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The Potential Productivity of Light-Chestnut Soils of the North-Western Precaspian Region in Connection with the Dynamics of Environmental Factors

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Abstract

The data on receipt of photo synthetically active radiation (FAR) on the soil surface and the coefficient of its use over the years and periods of the year depending on the hydrothermal conditions and dynamics of harmful salts in the soil are given. The items of the changes in the species composition of phytocenoses depending on the environmental factors are considered.

Subject Areas

Ecology, Soil Science

Keywords

Light-Chestnut Soil, Hydrothermal Conditions, Salt-Forming Ions, Salinity, Species Composition Phytocenosis, Aboveground and Underground Phytomass, Coefficient the Use of the FAR, Aridity Integral, Integral Moisture

1. Introduction

The flow of FAR on the soil surface depends on the geographic latitude and hypsometric marks and varies in significant limits: from of 34.6 kcal/cm^2 in the Leningrad area to 44.4 within Moscow and 56.87 kcal/cm^2 in the area of Derbent

[1]. In the same area the submontane districts of Dagestan come 47.55 (Buinaksk)—by 43.91 (Sergokala) kcal, in the Terek-Sulak of lowlands—49.94 (Babayurt)—51.19 (Kizlyar), and in the Terek-Kuma lowlands (Kochubey)—50.87, in the Coastal lowlands (Derbent)—56.87 kcal/cm^2 [2]. These indicators are the basis for the calculations of the theoretically possible yield of phytocenoses in any region of the globe.

In fact, the achieved yield of phytomass in ecosystems is not always consistent with the given data and it depends on prevailing climatic conditions of the year or the season (number and intensity of the precipitation, temperature and relative humidity, etc.) and soil conditions (water-physical characteristics, availability of nutrients, the degree and type of salinity, etc.). So, for the formation yields of 3.0 - 4.0 tonnes (t) of grain from 1 hectare (ha) even in the agrocenosis, the conditions of functioning to a large degree, regulated by means of intensification of production (fertilizers, means of plant protection from pests, irrigation) use no more than 1.5% - 2% of FAR [2].

In the North-Western Precaspain region, where Kochubeya biosphere station of Precaspain Institute of Biological Resources of Dagestan Scientific Center of the Russian Academy of Sciences (KBS PIBR DSC RAS) is located and the yield of air-dry aboveground phytomass is very low, a small amount of it is used. It can vary, depending on the usage of the pastures, from 1.6 to 4.4 c/ha (centner/hectare) [3], from the stage of development of the desertification process – from 1 - 3 to 5 - 6 c/ha [4], saline or alkalinity, even of the same subtype from 5.2 to 5.4 c/ha (light-chestnut) soils [5]. On the territory of the Yergeni highlands and the Precaspain lowlands in the Republic of Kalmykia, the productivity of phytocenoses depending on the composition of plant associations deviates from 1.4 to 17.1 c/ha [6].

According to our calculations, with the yield of 5 c/ha air-dry phytomass of arriving at the soil surface of 50.0 kcal/cm^2, pasture phytocenosis uses a total of 0.04% of the FAR entering the surface of the soil. In this regard, there is an extraordinary interest in scientific and practical terms for the study of actually achieved yield phytocenoses under various conditions of moisture territory, not only in the annual average, and seasonal, as well as taking into account the dynamics of toxic salts and the chemistry on soil horizons in the KBS. Such studies in these conditions and the adjacent regions of the Precaspain have not been previously conducted.

2. Material and Methods

The object of research is light-chestnut carbonate alkaline soil KBS on the territory of the Terek-Kuma lowland of the Precaspain. (2011-2013 years). Geographic coordinates—44˚41'00.154''N of north latitude, 046˚24'.29.898''E of east longitude, the density of the soil layer of 0 - 30 cm of 1.14 g/cm^3, the field moisture capacity (FC)—27.8%, humus content—1.12%, P_2O_5—1.11 mg/100 g, K_2O—20.12 mg/100g of soil. Type of salinity in the soil horizons varies from sulfate-chloride, chloride-sulfate, salinity from weak in the upper layers to a strong downward.

