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ABOUT THE CONCEPT OF ECOLOGICAL NICHE AND ITS ROLE IN DESIGN OF ADAPTIVE ARID PASTURE AGROECOSYSTEMS

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Abstract

The concept of ecological niche occupies the central position in modern ecology (Eu. Odum, 1975). The concept of ecological niche may to a certain extent explain how different species can normally function and produce, growing side by side with each other, and absorbing water and mineral resources within a certain ecotope. In the context of the traditional concept of ecological niche, the community can be imagined as extensive n -dimensional hyper space within which each specific population evolves in such direction to correspond to own part of this space (G. Huthinson, 1957). The niche is characterized by its position and the response to the factors within the hyperspace of this community. In recent years, along with the traditional concept of niche, there was a concept of neutralism which is actively developed by Stephen Hubbel and his supporters (G. Bell, 2001; J. Whitfield, 2002). According to this concept, species coexist thanks to similarity, but not distinctions, as a result of similarity on demographic characteristics, i.e. the similar specific speed of population growth and speed of settling of the released site. A number of authors have tried to unite within one model the neutralistic and niche mechanisms of functioning of species in community (D. Gravel et al., 2006). Now even more often ecologists speak about two types of communities (A.M. Gilyarov, 2010). Communities of the first type are organized according to the principle of a discrepancy of types on different ecological niches. Their existence is possible only because their niches are differing. Communities of the second type are organized and capable to coexist very long if are ecologically identical due to the same probability of an individual of different species to reproduce, die out, and occupy free spaces. It is supposed that if species long live in the same place, then they already are definitely rather close ecologically. We created multispecific, multi-tiered agroecosystems consisting of shrubs, semishrubs and grasses for arid conditions of Central Asia based on the traditional concept of a divergence of species in different ecological niches. For formation floristic and cenotic full-member multispecific pasture agroecosystems, we used fodder shrubs, typical for the southern deserts (*Haloxylon aphyllum*, *Aellenia subaphylla*), semi-shrubs (*Eurotia ceratoides*), draft semishrubs (*Kochia prostrata*, *Salsola orientalis*, *Camphorosma lessingii*, *Artemisia diffusa*), xerofitic perennial grasses (*Poa bulbosa*, *Carex pachystylis*) as the members of typical zonal flora. Multispecific shrubs-semishrubs-grassy pasture agrophytocenosis which were formed using zonal dominant species of fodder plants provided for a rapid restoration of biodiversity and the fodder efficiency lost under land degradation. The spring-summer and autumn-winter pasture agroecosystems created from mix of fodder shrubs, semishrubs, draft semishrubs and perennial grasses with different rhythmic of development, different type of root system, different drought resistance and heat resistance are more durable and productive than natural pasture ecosystems of the Central Asian deserts. Along with ecological advantages, multispecific pasture agroecosystems are much more various on structures of forages, they are better eaten and more stoutly satisfy physiological needs of animals for nutrients.

Keywords: natural pastures, constructed pastures, pasture agrophytocenosis, ecological niche

The ecological niche concept as a focus of modern ecology [1] was first suggested upon the attempt to formulate the role of a species in the community [2]. An ecological niche puts together plants, animals, and microorganisms to a sustainable unit which fits species living under specific environmental conditions. The concept of ecological niche may to a certain extent explain how different species can normally function, growing “side by side” and using water and nutrients within a certain ecotope. The interest of researchers to the concept of ecological niche has grown enormously over the last 60 years.

Purpose of present article is to justify construction perspectives of high productive everlasting multispecies pasture agricultural ecosystems in arid regions of the Central Asia.

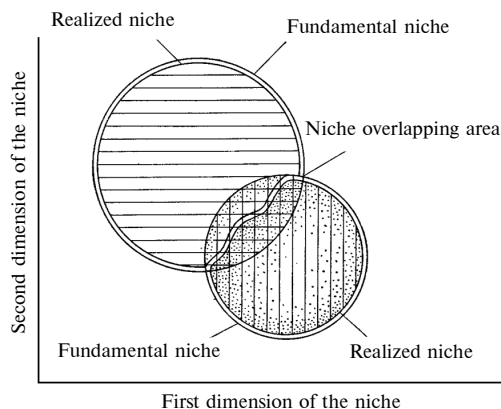


Fig. 1. The balance between the realized and fundamental niches for two species. Outer periphery limits (in two dimensions) the areas of the niche space where both species may potentially exist. At that, they push out each other from the part of overlapping area of fundamental niches. The realized niche is a real area occupied by any specie in a relevant space [7].

