PLANT PHYSIOLOGY

UDC 504.064.3:574

PECULIARITIES OF LIGHT CONDITIONS IN UNDERCROWN SPACE WITH WOODY PLANTS IN TERMS OF ARBORETUM OF NIKITA BOTANICAL GARDENS

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Introduction

Arboreal plants of the overwood layer extremely effect on above-soil vegetative cover, forming and changing habitat for lower layers plants. Crown architectonics of woody plants conditions light structure of a plantation. Light structure tends to be a determining factor for forest phytoclimate, regime of soil processes, moisture penetration through the forest canopy and for decomposition and mineralization of that canopy as well [10].

Combination of arboreal plant crowns with different density causes four types of light structures: 1) lighten with mainly ornamental crown cultivars; 2) half-lighten with mainly half-ornamentally crowned trees; 3) half-shady with mainly half-dense crowned cultivars; 4) shady with mainly dense-crowned cultivars [2]. Soil condition of herbaceous and shrub flora in the forest cenoces depends upon light penetration. Crown density effects on some characteristics of arboreal vegetation: shade tolerance, growth intensity, efficiency. As photosynthesis plays an important part for metabolism and vital functions of plants in general, light conditions could be a ground for optimal structure and density of plantations in parks and gardens. Development of technology of high-intensive park phytocenoses attaches a great importance to increasing the coefficient of solar radiation used by plants as well as to complex of agro technical events. It is possible to solve the matter due to correct matching of plant cultivars and setting the optimal growing space for them.

As arboreal plantations transform the environment, in their phytogenous fields specific conditions are created which effect on formation of specific light regime. Quantitative assessment of illumination change within area of plants influence, links of this ecological factor with crown architectonics, determined by genetic cultivar characteristics, its importance in morphogenetic and physiological processes are quite actual issues [5].

Research objective is to investigate peculiarities of the light conditions under the canopy of arboreal plants with different architectonics and density of crown.

Objects and methods of the research

Objects of our research were arboreal introducents of overwood layer from the I group: *Cedrus atlantica* (Endl.) G. Manetti ex Carrière, *Cupressus macrocarpa* Hartw. & Gordon, *Abies numidica* de Lannoy ex Carrière, *Sequoiadendron giganteum* (Lindl.) J. Buchholz, *Sequoia sempervirens* Endl., *Pinus pinea* L., and bushes of the I and II groups: *Pittosporum heterophyllum* Franch., *Buxus sempervirens* L., *Euonymus japonica* Thunb., *Mahonia aquifolium* (Pursh) Nutt., *Chimonanthus praecox* (L.) Link, *Viburnum tinus* L., *Cornus mas* L., *Laurocerasus officinalis* M. Roem., *Aucuba japonica* Thunb.

Pattern objects were trees of the overwood layer, aged by 130-160 years. Due to shadowing, tree waste, changes of moisture conditions in their undercrown space phytogenous fields were formed, that function as specific microsites for many overtopped plant cultivars and soil fauna [12]. Bushes selected as the lower layer are 30-60 years. At the moment of research these bushes had a crown typical for their age period, didn`t have any signs of damage or disease, ecological conditions completely supplied their normal growth and development.

Control values of parameters were fixed out of zone with study and other large plants influence. Light stream was measured by luxmeter U-166 according to recommendations by V.A. Alekseyev [1] under conditions of the full natural lighting, at noon, having minimal wind velocity. Analyzing light conditions, parameter of illumination under crown was taken, that was evaluated by % from the solar radiation reached the open area. The observations were carried out in May-September during active vegetation and in December after growing process and tree waste were finished.

