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TO THE STUDY OF MYCOSYMBIOTROPHISM PROCESSES IN FOREST ECOSYSTEMS OF KAZAKHSTAN (Analytical review)

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Key words: mycorrhiza, symbiosis, forest ecosystem, trees, fungi.
Abstract. The analytical review of the study of mycosymbiotrophism issues in forest ecosystems of Kazakhstan is presented in this article. Processes of mycorhiza forming between trees and fungi are showed.

The symbiotic interrelationships between higher plants and fungi (mycorrhiza) have been studied in Kazakhstan since the middle of the last century. A significant number of articles have been published to date, most of which are characterized by the presence and degree of mycotrophy of wild and cultivated trees and shrubs in various regions of the country.

Mycorrhizae of the main tree species were studied during the observation of natural and artificial plantations in the West Kazakhstan region. It was found that ectendotrophic mycorrhiza of Pedunculate Oak (*Quercus robur* L.) is claviform, rarely clusterlike, yellow-brown or brown-black, smooth or curly, while the Hartig net is well developed and the mycelium penetrates the cortical parenchyma cells of the root. Mycorrhiza of Elms (European White Elm (*Ulmus laevis* Pall.) and Chinese Elm (*Ulmus parvifolia* Jacq.)) is yellow-brown, smooth or slightly downy, the Hartig net is absent, the mycelium is found in cortical parenchyma cells [1]. Five species of willows (*Salix alba*, *S.viminalis*, *S.fragilis*, *S.carpea*, *S.daphoides*) were studied and ectendotrophic mycorrhiza is noted on their roots; in cross sections of this mycorrhiza a yellowish-brown fungal cover is well developed [1]. The thin fungal cover, which is formed by colorless or yellow intensive branching mycelium with buckles, is typical for the genus of Poplar (White Poplar (*Populus alba* L.), Black Poplar (*Populus nigra* L.), Lombardy Poplar (*Populus pyramidalis* Borkh.)) [1,2]. Ectendotrophic mycorrhiza of European White Birch (*Betula verrucosa* L.) is claviform, smooth, grayish brown, the Hartig net is well developed, the mycelium is thin, colorless, with buckles. The claviform, forked branching, sometimes dendriform ectendotrophic mycorrhiza with tight fungal cover is typical for Scotch pine (*Pinus silvestris* L.). The amount of hyphae is according to the age of not only individuals, but the whole plantation and is defined by the gradations of soil formation processes and quantity of litter [2]. Hyphae, which wind around the roots ends, were found on those of Oleaster; they are typical for ectotrophic mycorrhiza, although there were not references about the mycotrophy of Oleaster in the literature researched. Ectendotrophic mycorrhiza of European alder (*Alnus glutinosa* L.) with hyphae of two types: one is transparent branching and the other is thin dark-colored branching hyphae [1,2].

During the study of mycotrophy of desert plants of the Large Badgers Sands region mycorrhiza was found on 26 of the 27 plants which grow there [3]. Though the area was studied by others, S.R.Shvartsman has made a list of mycorrhizal fungi [4].

I.A.Selivanov [5] has studied 175 plants of Central Asia to identify the degree of incidence and characteristics of the structure of mycorrhiza. He found that ectendotrophic mycorrhiza which presented a fungal cover on the roots of the fourth order is found in only one specie – Sogdian plum (*Prunus sogdiana* Vass.). However, there was a small number of mycorrhizal tips on the roots of Sogdian plum and the mycelial cover and the Hartig net were underdeveloped. Endotrophic mycorhiza formed by Phycomycetes was found in 96 species of higher plants. The author has concluded that the natural phytocoenoses vary according to the ratio of mycotrophic and non-mycotrophic species, and the determinative factor of this proportion is soil moisture [5]. I.A.Selivanov has published several articles about the terminology and classification of mycorrhizae [6], structural features of Phycomycetous (vesicular-arbuscular) mycorrhizae [7], the physiological aspects of symbionts interrelationship [8-10], the modern concept of the taxonomy of mycorrhizal fungi [11] as well as other related subjects.

The study of plant-psammophytes mycotrophy in natural associations in Tau Kum dunes has shown a low percentage of mycorrhizal plants in comparison with other associations of landscape and geographic zones [12]. Dominant and subdominant vegetation in Tau Kum are typically non-mycorrhizal. Among trees and shrubs the mycorrhiza was found only on roots of the Legumes (*Fabaceae*) representatives (Acacia (*Acacia sp.*), Astragal (*Astragalus sp.*)); among semishrubs various species of Sagebrush (*Artemisia sp.*) and Ephedra (*Ephedra sp.*) are mycotrophic. The major part of the ephemerae and ephemeroids, which grow and develop in the seasons with a high degree of soil moisture, is characterized by the presence of mycorrhiza [13].