part of a multidimensional space, separate axis of which correspond to factors required for normal existence. The niche with n significant dimensions is described as n -dimension space or hyperspace by stepwise addition of one dimension. G.E. Hutchinson had introduced the term of fundamental niche (covers all multitude of optimal conditions in which any specie kind may exist in the absence of competition) and realized niche (actual set of conditions in which any specie usually exists) (Fig. 1). The realized niche is less than or equal to the fundamental one [3]. The ecological niches are discrete (fundamental niches are not overlapped), and species wealth of any community depends on the total occupied space and average size of each niche. The ecological niche of a species can be established through the distribution function of the activity of using a resource along its gradient [7]. Hyperspace of niches of any single specie involves parts of hyperspaces of other species. If overlapping is insignificant or if resources are overabundant, then species with overlapping niches may co-exist in practically separated niches. If niches are overlapped to a greater extent and if resources in the overlapping area are not enough to meet the demands of a species, then the more adapted species will limit the abundance of the less adapted species. As a result, a competitive exclusion may occur in the overlapping points. In extensive n -dimension hyperspace occupied by a community, each species population evolves to correspond to its part of the space. The niche of the species is due to its position and the response to the factors within the hyperspace occupied by the community [3].

The term “niche” was introduced by J. Grinnell [cit. ex 3] for denotation of the smallest unit of specie outspread; Ch. Elton [4] had defined it as a place of an organism in biotic environment. It was assumed that ecological niches in rare species are not overlapped. E. Pianka [2] and Yu. Odum [1] have developed a concept of competitive exclusion. According to G.F. Gause [5], an ecological niche is a space which could not be occupied by any two species for the unlimited long time. As per G.E. Hutchinson [6], a definition of ecological niche should account for all physical, chemical, and biological variables of the environment. Ecological niche of any specie can be represented as a

In 2000s, new approaches to study structure of communities appeared [8, 9]. The neutralism concept actively developed by S.P. Hubbell [10-12] and other researchers [13, 14] was an impulse. S.P. Hubbell had proposed neutral hypothesis subject to which various tree species coexist due to their similarity, rather than due to differences. To achieve stable coexistence, plants shall be similar, to a maximum extent, by its demographic characteristics, shall have similar specific population growth speed and occupation speed of a vacated area. The neutral theory was exemplified in tropic rain forests (Barro Colorado Island, Panama Canal area), where no notable separation of the ecologic niches between tree species exists [15]. It allows for coexistence of the species and does not require their compulsory deviation by different ecologic niches. Species of a single community may coexist due to similarity of their ecologic properties [16]. Herewith, neutrality is expressed at the level of individuals rather than species [13, 14]. According to S.P. Hubbell [11], the principal mechanism of high wealth of species in tropic forests is plant seedling elimination depending on the stand density. Such mechanism is considered as applicable to temperate forests [17, 18]. I. Volkov et al. [19] have mathematically substantiated the Hubbell's model. However, it was assumed [20, 21] that neutrality concept could be applied in particular cases and had no status of a universal theory. There were attempts [23, 24] to integrate neutral and niche mechanisms of species functioning. For instance, P.B. Adler et al. [24] had proposed a model linking the neutrality concept with traditional opinions on the niche structure of the community. The model is based on idea of P. Chesson [25] considering the neutrality as an extreme case of more general theory accounting primarily for the species deviations to different niches.

The past two decades had demonstrated the role of ecological niches in maintenance and preservation of plant biodiversity [26], optimization of the population and cenotic diversity [27] in forest successions [28, 29]. The concept of ecological niches is applicable in phytosociology [30], at differentiation of the ecological niches of grasses in the area of desert wooden plant [31], for maintenance of the species and intra-species population diversity of *Artemisia* genus [32], for stable development of feed production in arid regions [33], in studying invasive plant ecology [34, 35], at estimation of allelopathy of invasive plants [36] and competitiveness of invasive species [34], at assessment of cenotic stress on agrophytocenosis [37], as also at studying population diversity of pine marten [38] and morphological diversity of mammals [39].