Calculate the coefficient of use of the FAR was performed, using the formula A. Nichiporovich [7] to determine the theoretically possible yield of plants:

$$Y = R \times 10^8 \times K/10^2 \times 4 \times 10^3 \times 10^2 \quad (1)$$

where Y—biological yield of absolutely dry aboveground mass, kg/ha; R × 10^8—number of FAR coming on 1 ha over the growing period of plants, kcal; K—the planned coefficient of use of the FAR, %; 4 × 10^3—the amount of energy released by burning 1 kg of dry matter of biomass, kcal/kg; 10^2—translation kg per c (centner) of product.

To calculate the utilization of the FAR, the formula is:

$$K = У\times 10^2 \times 4 \times 10^3 \times 10^2/R \times 10^8 \quad (2)$$

In the calculations the duration of the vegetative period of plants was calculated based on the date of transition of daily average temperature of air through ±5˚C. The flow of FAR on the 1 cm^2 soil per year in the lowlands is 50.87 kcal (213.23 Kj), including by month (kcal): January—0.59, February—1.99, March—3.82, April—5.97, May—7.27, June—8.48, July—7.84, August—6.22, September—of 4.59, October—2.57, November—1.19, December—0.34 [8].

Climatograms over the years are compiled according to the method of Walter [9], in which, during dry periods the curve of air temperature is above the precipitation curve in the wet, on the contrary, the precipitation curve is above the curve of temperatures. To calculate the area of the plots between the lines of mean monthly air temperatures (˚C) and sum of monthly precipitation (mm) used integrals: $\int_a^b \max\left(T(t)-W(t),0\right)dt$ —to calculate the area of dry, $\int_a^b \max\left(W(t)-T(t),0\right)dt$ —to moist periods.

The stocks of aboveground and underground plant material were taken into account by the method of A.A. Titlyanova [10]. Aboveground mass was determined by the method of hay, with the release fractions of living phytomass (air-dry), rags (dead parts of plants, preserved communication with the plants, the steppe felt (dead plant remains on the soil surface, deprived of communication with plants). Underground mass was determined at the same time on the same experimental plots (after cutting above-ground mass) to a depth of 60 cm by the method of the monolith. The size of the monoliths 10 × 10 × 10 cm, repeated 4 times. The names of plants are given by S.K. Cherepanov [11]. The descriptive statistics derived from the use of statistic functions of MICROSOFT EXCEL 2010 and of STATISTICA.

3. Results and Discussion

Climatic conditions in the Terek-Kuma lowland over the years of our research have been developed more favorably, compared to multiyear data. The main indicator characterizing the presence of these conditions is the amount of precipitation during vegetation period of plant. In 2011-2013 years they fell to 15 - 31 mm more, but the air temperature over the same period was higher by 1.0 - 2.30 with in comparison with long-term data. Obviously, for this reason, the evaporation for the study years increased by 10.8% - 22.1%. If according to the index, coefficient of moisture in 2012, 2013 years it fits many years value—0.11 (deviation ± 0.01), and in 2011 year exceeded it by 0.03. Therefore, we can assume that the years of research, in general, were typical for the conditions of the Terek-Kuma lowland.

However, the amount of precipitation differed in the periods of vegetation in pasture phytocenoses. According to our observations, the most significant for achieving high productivity ephemeral synusia under these conditions, precipitation is in April and May. The temperature during these months also favors the formation of phytomass of plants. Respectively months it amounted to: 2011 year 9.2˚C and 18.4˚C, in 2012 year—15.1˚C and 20.9˚C in 2013 year—12.2˚C and 20.0˚C. For these months in 2011year 85 mm of precipitation fell in 2012—25.3 mm, in 2013—40.0 mm, that is, in the first year of studies, the amount of precipitation exceeded two years, 3.4 and 2.1 times. Between the amount of precipitation in April-May and productivity of aboveground phytomass of ephemers and ephemeroids there is a direct correlative relationship that in 2011 years had a strong ($r = 0.89$, $p \le 0.05$), and in two subsequent years - average ($r = 0.43$, $p \le 0.05$ and 0.35, $p \le 0.05$) severity.

