbaceous phytocenoses is 50-90% [10, 11]. In our studies, the weight of roots for meadow-chestnut soil and typical saline soil turned out to be 2.2 and 2.9 times less than for light-chestnut soil. The root weight comprised 85.0-87.2% from the total phytomass yield depending on the soil type. Such a high ratio of aboveground and underground mass (1:6.8-1:5.7) is typical for all arid regions worldwide [12, 13].

Our data show that the following regression equations describe the relationship between the accumulation of aboveground (x) and underground (y) mass in ecosystems in semi-desert conditions, depending on the type of soil:

for light chestnut soil $y = 0.6935x + 73.7823$ ($r = 0.97$, R = 0.96);

for meadow chestnut soil $y = 1.1804x + 30.7254$ ($r = 0.96$, R = 0.95);

for typical saline soil $y = 1.7925x + 21.0415$ ($r = 0.97$, R = 0.95).

The main reason for the decrease in the phytomass on the meadow- chestnut soil and saline soil is typically an increase in soil salinity and a change in its character towards an increase in the ratio of Cl^{-}:SO_4^{2-} ions [11]. It should be noted that the productivity of the grass ecosystems of the Terek-Kuma lowland was significantly lower than in other regions of the country, where it is 15-20 t/ha [10, 11]. Only on light-chestnut soil this indicator approached the lower of the indicated limits, and on meadow-chestnut soil and typical saline soil it turned out to be 2.2-2.6 times lower. Similar results were obtained by other authors in the territory of our study [5], in the Astrakhan region [14], in the dry and desertified steppe of Tuva [12, 13], in the arid regions of Iran [15], Panama [5], China [16], and in regions with arid climates.

In plant life, Ca plays an important role in the formation of cell walls, takes part in maintaining the structure of chromosomes, mitochondria, and ribosomes [17, 18], increases salt tolerance [19-21], plant resistance to heat stress [22] and negative effects of heavy metals [23], optimizes the growth and development of roots [24].

For 2013-2015 (April, August), the average values of Ca content in the green mass and other elements of vegetation cover in general corresponded to the accumulated yield of phytomass and amounted to 0.48% for light-chestnut soil, 0.41% for meadow-chestnut soil, and 0.40% for typical saline soil. Significant differences were noted in the content of the element among plant species. For light-chestnut soil, 51% of the total projective cover (77%) fell on cereals — *Anisantha tectorum* (L.) Nevski, *Bromus squarrosus* L., *Poa bulbosa* L., *Eragrostis minor* Host and *Eremopyrum triticeum* (Gaertn.) Nevski, 15% — on *Artemisia taurica* Willd and *A. lercheana* Web. ex Stechm, 5% — on saltwort, including *Ceratocarpus arenarius* L., *Salsola iberica* Sennen & Pau, *Petrosimonia brachiata* (Pall.) Bunge, 3% — on *Silene conica* L. and *Herniaria incana* Lam., and 3% — on *Alussum desertorum* Stapf. The calcium content was 1.03% for wormwoods, 0.93% for *Chenopodioideae*, 0.38% for *Caryophyllaceae*, 0.22% for *Cruciferae* and 0.58% for cereals.

On the meadow-chestnut soil, the projective cover of *Poaceae* plants decreased 5.1 times, of *Caryophyllaceae* 2.0 times, and *Cruciferae* 1.5 times, while wormwoods from the *Asteraceae* family increased 2.0 times. Despite the fact that on this type of soils the proportion of *Asteraceae* and *Chenopodioideae* soils with a high Ca accumulation increased, the average content of the element decreased to 0.47% in the *Poaceae* group compared to that for light-chestnut soil, and up to 0.90% in the *Chenopodioideae* with insignificant deviations in other families. On a typical saline soil, the total projective cover by phytocenosis (43.5%) approached the value on meadow-chestnut soil (48.5%), but the content of the element decreased only in saltwort (by 0.24%) with relatively similar values in other groups of plants.

The decrease in Ca content in the phytomass as light-chestnut soils > meadow-chestnut soils > typical saline soil, we associate with a slight decrease in the pH of the soil solution in the same row (8.6 > 8.2 > 8.0), which becomes the reason for more easy availability of Ca from soils, the same is confirmed by other authors [25]. In addition, the increase in salinity and the transition from its sulfate type to the sulfate-chloride type affect [11]. These factors significantly reduce the availability of Ca for plants from meadow-chestnut soil and typical saline soil compared to the light-chestnut type.

It is known that the influx of ions of various metals from the soil into the root system and aboveground organs of plants is due to the dynamics of osmotic pressure with the participation of ion transporter encoded by different genes [26]. The following equation describes the role of soil type (x) and species composition of phytocenoses (y) in changes in Ca concentration (z):

$$z = 0,1057 - 0,4999x + 1,1898y.$$

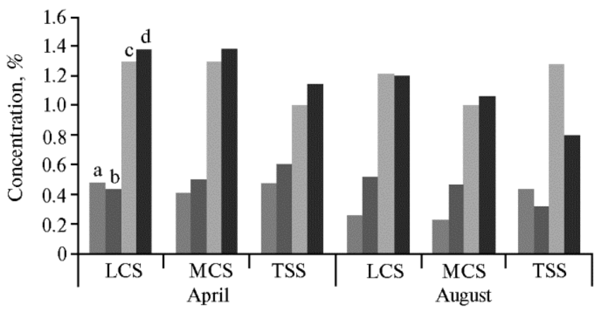

Fig. 1. Ca accumulation in phytocenoses of the Terek-Kuma Lowland depending on soil types and seasons: LCS — light-chestnut soil, MCS — meadow-chestnut soil, TSS — typical saline soil; a — green mass, b — rags, c — steppe felt, d — roots (Kochubey Biosphere Station of the Precaspian Institute of Biological Resources, the Dagestan Federal Research Center RAS, 2013-2015).