Results and discussion

Illumination as a parameter of energy supplying is widespread in different calculations of energy characteristics and while discussing the ecological issues concerning forest phytocenoces [3, 15]. It is one of the ecological factors, its level of influence is mostly changed by vegetative cover. Each of zones from phytogenous field (stem-by rise, undercrown space, zone of crown edge, intercrown space) is characterized by a definite illumination level that effects on vegetation of the lower layer depending on species composition, structure, ornamentality and degree of crown density [6,18]. Intensity of solar radiation decreases as far as penetrating into the crown mass. In May-June on fine days illumination on the open areas not-shaded by tree crowns reached 65000-70000 lx. In case of intensive shadowing much less solar radiation could penetrate under the tree canopy. The highest average illumination point (13196 lx) and coefficient of penetration (26,9%) in undercrown space was registered for *Cedrus atlantica* with wide cone-shaped and half-illuminated crown. The lowest values of these parameters (852 lx and 1,7%) were typical for *Sequoia sempervirens* with narrow cone-shaped and dense shady crown (table 1).

The investigations permitted to make a line of relative illumination in the phytogenous field of the undercrown space for study cultivars according to decreasing value of solar radiation penetration coefficient:

Cedrus atlantica → Sequoiadendron giganteum → Cupressus macrocarpa → Pinus pinea → Abies numidica → Sequoia sempervirens

Table 1

Archytechtonics, light structure and characteristics of arboreal introducents crowns

Cultivar	Crown shape	Ecological structure	Light structure	Light penetration into the undercrown space in summer (sunny day)			
				Illumination, lx	K_{v1}, %	K_{pen}, %	K_{v2}, %
Cedrus atlantica	Wide cone-shaped	Half-ornamentally crowned	Half-lighted	13196±7583	71,2	26,9±13,3	59,7
Sequoiadendron giganteum	Loose, cone-shaped, rounded to the top	Half-dense crowned	Half-shady	8243±3902	60,8	16,9±6,4	46,8
Cupressus	Flat-	Half-dense	Half-shady	4635±3976	85,8	9,4±7,8	82,5

macrocarpa	umbrellate with bias growing up branches	crowned					
Pinus pinea	Umbrella-shaped with branches growing horizontally	Half-dense crowned	Half-shady	4297±1818	58,6	8,6±2,7	45,0
Abies numidica	Cone-shaped, densely branched	Dense-crowned	shady	2772±1171	55,7	5,7±2,0	44,5
Sequoia sempervirens	Narrow cone-shaped	Dense-crowned	shady	852±313	46,5	1,7±0,4	32,3
Notes: K_{pen} – coefficient of penetration, K_{v1} and K_{v2} – coefficients of illumination and penetration variations relatively							

Illumination in undercrown space is the most variable among parameters of plantations microclimate. Regime of so-called “patches of sunlight” is of great importance to determine the illumination conditions [3, 15, 19]. In case of “patch of sunlight” regime light fluctuation grounds often illumination change. Periods of contrast illumination are rated by changes in every point from 1 to 10 000 lx per every 10 minutes [17]. On a sunny day at about noon o`clock variation of solar radiation penetration coefficient, allowing for minimal wind velocity, under the *Cupressus macrocarpa* crown layer made 82,5, while coefficient of variation less than 33%, typical for homogeneous population, was registered only under dense shady crown of *Sequoia sempervirens* (see table 1).