Moisture integral for the same months in 2011 years was 29.8. In 2012 and 2013 years curve of moisture fell below the curve of mean daily air temperatures, therefore, aridity integral was formed, which was respectively by years, and 37.3 and 98.9. Difference in his performance between the first and the two subsequent years was 67.1 (2012 year) and 128.7 (2013 year) and impact significantly on the productivity of ephemeral synusia. Mainly for this reason, the yield of living above-ground phytomass latest for 2012-2013 years decreased compared to 2011 year respectively, 9.2 and 1.5 times.

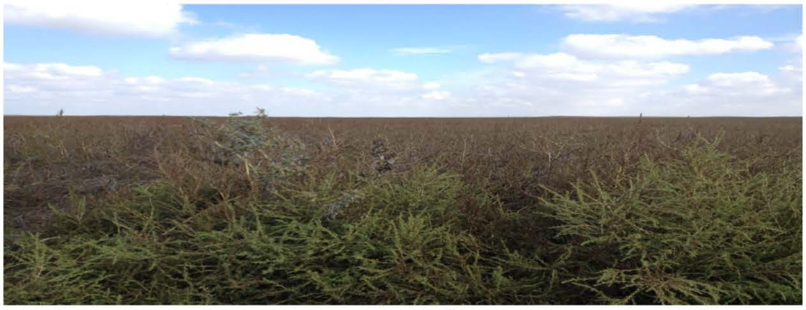
Dominants of the ephemeral in the experimental area are: from the family Poaceae species the *Poaannua* L., *Poabulbosa* L., *Eremopyrum orientale* (L.) Jaub.etSpach., *Bromus squarrosus* L., *Anisantha tectorum* L., *Eragrostic minor* Host., from the family Brassicaceae species the *Alussum desertorum* Stapf.

Precipitation in the first two decades of June in 2011 years did not provide significant improvement of phytomass. By this time the harvest ephemers has been formed and the rainfall of this period could not give a substantial addition. And high air temperatures during this and the next two months (respectively 24.3; 27.9˚C and 24.9˚C) contributing to the intense moisture of precipitation since the evaporation for the same months amounted to 291; 337 and 293 mm, the coefficient of moisture—respectively 0.08; 0.04 and 0.18. Therefore, the total yield of grass and saltworts in the months of the growing season amounted to only 8.9 c/ha and 67% yield of ephemers and ephemeroids shown in **Figure 1**.

May 2011. integral moisture 29.8

September 2011. the integral of aridity 63.4

May 2012. the integral of aridity 37.3



September, 2012. Integral moisture 203.8

Figure 1. Phytocenoses on light chestnut soil and integrals of moisture and aridity of climate over periods of year.

In 2012 years the integral of aridity in April-May amounted to 37.3, the evaporation increased by 67 mm, the coefficient of moisture, has decreased 5 times is given in **Table 1**.

These conditions contributed to the rise of the water-soluble salts to the upper soil horizon and a significant change in the species composition of phytocenoses.

Table 1. Dynamics of environmental factors and the content of harmful salts in horizon A (0 - 8 cm) and B_1 (9 - 20 cm) light-chestnut soil during the vegetation periods of 2011 to 2013 year.