Ecologists mostly discuss two types of communities [40], the niche assembled communities, and dispersal assembled communities, at probable appearance of a species at a particular location with further survival, regardless of similarity with neighbors. It is assumed that if species coexist in the same place, they are ecologically close.

An example of the approach corresponding to the traditional concept of ecological niches is the studied herein formation of pasture agricultural ecosystems based on dispersal of phytocenotically balanced mixtures of feeding plants different in ecologic and biological sense in the context of Karnabchul desert. It ensures successive recovery of biodiversity and feeding productivity of the pasture agricultural ecosystems in area of degraded lands. Earlier [33, 41], we have empirically demonstrated that in such conditions the fullest mastering of the fundamental ecological niche and its resources could be reached at modeling by type of the natural zonal biogeocenotic structures. They represent a mixture of ecologically and biologically diversified feeding shrubs, sub-shrubs, suffrutices, and grasses. Usually, integrity of species, ecotypes, and cultivars of fodder crops, which suite to the zonal biogeocenose types [2] and are ecobiologically and phy-

toecologically compatible, gives synergic effect [41].

Upon use of the external niche resources, L.G. Ramensky [42] had distinguished interoperation of species by type of additions. K.A. Kurkin [43] had developed a principle of ecological niche differentiation by type of complementarities in species during formation of narrow pasture ecosystems. At construction of pasture agricultural ecosystems in the arid regions of the Central Asia and Russia, fluctuation type is important. Optimal productivity of such pastures requires use of fodder plants growing in different conditions but having in the ecosystems the same function, with mutual replacement upon environment changes.

N.T. Nechaeva [44] indicates that in different *Carex* species (*Carex physodes*, *C. subphysoides*, *C. pachystylis*), co-growing in foothill semi-desert Turkmenistan the yields in different years are similar in quality and quantity. Such communities are created by type of ecologically functional aggregations of close species, when two and more species are involved in cenose as an ecologic sum of types, in which such representative of community (specie) is distinguished and which is more adapted to certain environment [45]. Variability of environment factors causes response at biocenotic level. Arid territories require multi-component mixtures of replaceable fodder plants to stabilize productivity of the ecosystems. Thus, mixtures of *Bassia prostrata*, *Salsola* sp., and *Artemisia* sp. with bulbous bluegrass and ephemeral plants are good on piedmont and foothills in the Central Asia [46].

Seasonal complementary type is based on combination in the pasture agricultural ecosystems of the species, ecotypes, and genus of feeding plants with different growth and development rhythms (long-sustained vegetating, short-term vegetating, and ephemeral phenorhythmotypes). Species vegetating all year around or during its most part may involve feeding shrubs such as *Haloxylon aphyllum*, *Salsola paletziana*, *Haloxylon persicum*, *Aellenia subaphylla*, *Ephedra strobilacea*; semi-shrubs — *Kochia prostrata*, *Salsola orientalis*, *Camphorosma lessingii*, *Salsola gemmascens*, and battle sansola as annual species. Short-term vegetating types of feeding plants growing in spring and at beginning of summer involve *Astragalus*, *Calligonum*, dry sansolas, several longstanding grains, ephemerooids (*Poa bulbosa*) and ephemeral plants (*Bromus tectorum*, *Malcolmia grandiflora*, *Eremopyrum orientalis*, *Leptaleum filifolium*, etc.).

Phenological diversity of species promotes longstanding increase in the pasture feed. Combination of ephemerooids of *Poa bulbosa* and *Carex pachystylis* vegetating from February until May, and annual sansola genus (*Climacoptera lanata*, *Gamanthus gamacarpus*, *Halimocnemis villosa*) vegetating from May to the end of November is an example of high seasonal productivity of pastures in piedmont of the Central Asia [47].