Figure 1 gives some ideas about illumination in tree undercrown space. We supposed that illumination degree depends upon crown length and density along vertically above different points in undercrown space. Due to cone-shaped crown of *Abies numidica* its length from a stem to the edge evenly decreases what causes gradual gain of illumination (fig.1, curve 3). In spite of illumination going up from a stem to branch, transmission of light through crowns of *Cupressus macrocarpa* and *Sequoiadendron giganteum* differs a bit. Than further from a stem, from 2 to 3 m, in undercrown space of *Cupressus macrocarpa,* than illumination level is almost double higher, it rises from 7 to 14% (fig.1, curve 2). Such a regime of illumination is easily explained by flat-umbrallate shape of crown with huge directed up branches. Approximately at the same distance from a stem in undercrown space of *Sequoiadendron giganteum*, as opposite to *Cupressus macrocarpa,* a slight reduction of illumination level is registered (0,6-0,8% less, see fig.1, curve 4). Most probably it`s caused by growth of crown density, evenly branched tree structure with thin shoots. Considerable differences in illumination regime are fixed for *Cedrus atlantica* and *Pinus pinea,* in comparison with previous cultivars (fig.1, curves 1, 6). Depending upon crown architectonics, the most illuminated area for *Cedrus atlantica* is undercrown space, distant from a stem for 2-3 m (32%), *Pinus pinea* – 1-2 m 10-12%). The least illuminated zones of *Cedrus atlantica* were areas under crown edge and periphery, distance from a stem is 4-5m, while for *Pinus pinea* the lowest point of illumination level was near-by a stem and under crown edge (6-7%). Extremely low illumination in undercrown space of *Sequoia sempervirens*, that doesn`t exceed 2-3% from its parameter on an open area (fig.1, curve 5) is caused by dense narrow cone-shaped crown and considerable absorption ability of dark conifer, mainly located in top and external crown parts, by its low growing from the ground, what reduces side illumination level in undercrown horizon.

Therefore, shady crown effect creates special illumination regime in undercrown space of top layer, what becomes apparent in zone of permanent and variable shade in phytogenous field of *Cedrus atlantica, Sequoiadendron giganteum, Cupressus macrocarpa, Pinus pinea, Abies numidica* and zone of permanent shade only for *Sequoia sempervirens*. In this case higher absorption ability of dark conifer should be considered. Among study conifer cultivars the highest penetration ability is fixed for *Cedrus atlantica* (26,9%), the lowest - *Sequoia sempervirens* (1,7%). Unfavourable conditions for the second layer plants are created just in undercrown space of *Sequoia sempervirens*.

Weather conditions are of great importance for illumination parameters in undercrown space. In a cloudy day illumination in forest undercrown space 3-5 times less and better unchangeable in comparison with illumination on an open place [8, 15, 16]. Some balancing of extreme illumination values take place. All these facts indicate the complication and variety of radiation conditions for all layers of plantations. That`s why, according to opinions of some authors, illumination conditions are not correlated with such parameters as density of canopy, absolute forest stand, thickness [4, 6]. Determined, according to these or those origins, correlations of illumination under forest canopy with canopy structure are considered just in particular cases [4, 7, 15].