The analysis of mycosymbiotrophism of a large number of higher plants species has shown that some taxa almost always have mycorrhizae, while others are non-mycorrhizal [14]. The presence of mycorrhizae and features of their structure are mainly related to the systematic position of the host plant. Mycorrhizae are usually not formed on the roots of higher spore plants including club mosses (*Lycopodium sp.*) and horsetails (*Equisetum sp.*). All species of Gymnosperms are mycotrophic, while seventy six percent of flowering plants form mycorrhiza [14]. Mycorrhizal plants compose three quarters of all species of monocotyledonous plants; Zygomycetes (vesicular-arbuscular) mycorrhizae are typical for them [13].

Data on the distribution of mycorrhizal plants in phytocoenoses of different landscape and geographic zones have been received as a result of long-term research of Perm, Russia mycologists under the guidance of I.A.Selivanov [15,16]. It was found that the saturation degree of mycotrophic plant species is eighty percent and more in the majority of forests, meadow, forest-steppe and steppe phytocoenoses. Desert and tundra plants are characterized by a far less degree of mycotrophy [16].

During the study of plants mycotrophy of the tugai forests [17] it was found that among the fifty two researched species of vascular plants belonging to nineteen families, twenty nine of these species from fifteen families are mycotrophic. Dominants and subdominants of the typical tugai communities (trees, shrubs and perennials) are mainly medium and high mycotrophic. The major part of mycotrophic plants forms endotrophic arbuscular-vesicular mycorrhiza. Mycorrhiza of Dzungarian Willow (*Salix songarica* Andress.) is ectendotrophic with a subtype B fungal cover [17].

About sixty five percent of the representatives of higher plants (one hundred fifty three species of the two hundred thirty four tested) come into a symbiosis with fungi in the flora of the northern deserts of Kazakhstan [18]. Mycorrhizae, formed during the process of the symbiosis, have neither a high degree of development, nor a variety of types and subtypes; the majority of observed plants have endotrophic arbuscular-vesicular mycorrhiza, while only Dzungarian Willow forms ectendotrophic mycorrhiza [18]. There are significant seasonal changes in the degree of plant mycotrophy in the northern deserts: an abundance of elements of mycorrhizal fungi (mycelium and arbusculars) on the covering of the root which is more prolific in the plant flowering phase [19]. Many vesicles in the roots of plants appear in the middle of the growing season, and especially in the fruiting period, while in roots of the ephemeral and ephemeroids the vesicles appear by the end of the growing season [19]. Noting the absence of fungal mycelium in the roots of seedlings, many cases of the introduction of the fungi in the epidermal cells and the presence of germinating vesicles, the authors conclude that the primary infection of the roots of mycorrhizal fungi comes from the soil.

Researches of E.M.Shkaraba and K.D.Muhamedshin [20,21] have shown that the junipers, as the other representatives of the family Cupressaceae, come into a symbiosis with Zygomycetes to form vesicular-arbuscular mycorrhiza. The authors have noted the stability of the process of mycorrhiza formation and the change of its intensity depending on a complex of factors, including altitude and slope exposure. Apparently, in the natural plant communities the highest intensity of mycorrhiza formation is observable optimum growth conditions for the host plant; their deterioration leads to the weakening of the mycorrhiza formation [20].

I.A.Kenzin has studied mycorrhizae of introduced tree species [22,23]. During his study of mycotrophy of fourteen of trees introducents species in the foothills of the Zailiysky Alatau Mountains the endotrophic arbuscular-vesicular mycorrhiza was found in roots of Horse-chestnut (*Aesculus hyppocastanum* L.), American Arborvitae (*Thuja occidentalis* L.), Eastern Red-cedar (*Juniperus virginiana* L.), Common Juniper (*Juniperus communis* L.) and Black Locust (*Robinia pseudoacacia* L.) [22]. Ectomycorrhiza with a mycelial cover and a Hartig net is formed on absorbing roots of Scotch Pine (*Pinus silvestris* L.), Mountain Pine (*Pinus mugo* Turra), Siberian Larch (*Larix sibirica* Ledeb.), Kamchatkan Dahurian Larch (*Larix kamtschatica* Rupr.), Colorado Blue Spruce (*Picea pungens* Engelm.), Pedunculate Oak (*Quercus robur* L.), European White Birch (*Betula pendula* L.) [22]. Mycorrhiza of seedlings of Scotch Pine is well developed with the mycelial cover of subtypes A, B, D, a Hartig net wraps of two to five cortical layers [23]. The multilayered Hartig net and the thin mycelial cover of subtypes B and F are formed in mycorrhiza of larch seedlings; the Hartig net of spruce seedlings is also multilayered, while the mycelial cover is of subtypes A, B and F [23]. I.A.Kenzin has attempted to classify mycorrhizae forms and root tips of trees [24].