Time year, layer of soil	2011			2012			2013		
Spring April-May	1—85 mm; 2˚C - 13.8˚C; 3% - 73%; 4—135 mm; 5—0.30; 6a—15.7 c/ha*			1—25 mm; 21˚C - 18.0˚C; 31% - 61%; 4—202 mm; 5—0.06; 6a—1.7 c/ha			1—40 mm; 2˚C - 16.4˚C; 3% - 64%; 4—178 mm; 5—0.10; 6a—10.7 c/ha		
	content ofions		ratio	content ofions		ratio	content ofions		ratio
	Cl^-	SO_4^-	$Cl^-: SO_4^-$	Cl^-	SO_4^-	$Cl^-: SO_4^-$	Cl^-	SO_4^-	$Cl^-: SO_4^-$
0 - 8 cm	0.21	1.50	0.14	0.82	1.62	0.51	0.39	1.38	0.28
9 - 20 cm	0.30	0.85	0.35	0.88	1.77	0.50	0.37	1.48	0.25
Summer July-August	1—64 mm; 2˚C - 27.4˚C; 3% - 58%; 4—315 mm; 5—0.11; 6b—8.9 c/ha			1—102 mm; 2˚C - 25.8˚C; 3% - 62%; 4—275 mm; 5—0.21; 6b—68.5 c/ha			1—83 mm; 2˚C - 25.0˚C; 3% - 59%; 4—355 mm; 5—0.11; 6b—36.3 c/ha		
	content of ions		ratio	content of ions		ratio	content of ions		ratio
	Cl^-	SO_4^-	$Cl^-: SO_4^-$	Cl^-	SO_4^-	$Cl^-: SO_4^-$	Cl^-	SO_4^-	$Cl^-: SO_4^-$
0 - 8 cm	0.96	1.82	0.50	0.28	0.82	0.34	0.41	0.89	0.46
9 - 20 cm	0.87	1.41	0.61	0.38	0.87	0.44	0.46	0.95	0.48

*1—Σprecipitation; average values: 2—air temperature; 3—relative humidity; 4—evaporation; 5—the coefficient of moisture; 6a—the yield of phytomassephemers and ephemeroids; 6b—the yield of phytomass of grasses and saltworts.

The content of Cl^- in the layer 0 - 20 cm compared to the same period in 2011 year increased 3.9 times, SO_4^- 1.7 times. In the m layer corresponds to the ion 2.2 times and 1.4 times. If in 2011 year the degree of salinity in the layer of 0 - 35 cm was characterized as weak (according to the classification Bazilevich N. and. and Pankova E.I., 1968) [12], in 2012 year medium with the same chloride-sulphate type of salinity.

The opposite pattern was observed for the same period in the summer. In the dry months of 2011 year (July-August) the Cl^- ion is in the layer 0 - 20 cm, where the bulk of the roots was kept to 2.30 mg-Equation/100 g, and in 2012 year 1.6 times smaller, the ratio of $Cl^-: SO_4^-$, respectively 1.24 and 0.59 type of salinization of the soil layer 0 - 8 cm in the first case was characterized as sulfate-chloride, the other is chloride-sulfate. Obviously, the decrease in the content of the ions Cl^- and its relationship to SO_4^- contributed to a sharp increase in the yield of grass and saltworts in 2012 year. Especially prominent was the explosive growth from the family Chenopodiaceae species the *Salsola iberica* Sennen et Раи. In the period from August to October in the phytomass of met and other members from the family Chenopodiaceae species the *Salsola australis* R.Br., *Petrosimonia oppositifolia* Pall. Litv, *Petrosimonia triandra* Pall., from the family of Asteraceae species the *Artemisia taurica* Willd and *Artemisia lercheana* Web.ex Stechm. But, the share species of Salsola iberica in total phytomass was the most prevalent, respectively 53.6 - 68.1 c/ha. Aboveground phytomass of saltworts in 2012 year exceeded the figure of the year of 2011 at 20.1 times. Such an abundance of plants (60 - 76 instances/m^2) Salsola iberica, such intensive growth (up to 1.0 - 1.2 m) and formation of phytomass as in 2012 year previously under these conditions was not observed, although pockets they met every year on large areas. Biological feature of this plant, obviously, is that the dry period in April-May (the integral of aridity 37.3) and the subsequent optimization of the conditions of hydration, contribute to the achievement of high productivity of plants.