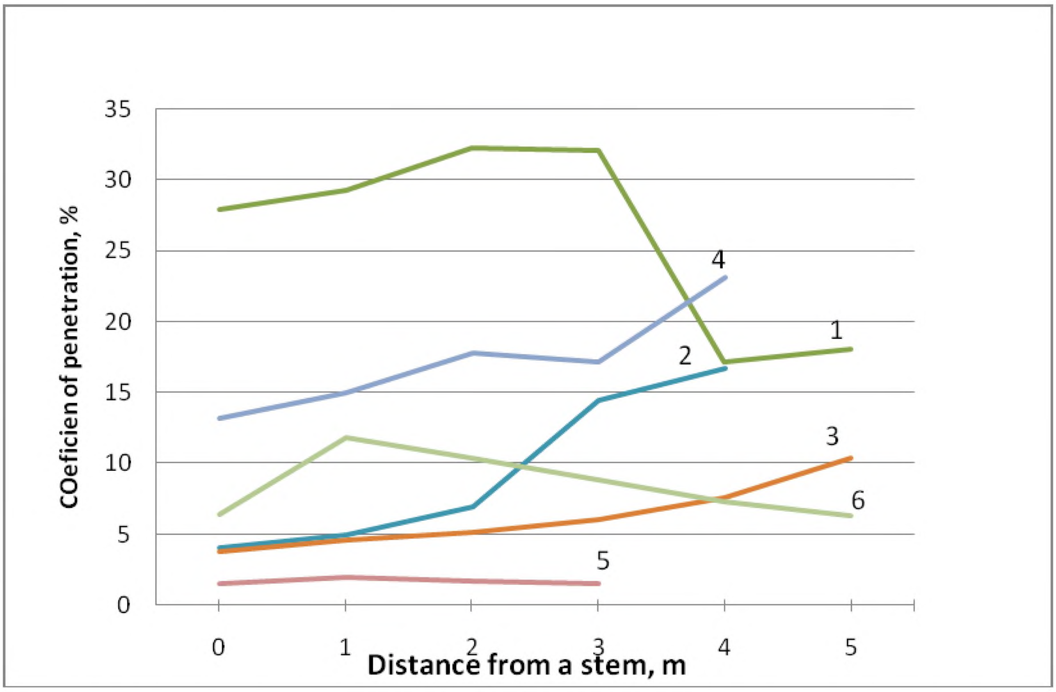

Fig.1 Illumination changes in phytogenous field of arboreal plants within Arboretum of Nikita Botanical Gardens

Tree cultivars: 1 - *Cedrus atlantica*; 2 - *Cupressus macrocarpa*; 3 - *Abies numidica*; 4 - *Sequoiadendron giganteum*; 5 - *Sequoia sempervirens*; 6 - *Pinus pinea*

Method of three-factor dispersed analysis was applied to reveal common tendencies of illumination changes in undercrown space of study trees of top layers level within Arboretum of Nikita Botanical Garden, which are grounded by cultivar effect, cardinal points, distance from a stem and possible combination of their interaction. Under crown of every of six conifer exots 768 measurements of illumination were carried out. Measurements were conducted close to a stem and on distance 1, 2 and 3 m far in northern, eastern, southern and western directions (N, E, S, W). Figure 2 presents dynamics of average values of illumination coefficient according to cardinal points and distance from a stem. It`s possible to follow consecutive increasing of illumination level as removing from a stem and sharp increasing from southern side near-by a stem and gradual effect smoothing of cardinal points as far as remove from a stem. At the same time within a radius of 3 m tendency of maximum illumination under crown from southern side and minimal from western side is keeping on.

To create a complete factor model we applied a method that makes crossed decomposition of squares sum, marks out principal factors, all effects of their couple interaction and effect of joint action of all three factors:

$$Y = m + A + B + C + A*B + A*C + B*C + A*B*C + e,$$

where,

Y – coefficient of illumination penetration, %

A – plant cultivar, B – direction according to cardinal points, C – distance from a stem, m; e – effect of random factors; m – general average value; symbol "*" connects factors, for which effect of interaction is calculated.