Critical processing of materials of the herbarium fund of the Institute of Botany and Phytointroduction in Almaty, Kazakhstan is the basis for the publication of Volume XIII «Flora of Spore Plants in Kazakhstan–Agarics Mushrooms (*Agaricales*) » [25]. In two published books four hundred eighty one species of agarics mushrooms, belonging to eighty three genera, have been described. The keys to determination of agaricoid mushrooms, as well as their location and other data have been describe along with general information about their structural features, the history of their research in the territory of the Republic of Kazakhstan as well as their growing conditions. Symbiotrophic fungi are the one hundred fifty one species that represent a group of ectotrophic mycorrhiza formers. Most of these species belong to the genera *Russula*–thirty four species, *Cortinarius*–twenty seven species, *Lactarius*–twenty two species, *Tricholoma*–twelve species, *Amanita*–ten species and *Suillus*–nine species [25].

During the identification of macromycetes trophic groups in Almaty State Reserve it was found that the group of symbiotrophes was 21,4% (twenty one percent) of the total number of detected species. In the territory of the Reserve fifty one species of fungi which formed ectotrophic mycorrhiza with vascular plants were identified, and spruce was the most mycotrophic genera: eighteen species of symbiotic fungi were found on roots of spruce [26]. Ten species of mycorrhiza formers fungi were found on roots of birch; two species on roots of aspen [26].

Quite a large part of the research has been devoted to the study of mycotrophy of various wild and cultivated grasses. Objectives of the research of I.S.Skalon [27] were the four types of feather (*Stipa rubens, S.lessingiana, S.sareptana, S.capillata*) and fescue grass (*Festuca sulcata*). Endotrophic mycorrhiza of Phycomycetes type was found in all these species. Microscopic studies performed by the same author have shown that the mycelium of fungi forming the endotrophic mycorrhiza has been distributed mainly in the cells of the inner layer of cortical parenchyma of the lateral roots [27].

During the study of mycotrophy of Aeropolus (*Aeluropus litoralis* Parl.) in the Kerbulak mountain area (the tract which stands out among the surrounding landscape by natural boundaries or margins an example is the forest within the field or marsh or meadow within the forest) near the mid-channel of the Ili River, non-mycorrhizal representatives of Aeropolus were not detected [28]. The highest intensity of mycorrhizal infection has been characteristic of those communities where Aeropolus was dominant or subdominant [28]. It should be noted that representatives of Aeropolus with the greatest intensity of infection were found at the maximum depth of root penetration, the greatest density of vegetation and number of spikes per square meter [29].

Almost thirty years ago the study mycotrophizm of plants which grow in different vertical zones of the Zailiyskiy Alatau range was begun [30]. Research found that in all the studied zones mycotrophic species dominate over non-mycotrophic. Plant species with mycorrhiza are most common in shrubby-mixed herb and forest zones where the frequency of the occurrence of mycotrophic species is on average ninety one point six percent and eighty five percent respectively [30]. Plants are characterized by the lowest degree of mycorrhizal infection in the Zailiyskiy Alatau high mountain region. Virtually all the dominant species except sedges in the alpine zone had mycorrhiza [30]. During the study of the systematic position of fungi symbionts it was found that in this region mycorrhiza of plants was formed by twelve species of Zygomycetes belonging to the genera *Glomus*, *Gigaspora* and *Acaulospora*. The species composition of fungi depended on the vertical zonation. The highest number of species was typical for shrubby-mixed herb and forest zones with ten species of fungi-symbionts in each zone; the lowest was the alpine zone with seven types [31,32,33,34]. The upper level of distribution of mycorrhizal infection in the Zailiyskiy Alatau was at an altitude of three thousand six hundred meters above sea level [35].

During research done in the project framework of the World Development Bank, "Forest Conservation and Increase of Forest Cover Percent in the Territory of Kazakhstan", forty seven species of mycorrhizal fungi were found belonging to twenty two genera, nine families and four orders of agaricoid fungi in the ribbon-like relic pine forests of the Irtysh River [36]. Pure cultures of the eight species of mycorrhizal fungi (Pine Cepe - *Boletus pinicola*, Russule - *Russula sp.*, Blewits (Blue-leg) - *Lepista personata*, Sharp Agaric - Lactarius torminosus, Waxy Laccaria - *Laccaria laccata*, St. Georges Mushroom - *Calocybe gambosa*, Yellow Knight (or Man on Horseback) - *Tricholoma flavovirens*, Brown Roll-Rim (or Poison Pax) - *Paxillus involutus*) which can be used for artificial mycorrhization of planting material were isolated from mushroom carpophores [37]. The technology of mycelium cultivation was developed for artificial mycorrhization of the planting and seed material for this pine forest restoration in burnt areas [37]. In forest nurseries of these ribbon-like relic pine forests from fifty one percent to seventy two percent of two-year seedlings have natural mycorrhizae on their roots. The mycorrhization degree of root systems of the seedlings is not uniform and varies from fourteen percent to fifty four percent. The inverse relation between the degree of mycorrhization of the root systems and the root colonization of pathogenic fungal flora was established in this research. Findings concluded that in the presence of mycorrhiza the development of pathogenic fungal flora on the seedling roots is not a threat of epiphytotics in the forest nurseries [36].