Successive complementary type presupposes replacement of less sustainable species by more sustainable that ensures rapid achievement of the maximum productivity by less sustainable species. It is reasonable to select high productive species that are relatively resistant to a set of abiotic stresses. Species forming from the second year of life sufficiently high feeding mass crops in the complex of pasture agricultural ecosystems involve *Kochia prostrata*, *Camphorosma lessingii*, *Aellenia subaphylla*, and *Sansola orientalis*. During 3-6 years biomass yield increases, and then during 6-12 years their productivity becomes flat with further stepwise decreasing thereof. In this, *Camphorosma lessingii*, followed by *Kochia prostrata*, *Aellenia subaphylla* and *Sansola orientalis* give place to *Haloxylon* sp., *Salsola paletziana*, *Salsola Richteri*, and *Ephedra strobilacea* without any changes in the upper productivity threshold of the agrophytocenose (at least 6-8 c/ha in dry mass). Ephemeral plants and annual *Sansola* sp. may successively replace species of longstanding pasture agricultural ecosystems.

Tier-based plant stand complementarity ensures mastering of various ecological niches and intensified use of eco-resources in arid areas of the Central Asia and Russia [47]. This principle applies at ecologic recovery of degraded landscapes by use of the mixture of various forms and species of fodder plants. Ecologically and biologically diversified species get different ecologic niches during formation of the pasture ecosystems and further can interact temporally and spatially.

Functional differentiation of ecological niches is essential in productivity and sustainability of agro-ecosystems and may become a sufficient reserve for recovery of degraded lands and increase in pasture productivity. Feeding shrubs and semi-shrubs which are unable to produce grassy turf sustainable for pasture are usually used upon creation of the pasture agricultural ecosystems on degraded lands. *Poa bulbosa* and *Carex pachystylis* (or each of these species) may form grassy sod preventing pasture digression. One more example of functional complementation is the use of condensed moisture by xerohalophilous shrubs (*Haloxylon* sp.) at sesquialteral or double maximum hygroscopticity of soil.

Until the middle of XX century, restoration of biodiversity and productivity of desert pastures was deemed impossible. However, such technology was proposed later [41, 46]. There is an opinion that all зкyyтe arid ecosystems are secondary antropogenous [48]. Because of overpasture, burning out, and plowing, they lost certain species, become simplified and cenotically incomplete. The floristic composition of grass stand and horizons of arid plant communities became poorer. In such communities ecological niches remain free, and resources of heat, moisture, and mineral nutrition are not fully used. Thus, the fodder productivity of such communities is always lower compared to floristically full phytocenoses [49].

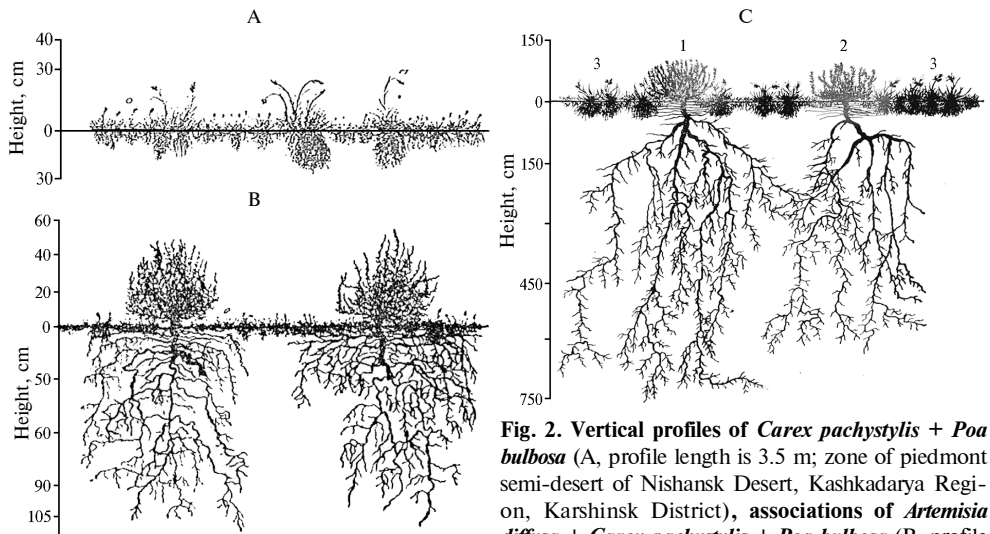


Fig. 2. Vertical profiles of *Carex pachystylis* + *Poa bulbosa* (A, profile length is 3.5 m; zone of piedmont semi-desert of Nishansk Desert, Kashkadarya Region, Karshinsk District), associations of *Artemisia diffusa* + *Carex pachystylis* + *Poa bulbosa* (B, profile length is 3 m; zone of absinthic-ephemeral Karna-

bchul desert, Samarkand Region, Sovetobadsky District) and spring-summer suffrutex-grassy ecosystem aged 8 years (C, profile length 3.5 m; Samarkand Region, Sovetobadsky District): 1 — *Kochia prostrata*, 2 — *Camphorosma lessingii*, 3 — *Poa bulbosa*.