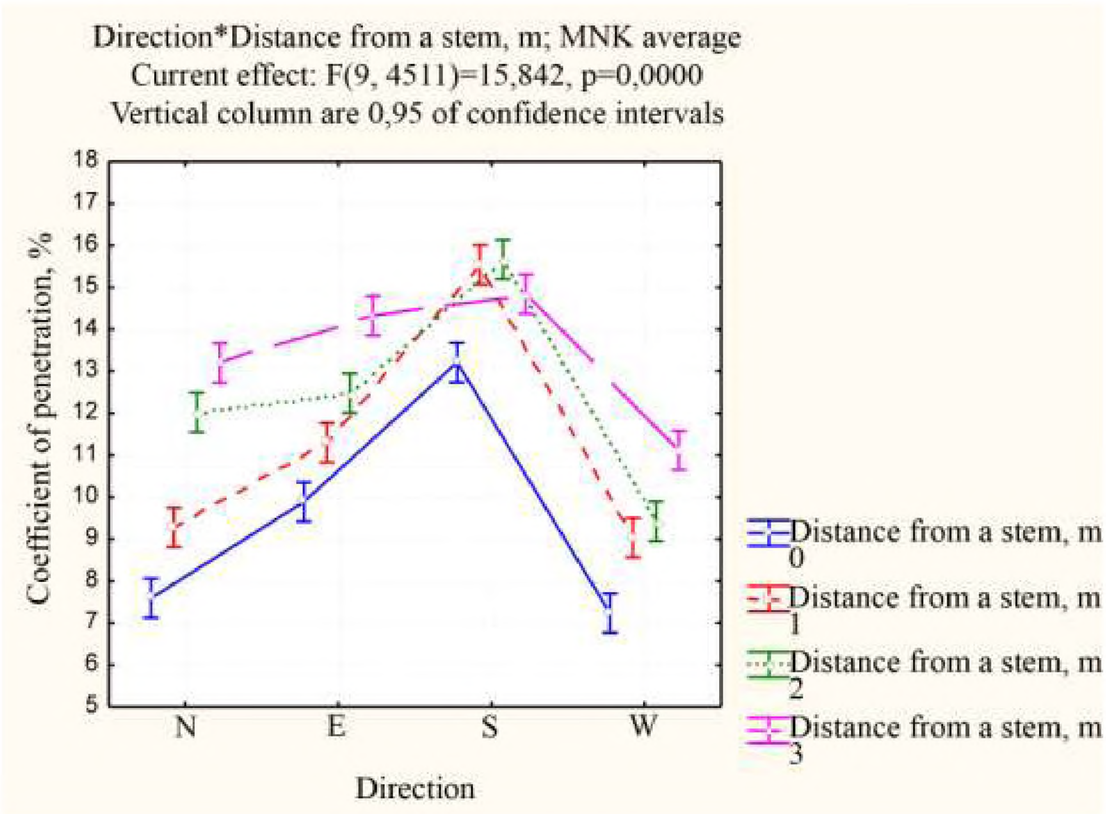

Fig.2 Correlation of illumination condition in the phytogenous field of arboreal plants within Arboretum of Nikita Botanical Gardens with cardinal points and distance from a stem (there are average values and their usual mistakes)

Calculation were carried out due to program STATISTICA, version 6.1, package Analysis (Factorial Yes). Results of dispersal analysis are presented in table 2. Coefficient of multiple correlation of the model R=0,95, while coefficient of determination R^2=0,90, dispersal ration of Fisher Fcommon=429 having 4511 degrees of freedom; statistic importance of factorial model in general p=0,00. Presented in table 2 results certify that all these effects gained in out research, are of great importance for statistics.

Table 2

Result of effects dispersal analysis of combined impact of plant cultivar, direction according to cardinal points and distance from a stem on illumination in undercrown space

Source of changeability	SS	Degrees of freedom	MS	F	p
1	2	3	4	5	6
Free member	623350,4	1	623350,4	37877,97	0,00
Cultivar	410070,8	5	82014,2	4983,60	0,00
Direction	20038,1	3	6679,4	405,87	0,00
Distance from a stem, m	9612,4	3	3204,1	194,70	0,00
Cultivar*Direction	176773,7	15	11784,9	716,11	0,00
Cultivar*Distance from a stem, m	12166,6	15	811,1	49,29	0,00
Direction*Direction from a stem, m	2346,4	9	260,7	15,84	0,00
Cultivar*Direction*Distance from a stem, m	40084,7	45	890,8	54,13	0,00
The rest	74236,7	4511	16,5		

Effect of the model separate components on illumination level in undercrown space could be characterized due to results, presented in table 3. Dispersal analysis proves that dominant impact in creating the illumination regime in undercrown space is caused by genotypical peculiarities of a cultivar. At the same time it shows considerable mutual influence of cultivar and direction (according to cardinal points) on illumination level. Impact of the rest model components is insignificant.

Table 3

Matrix of dispersions/covariations of intergroup effects of a plant cultivar, direction according to cardinal points and distance from a stem on illumination level in undercrown space.