In the rags and felt, the Ca content leveled off, and in the underground organs it decreased from 1.38% for the first two types of soils to 1.14% for typical saline soil (Fig. 1). A sufficiently high amount of Ca in the phytomass under the conditions of a non-flush water regime promoted the maintenance of a neutral and slightly alkaline reaction in the soil solution [10].

The reserves of the element in the root mass for all soils were higher than in the aboveground one, by an average of 12.6 times (73.81 kg/ha vs. 5.85 kg ha). Given the above data, the Ca balance was compiled in biogeocenoses of the considered soil types (Fig. 2). In herbal ecosystems, calcium is consumed significantly more than in forest ones [16]. In our study, for light-chestnut soil, 42.0% of a total 125.23 kg/ha Ca, consumed by the phytocenosis per year, returned to the soil during the decomposition of steppe felt, the value for underground organs was 58.0%. For the meadow-chestnut soil, the share of Ca received during the felt decomposition decreased to 36.8%, while for a typical saline soil it increased to 48.4%.

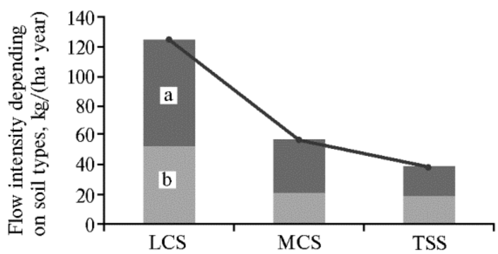

Fig. 2. Calcium budget in phytocenoses of the Terek-Kuma lowland depending on the soil type: LCS — light chestnut soil, MCS — meadow chestnut soil, TSS — typical saline soil; a — entered the soil during the decomposition of underground organs, b — entered the soil during the decomposition of felt; the graph shows amount of Ca taken up by growing plants (Kochubey Biosphere Station of the Caspian Institute of Biological Resources, the Dagestan Federal Research Center RAS, 2013-2015).

The relatively high productivity of phytocenoses on light-chestnut soil contributes to the enrichment of its upper horizons with Ca and other biophilic elements (Fe, Si, Al), which serve as the main factor in the biosynthesis of secondary clay minerals that form the absorbing soil complex. The high content of Ca in the phytomass of herbaceous plants (along with Mg and S) leads to the saturation of the absorbing complex of soils of the Terek-Kuma lowland with this strong coagulator, which ensures the formation of favorable agrophysical soil properties and an improvement in its structure [1].

For all types of soils, a higher Ca content was observed in spring compared to the summer period (1st decade of August), which is explained by the favorable water regime of the soil during this period, promoting the entry of chemical elements into plants. A decrease in the amount of Ca in August is associated with an increase in soil salinity, an increase in the osmotic pressure of the soil solution, and a slowdown in the supply of soil moisture and nutrients to plants. These data confirm the validity of the conclusion that the intensity of the influx of chemical elements, including Ca, into plants is associated with favorable hydrothermal conditions [10], and not with the transformation of meadow-wormwood communities into ephemero-wormwood and wormwood [3, 4].

Another reason for the decrease in the accumulation of Ca in pasture phytocenoses by the end of the growing season or by the next spring is the outflow of some elements from aging and dying plant tissues into young or newly formed ones. According to Titlyanova [10], the process of re-location of nutrients is universal and inherent in all ecosystems. Consequently, on the main types of the studied soils, a sufficient content of Ca in the phytomass and its subsequent supply to the upper part of the soil profile, becomes the basis for the biological cycles of Ca in herbal cenoses.

Thus, in the conditions of Terek-Kuma lowland, the light-chestnut soil provides the maximum reserves of photosynthesizing phytomass (4.84 t/ha per year), rags (3.21 t/ha per year), steppe felt (4.32 t/ha per year) and roots (83.71 t/ha per year). These values decreased 2.3, 1.5, 2.3 and 2.2 times, respectively, for meadow-chestnut soil, and 2.6. 1.7. 2.5 and 2.7 times for a typical saline soil. The accumulation of Ca in the aboveground and underground parts corresponded to the yield of phytocenoses. Its content averaged 0.48-0.40% in the green mass, 1.0-1.3% in felt, and 1.14-1.38% in underground organs. The maximum reserves of the element in the aboveground parts during the growing seasons accumulated the light-chestnut soil (9.71 t/ha per year), exceeding similar indicators for meadow-chestnut soil and typical saline soil 2.7-fold and 3.1-fold, respectively. During decomposition of steppe felt, 42.0% of Ca consumed by plants was returned to the light-chestnut soil, 36.0% to the meadow-chestnut soil, and 48.4% to the typical saline soil. The same amount of the element moved to the above-ground organs. During the decomposition of underground organs, plants received, according to soil types, 58.0, 64.0 and 51.6% of the released Ca, respectively. It was revealed that the difference in the dynamics of Ca accumulation in the phytomass structural components (photosynthesizing parts, rags, steppe felt, and roots) of semi-desert phytocenoses depends on the plant species composition, soil type, and season.

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