Floristic and cenotic deficiency and availability of unused ecologic niches in the existing ephemeroïd and ephemeroïd-absinthic pasture ecosystems we showed in our past studies [33, 41]. Ecological niches of ephemeroïd sedge-poeceae communities are small (Fig. 2, A), those of ephemeroïd-absinthic communities are somewhat larger (see Fig. 2, B). These natural phytocenoses use resources available in small amount in air and soil. Constructed multispecies

and multitier pasture ecosystems with zonal typical fodder shrubs, semi-shrubs and suffrutices which roots deeply penetrate into the soil ensure new ecological niches and consumption of moisture and nutritional reserves from significantly more soil layers (see Fig. 2, C).

In spring-summer suffrutex-grassy ecosystems for southern deserts we used semi-shrub *Eurotia ceratoides*, 25 % + suffrutices *Kochia prostrata*, 30 % + *Camphorosma lessingii*, 25 % + *Poa bulbosa*, 20 %. The pasture ecosystem created on disturbed natural forage lands in Karnabchul Desert consisted of two synusia. The first one was *Eurotia ceratoides*, *Kochia prostrate*, and *Camphorosma lessingii*. The above-ground heights of the plants were 75-78 cm, 70-75 cm, and 57-60 cm, respectively. The number of generative and vegetative shoots per shrub was up to 27 and 38 for *Eurotia ceratoides*, and up to 24 to 41 for *Kochia prostrate*, with of generative and vegetative shoot length of 50-75 cm and 10-24 cm, respectively. In *Camphorosma lessingii*, shoot number was much lower — 38-42, of which 9-11 shoots were generative (32-48 cm), and the remaining ones were vegetative (5-12 cm). Suffrutices aged 6 years had formed powerful, deeply penetrating root system. Roots of *Kochia prostrata* reached a depth of 750 cm and were spread horizontally to 355 cm. The depth and width of roots of *Camphorosma lessingii* were 700 cm and 250 cm, respectively (see Fig. 2, C).

Ephemeroids *Poa bulbosa*, *Carex pachystylis*, together with ephemeral plants *Bromus tectorum*, *Boissiera purnilio* and *Trigonella grandiflora* were the grassy synusia of the suffrutex-grassy pasture ecosystem. The height of plants averaged 18-20 cm. The depth of *Poa bulbosa*, *Bromus tectorum*, and *Boissiera purnilio* roots reached up to 30 cm, with some root depth of 45 cm. *Poa bulbosa* and *Carex pachystylis* plants formed a dense grassy sod. The roots of the synusia main occupied the 0-20 cm soil layer.

In the *Kochia*—*Camphorosma* pasture ecosystem aged 3 years ephemeral plants became numerous. They appeared in the spring and summer due to germination of the seeds from the soil and those brought from outside. After seeding *Kochia prostrata* and *Camphorosma lessingii*, single *Bromus tectorum* and *Boissiera purnilio* plants were found in the first and second years, and they grew in number starting from the third year of life. A total of 17 ephemeral species of 7 families were in the ecosystem. They were mainly represented by grasses (7-10 species), crucifers (2-4 species), and leguminous (2-4 species) plants. Nutritionally valuable ephemeroids, ephemeral plants, etc. (12-17 species), including *Bromus tectorum*, *Boissiera purnilio*, *Poa bulbosa*, *Malcolmia turkestanica* and *Trigonella grandiflora* which can form the base of the pasture grassy layer were insignificant in number.

Starting from the 2-3 year of life and in the next 6 years, fodder productivity of the ecosystem increased (Fig. 3), with the maximum at years 5-6. Sharp increase of the feeding mass happened from year 2 when pasture agro-ecosystem is recommended for use.