Source of changeability	Coefficient of penetration, %
Cultivar	89,02970
Direction	4,35044
Distance from a stem, m	2,08694
Cultivar*Direction	38,37901
Cultivar*Distance from a stem, m	2,64147
Direction*Distance from a stem, m	0,50943
Cultivar*Direction*Distance from a stem, m	8,70271

Illumination condition and luminosity of penetrated light under the plantation canopy depends to a large extent on season [11,15]. One of the key factors of climate is a stream of solar radiation that depends upon plantation structure, soil composition, age, density, age structure of the top layer. Illumination conditions, created by dominant cultivars, determine special diversity of cenoses. Cultivars-edificators plays a principal role in creating special environment around some specimens and totally, their influence mainly defines their views [14]. That`s why changes of illumination conditions in seasonal rhythm emphasizes role of arboreal plants for phytoclimate creation in undercrown space. Phytoclimate of plantations is mainly determined by character of energy reaching the canopy profile. Seasonal regularities of transmission capacity of top layer conifer cultivars are presented at figure 3.

Reflection and absorption of the main part of photosynthetic active solar radiation (PAR) by plants of top layers having a large crown density provide minimum light stream for plants of lower layers, and light-requiring cultivars are not available to grow in spite of other favorable conditions. Researches revealed that undercrown space of *Sequoia sempervirens* gets on average 2-3% of solar radiation reaching the open place, that is almost all PAR is absorbed, season doesn`t matter. Considerable differences at illumination penetration in winter and summer period weren`t found out for *Pinus pinea* undercrown space: 8-9% (fig.3). Undercrown space of other cultivars (*Cedrus atlantica, Sequoiadendron giganteum, Cupressus macrocarpa, Abies numidica*) got 5-11% much in summer than in winter (fig.3). Perhaps in case of conifer plants it`s caused by canopy structure and height of solstice.

Therefore arboreal canopy of study conifer introducents during a year has the following average data of solar radiation penetration: *Cedrus atlantica* – 16-27%, *Sequoiadendron giganteum* – 11-17%, *Cupressus macrocarpa* – 3-14%, *Pinus pinea* – 8-9%, *Abies numidica* – 4-8%, *Sequoia sempervirens* – 2-3%.

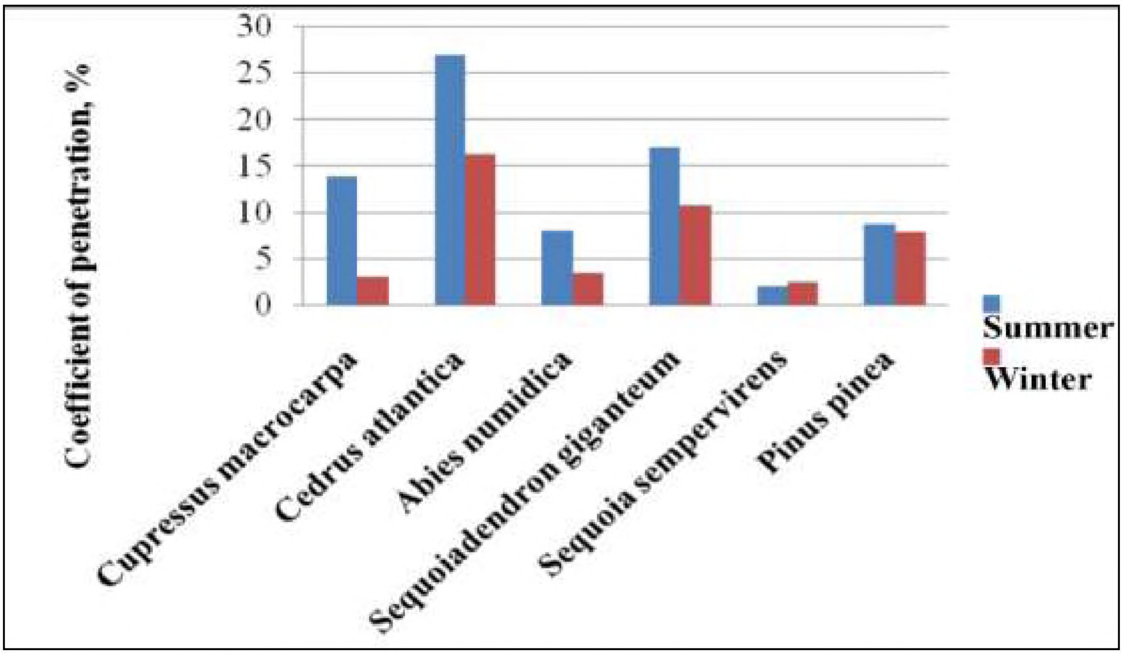

Fig.3 Seasonal variations of solar radiation penetration within canopy of top layer conifer cultivars