The yeild of green biomass in late summer of 2012 year increased by herbs and in the first place, from the family of Asteraceae species the *Artemisia taurica*and *Artemisia lercheana*, from the family Chenopodiaceae species the *Petrosimonia oppositifolia*, *Petrosimonia triandra*, *Salsola australis*, *Atriplex tatarica*, from the family of Zygophyllaceae species the *Zygophyllum vulgaris* L, from the family of Poaceae species the *Agropyron desertorum* (Fisch. Ex Link) Schult.

The environmental conditions of the functioning of ecosystems in 2013 year occupy an intermediate position between the two previous years of research. This also applies to climatic conditions, and the concentration of salt ions in the soil, and yields of phytomass.

The increase or decrease in the yield of the aboveground phytomass (x) is accompanied by a corresponding dynamics of plant root mass (y). Correlative dependence between these two indicators is different in years with different moisture availability. So, according to our calculations, in the most humid 2011 year (301 mm precipitation during the growing season) it is expressed by the regression equation: $Y = 3.37x - 25.54$ when r = 0.84; in the less moisturized 2012 year (298 mm): $Y = 0.238x + 46.45$; r = 0.51; a dry 2013 year (185 mm): $Y = 10.16 + 37.35$; r = 0.17. Thus, the formation of phytomass and species composition in the KBS, respectively, and in the territory of the Terek-Kuma lowland of the Precaspain, is the result of combined action of different environmental factors, the main ones are: rainfall, air temperature, relative humidity, evaporation, moisture ratio, as well as the extent and chemistry of the soil salinity.

Dependencies between these factors are expressed by the following multiple regression equations:

for ephemeral synusia:

$$Y = 17.13 + 0.0425X_1 + 0.0087X_2 - 4.66X_3 - 20.65X_4 + 0.6X_5,$$

for grasses and saltworts:

$$Y = 9.65 + 0.18X_1 - 0.0147X_2 - 15.54X_3 + 45.78X_4 - 21.44X_5;$$

where Y—the yield of air-dry phytomass, c/ha; X_1—precipitation during the vegetation period, mm; X_2—the rate of evaporation, mm; X_3—the coefficient of moisture; X_4—contents of Cl^- in the layer 0 - 20 cm, mg-Eq/100g почвы; X_5—the ratio of $Cl^-: SO_4^-$ in the layer of 0 - 20 cm.

The effectiveness of the use of pasture phytocenosis of FAR, it is necessary to know the duration of the vegetation period and the number of calories on the soil surface during this period. Long-term data on the average duration of the vegetation period of grassland phytocenoses in the area of Kochubey is 260 days (from 27 March to 15 November). Over the years of conducting our research, the transition to the specified temperature through ±5˚C in 2011 year noted on 15 March and 2 November, 2012 year—March 24 and November 30, 2013 year—1 March and 27 November. The duration of the vegetation period of grassland ecosystems was respectively by years 232-274 of day, number of FAR submitted for 1 cm^2 soil over the years—50.00; 50.00 and 52.96 kcal are given in Table 2.

The coefficients of use of the FAR grazing plant communities on light chestnut soil that are calculated using these data and Equation (2), for Kochubeevskoe biosphere station in the period of 2011-2013 years show that solar energy resources in the considered conditions are used inefficiently because of insufficient rainfall and soil salinity are given in Table 3.