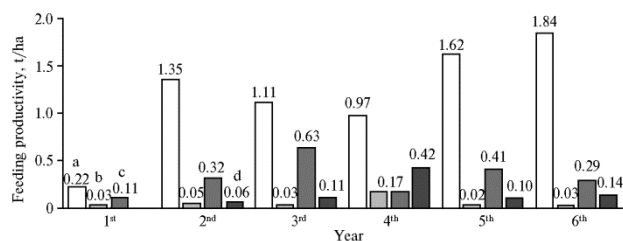


Fig. 3. Feeding productivity of spring-summertime suffrutex-grassy pasture ecosystem: a — *Kochia prostrata*, b — *Eurotia ceratoides*, c — *Camphorosma lessingii*, d — *Poa bulbosa* (Karnabchul Desert, Samarkand Region, Sovetobadsky District, 2002-2007).

Characteristic feature of the created spring-summer pasture ecosystems is rapid growing during spring. By the mid-April, from 0.50 to 0.65 t/ha of dry

feeding mass were accumulated depending on the meteorological conditions. Productivity of the natural pastures by this period did not exceed 0.01 t/ha for dry matter in dry years, and 0.3 t/ha in favorable wet periods. By the mid-May ecosystem accumulated from 50 to 80 % of the yield at the end of summer. Intensive growth of *Kochia prostrata* feeding mass was mainly by the end of June (60-80 %) followed by slowing down. Until the mid-summer (end of June) green biomass of *Camphorosma lessingii* was slowly growing with further notable growth. Such complementation ensures a uniform distribution of herbaceous plants in spring-summer pasture ecosystems, which allows animals to eat well

Shrub *Haloxylon aphyllum*, 15 % + semi-shrub *Aellenia subaphylla*, 20 % + suffrutices *Artemisia diffusa*, 35 % + *Salsola orientalis*, 30 % were used in fall-winter shrub-grassy pasture ecosystems. This agricultural ecosystem consisted of five synusiae different in aboveground and underground spheres (Fig. 4).

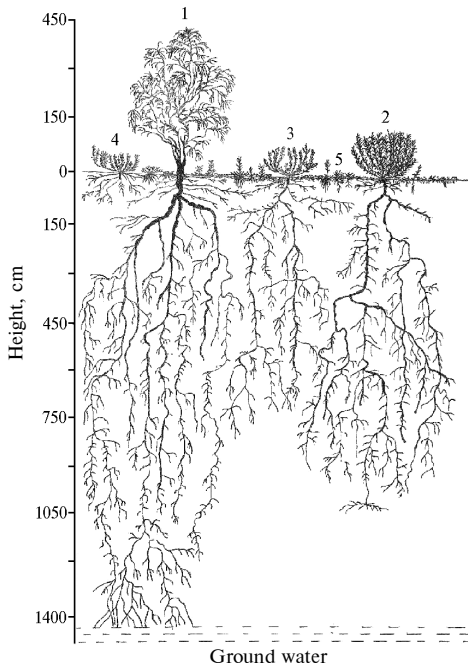


Fig. 4. Vertical profile of fall-winter pasture shrub-suffrutex-grassy ecosystem aged 7 years: 1 — *Haloxylon aphyllum*, 2 — *Halothamnus subaphylla*, 3 — *Salsola orientalis*, 4 — *Artemisia diffusa*, 5 — *Ephemeretum* (profile length 4.5 m; Karnabchul Desert, Samarkand Region, Sovetobadsky District).

Ephemeroid *Poa bulbosa* and ephemeral plants *Bromus tectorum*, *Malcolmia turkestanica* prevailed in the fifth synusia. Their height was 20-25 cm. Roots of *Poa bulbosa* and *Bromus tectorum* are filiceous and form dense grassy sod at soil surface (0-5 cm). Main part of roots (up to 85 %) was at the 0-15 cm soil layer.