There was an experiment of artificial mycorrhization of pine seedlings with Blewits (Blue-leg) mycelium in the open ground forest nurseries. The experiments did not have positive effects to growth and development of the seedlings. Signs of artificial mycorrhiza of agaricoid fungi on plant roots were not found. There was a presence of an already established indigenous microbiologic balance in the seedling rhizosphere that did not contribute to the penetration of other organisms in an occupied niche. Therefore almost sterile compost mycelium which was brought into the soil was not able to compete with the existing soil microorganisms to the full extent and to have a positive influence on the growth and development of seedlings [36].

Experiments with the application of mycorrhizal compost during growing seedlings with a closed root system were carried out. Substrates consisted of such components as peat, sand, perlite, vermiculite and sunflower seed husks. The components were mixed in different proportions [38]. The substrates were infected by mycorrhizal compost of the St. Georges Mushroom (*Calocybe gambosa* (Fr.) Donk). Seedlings of Scotch Pine (*Pinus silvestris* L.) were grown with closed root system in containers in the greenhouse of Kazakh National Agrarian University, Almaty, Kazakhstan. It was concluded that the substrate consisting of peat, vermiculite and sunflower seed husks in the ratio 6:1.5:2.5 is the most effective for making mycorrhizal compost and for growing Scotch pine seedlings with closed root system [38].

At the present time the study the mycosymbiotrophizm in forest coenoses continues under a grant of the budget programs of scientific research activity of Kazakhstan for 2012-2014. The Almaty branch of The Kazakh Forestry Research Institute Ltd. is responsible for the fundamental research in the Kyzylorda region studying consort connections between plants and fungi during the process of overgrowth in the drained bed of the Aral Sea [39]. Researchers studied phytocoenoses in twenty two positions within one of the routes, described thirty species from fourteen families which were involved in the reconstruction process on the drained bed, collected more than three hundred fifty samples including plant vegetative parts, root systems and soil, conserving the roots. In the laboratory conditions the collected material of plant hosts was identified and the herbarium was made; effective ways for studying the root and soil samples were identified; their microscopy for the presence mycobiota was carried out. According to the results of preliminary identification in the cells of the roots of twenty species of the host plants from seven families (*Poaceae, Chenopodium, Zygophyllaceae, Polygonaceae, Nitrariaceae, Amaranthа́ceae, Solanacea*), the vesicular-arbuscular mycorrhizae of endophytic fungus of the genus *Glomus* was defined.

Quantitative characterization of mycotrophizm (known as a degree of mycorrhizal infection and its distribution in the root system) will be conducted in the next season and will be expressed in such terms as, for example, a frequency of occurrence for the mycorrhizal infection and intensity.

Study of consort connections in forest biocoenosis and getting new factual material on the availability, status and dynamics of native mycobiota will enhance the volume of knowledge about the restoration of damaged ecosystems.

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К ИЗУЧЕНИЮ ПРОЦЕССОВ МИКОСИМБИОТРОФИЗМА В ЛЕСНЫХ СИСТЕМАХ КАЗАХСТАНА
(Аналитический обзор)

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Ключевые слова: микориза, симбиоз, лесная экосистема, деревья, грибы.

Аннотация. В статье приводится аналитический обзор вопросов изучения микосимбиотрофизма в лесных экосистемах Казахстана. Рассмотрены процессы формирования микоризы между деревьями и грибными организмами.

ҚАЗАҚСТАННЫҢ ОРМАН ЖҮЙЕСІНДЕ МИКОСИМБИОТРОФИЗМАЛЫҚ ҮРДІСТЕРДІ ЗЕРТТЕУ
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Тірек сөздер: микориза, симбиоз, орман экожүйесі, ағаштар, саңырауқұлақтар.

Аннотация. Мақалада Қазақстанның орман экожүйесіндегі микосимбиотрофизмалық мәселелерге аналитикалық шолу жасалады. Ағаш пен саңырауқұлақ арасындағы микоризаның түзілу процесі қарас-тарылады.

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