Depending on the climatic conditions of the year pasture phytocenoses use 0.20% - 0.57% of the FAR. The share of ephemers and ephemeroids of this amount on average over the years of research about 20%, the remaining 80% wild grasses and thistles, most of which occur in *Salsola iberica* is bad we eat the animals and less valuable in relation to fodder plant. However, given the tolerance of plants and greater vegetative mass, created on saline soils, in our opinion, the perspective is to continue further studies with *Salsola iberica* for towards phytomelioration role under these conditions.

4. Conclusions

1) In KBS PIBR DSC RAS in the whole of the Terek-Kuma lowland of the North-Western Precaspain two peaks of productivity of phytocoenosis have

Table 2. The duration of the period with air temperatures above 5˚C and the amount of the FAR is coming on 1 cm^2 at the weather station Kochubey for 2011-2013 years.

Month	duration of the period with temperatures above 5˚C (day)			amount of FAR coming on 1 cm^2 during this period, kcal		
	2011	2012	2013	2011	2012	2013
March	16	7	30	1.97	0.86	3.82
April-October	214	214	214	47.95	47.95	47.95
November	2	30	30	0.08	1.19	1.19
During the growing season	232	251	274	50.00	50.00	52.96

Table 3. The use of the FAR grazing plant communities on light chestnut soil Kochubeevskoe biosphere station, 2011-2013 year.

Year	Total	Accounted for, %	
		ephemers and ephemeroids	grasses and saltworts
2011	0.20	63.8	36.2
2012	0.57	2.4	97.6
2013	0.36	22.8	77.2
Average	0.38	19.7	80.3

been observed: the first is ephemeral synusia in the middle of May-early June; second—motley grass and saltworts in the second half of September.

2) The high productivity of ephemeris and ephemeroids (2011 year—13 - 15 c/ha of air-dry weight) on light chestnut soil is achieved at the confluence of the following environmental factors during April-May precipitation 80 - 85 mm; the average temperature is 15˚C - 16˚C, relative humidity of 70% - 73%, volatility of 130 - 140 mm, the coefficient of moisture – 0.30, and integral hydration period 29.8 reaches. Thanks to these climatic conditions, the salinity of the soil layer of 0-35 cm was classified as weak; salinity type is chloride-sulfate. The coefficient of use of the FAR only for ephemeral synusia was 0.13% and the whole phytomass during the vegetation period is 0.20%.

The deterioration of hydrothermal indicators in the same period of 2012 year expressed in the decrease in precipitation up to 25 - 26 mm, relative humidity up to 61%, and the coefficient of moisture—0.06, while increasing the average daily air temperature to 18.0˚C, evaporation to 200 - 202 mm, and also the formation of the integral of aridity (−37.3) lead to the increase in the content of ions Cl^- in the same layer of soil to 0.82 - 0.85 mg-Eq, lower yields of biomass up to 1.7 c/ha (in the year of 2012) and the coefficients of use of the FAR to 0.01%.

3) In years with abundant rainfall in July-August (102 mm), despite the increase in average daily air temperature to 25˚C - 26˚C and evaporation to 275 mm, remains relatively high in the coefficient of moisture (−0.21); the content of CL^- in the layer of 0 - 20 cm decreases up to 1, 40 mg-Eq./100g, the ratio of $Cl^-:SO_4^-$ up to 0.59 at 0.84 in the second half of the summer, and the yield of grass and saltworts (mostly *Salsola iberica*) is increased to 69.5 c/ha. The coefficients of use of the FAR reache to 0.57, of which the share of phytomass of grass and *Salsola iberica* accounts of 87.6% (2012 year). The challenge for further research is to assess the phitomeliorative role of this plant in the determination of the removal of salt ions from the soil and their further redistribution in the ecosystem.

4) In normal climatic conditions (2013 year), when precipitation during the vegetation period is distributed relatively evenly, the productivity of ephemers and ephemeroids is 10.7 c/ha, grasses and saltwort's—36.3 c/ha; the coefficients of use of the FAR during the growing season reaches to 0.36; the proportion of ephemeral synusia is just 22.6%.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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