Investigation of breeds shade tolerance, peculiarities of their illumination regime are of great importance for cultivars and breeds matched for plantation to create landscape compositions. Shade tolerant plants possess wide ecological amplitude as to light conditions, as they are more comfortable in conditions of good illumination, but at the same time can adapt to low-light; such plants could be divided into more and less shade tolerant plants. Less shade tolerant arboreal plants (light-requiring) are considered trees and bushes growing on the open areas without tolerance to prolonged shading. Photosynthesis of study breeds gets the highest level under conditions of high illumination. This group includes: *Betula, Salix, Larix, Populus tremula, Juglans regia, Robinia, Pinus, Fraxinus.* Trees and bushes tolerant to slight shadowing, but well growing under conditions of high illumination as well are shadow tolerant arboreal plants. The highest rate of photosynthesis is typical for cultivars with 0,1-0,01 of complete solar illumination. The most shade-tolerant cultivars are: *Taxus, Abies, Buxus, Fagus, Carpinus, Siberian cedar, Tilia, Pices, Acer, elm tree, Viburnum, Euonymus, Prunus laurocerasus, Aucuba japonica, Corylus* [9,13]. Minimum illumination, that gets leaves makes the following portions from the total solar illumination: *Larix* – 1/5, *Fraxinus* –

1/6, *Betula verrucosa*– 1/7-1/9, *Populus tremula* – 1/8, *Pinus*– 1/10, *Quercus* – 1 /20, *Pices* – from 1/9 till 1/32, *Acer* – 1/55, *Fagus* – 1/60, *Buxus* – 1/100 [13].

Due to character of shoot location, degree of bush compactness, peculiarity of place and optical leaves properties, illumination within inside part of phytogenous field of study lower layer plants in August-September fluctuated from 0,6-0,7% (*Chimonanthus praecox, Buxus sempervirens)* till 2,6% *(Cornus mas)* of the total illumination (table 4).

Table 4

Physiological characteristics and illumination condtions of lower layer shrubs

Cultivar	Life form	Crown structure	Crown shape	Light penetration, % into undercrown space (sunny day)	
				summer	winter
Pittosporum heterophyllum	Evergreen	Friable	Inversely egg-shaped	1,4±0,6	1,6±0,6
Buxus sempervirens	Evergreen	Dense	Inversely egg-shaped	0,7±0,1	2,5±1,0
Euonymus japonica	Evergreen	Friable	Inversely egg-shaped	1,7±0,7	3,5±1,7
Mahonia aquifolium	Evergreen	Friable	Globular	1,5±0,2	4,4±1,7
Chimonanthus praecox	Deciduous	Close	Branchy	0,6±0,1	1,1±0,4
Viburnum tinus	Evergreen	Friable	Inversely egg-shaped	1,5±0,3	5,7±2,3
Cornus mas	Deciduous	Friable	Branchy	2,6±0,4	36,2±9,9
Laurocerasus officinalis	Evergreen	Friable	Branchy	1,1±0,5	6,9±2,6
Aucuba japonica	Evergreen	Friable	Inversely egg-shaped	1,0±0,2	2,0±0,5

In comparison with arboreal conifer cultivars, light penetration into undercrown space of lower layer shrubs in winter period (December) was higher, than in August – September either under evergreen plants or deciduous tree cultivars of top layer (fig.4).