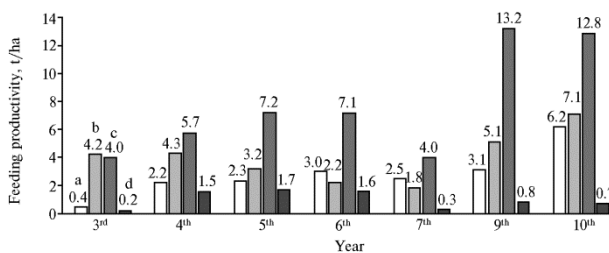


Fig. 5. Pasture productivity of fall-winter shrub-suffrutex-grassy ecosystem: a — *Haloxylon aphyllum*, b — *Aellenia subaphylla*, c — *Salsola orientalis*, d — *Artemisia diffusa* (Karnabchul Desert, Samarkand Region, Sovetobadsky District, 2004-2011).

At age of 7 years, *Haloxylon aphyllum* of the first synusia, had reached 400-450 cm in height with head diameter of 320-350 cm. Powerful root system penetrated into the soil up to 14 m and spread horizontally, depending on the mechanical composition of soil layers, up to 2.5-5.0 meters. Roots of *Haloxylon* sp. reaching the soil layers of capillary wetting by ground waters (at depth of 10-12 m), formed numerous small roots. Height of *Aellenia subaphylla* plants of the second synusia was 120-140 cm. Rooting system was powerful and penetrated into soil up to 750 cm. In synusia of *Salsola orientalis* the shrub height and width were 50-60 cm and 40-45 cm, respectively. Dimensions of its roots were up to 700 cm in depth and up to 200 cm in the horizontal direction. *Artemisia diffusa* formed the fourth synusia with height of plants of 35-40 cm at diameter of bushes of 40-45 cm. Depth of the roots of *Artemisia diffusa* was up to 110 cm, size in the horizontal direction was up to 150 cm. Ephemeroid *Poa bulbosa* and ephemeral

Created pasture ecosystem of fall-winter use had high and stable feeding productivity (Fig. 5), which as early as within 3 years was twice higher than in the natural desert-like pastures (0.3 t/ha). Feeding productivity growth was sustainable until 9-10 years of life due to *Haloxylon aphyllum*, *Salsola subaphylla*, suffruticulose (*Salsola orientalis*, *Artemisia diffusa*) typical for the Karnabchul Desert with participation of the naturally growing *Poa bulbosa*. Maximum yield of the fall-winter pasture ecosystem was at the age of 9-10 years (2.2-2.6 t/ha of dry matter). The portion of fodder plants in total yield of the ecosystem depended on the species and living forms of the plants. The maximum yield was from *Salsola orientalis* (11.6-59.4 % depending on the plant age and meteorological conditions of the year). Yield of *Aellenia subaphylla* and *Artemisia halophila* significantly varied.

Aellenia subaphylla and *Salsola orientalis* can rapidly accumulate green mass during the first years of life (2-4 years), while *Haloxylon aphyllum* displays this ability significantly slower. Depending on the age and meteorological conditions, *Haloxylon aphyllum* made 3.6 to 28.1 % of yield of the pasture ecosystem. Presence *Salsola orientalis*, *Artemisia halophila* and *Aellenia subaphylla* makes the pastures excellent for grazing sheep in fall-winter period. In its turn, *Haloxylon aphyllum* not only gives enough fodder for animals during fall and winter, but also protects them from strong winds at low winter temperatures.

Therefore, the ecological niche concept is important for improvement of the theoretical principles and methods to adaptively construct floristically and cenotically complete pasture agro-ecosystems in arid areas of the Central Asia. Accelerated ecological reclamation by creation of arid pasture ecosystems which are based on staged, seasonal, successive, functional, and fluctuation differentiation of the ecologic niches ensures recovery of biodiversity and growth of feed productivity. We have realized this approach in the Central-Asian region by seeding phytocenotically balanced combinations of zonally typical dominants of the natural flora which are the most ecologically suitable for arid conditions of the region. Pasture suffrutex-grassy agro-ecosystems for spring-summer period have high and stable productivity and may be used as pastures for sheep, meat cattle, and camels. Fall-winter agro-ecosystems consist of shrubs, semi-shrubs, suffrutices and grasses, occupy various ecological niches in the aboveground and underground (edaphic) spheres, complement each other by important ecological, biological and economic characteristics, and effectively use environmental resources. It allows us to restore biodiversity, to increase yielding on low-productive territories and badlands, to optimize arid biocenoses of the Central-Asian region. All these will ensure sustainability of the pasture livestock sector.

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