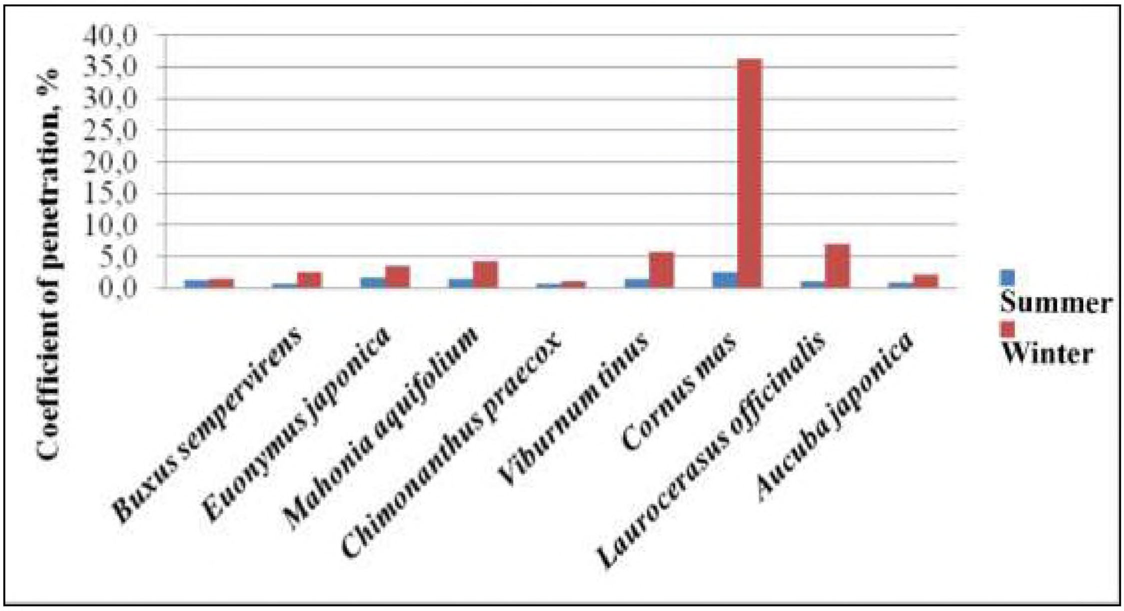

Fig.4 Seasonal variations of solar radiation penetration under canopy of lower layer plants

At the same time absolute values had some differences. *Pittosporum heterophyllum, Buxus sempervirens, Euonymus japonica, Mahonia aquifolium, Chimonanthus praecox and Aucuba japonica* which grow under crowns of evergreen trees penetrated into the undercrown space solar radiation only 0,2-2,8% as much, while *Viburnum tinus* and *Laurocerasus officinalis* growing under deciduous trees - 4,2-5,8% as much. The most considerable changes of illumination conditions within inside part of phytogenous field was registered for *Cornus mas*, a deciduous shrub, growing on an open area. The average penetration of its crown made 2,6% on a sunny day during the period of a total foliage, but after leaf fall it reached 36,2% (see table 4).

Research results indicate the complexity and variety of radiation conditions for all layers and depend upon species composition, age and density of stands of trees. Percentage of solar radiation capable to reach the soil surface within plantation, mainly depends upon plantation structure, its distribution across the canopy profile. Analyzing these data, it makes possible to conclude that transformation character of the light stream by lower layer plants depends on development of photosynthesizing apparatus within both layers (either top or lower layers).

Conclusions

1. Arboreal plants of the top layer with a high crown provide rather better conditions for lower layers due to side illumination.
2. In summer light stream of the study conifer exots besides *Sequoia sempervirens*, ranges from 8 till 27% from the total illumination what causes quite favorable conditions for soil cover plants.
3. More severe conditions according to this parameter are fixed for shrubs, which illumination of soil horizon makes from 1 till 3 % from the total light stream.
4. Degree of the light penetration that characterizes regime of light climate in undercrown space, is mainly determined not only by environmental parameters but genotypical peculiarities of a cultivar with its special crown architectonics.
5. Due to shady crown effect a special light regime occurs that is zones of permanent and changeable shadow within phytogenous field of plantations. The way of light stream transformation in the top layer undercrown space could be considered as a criterion of plant matching for the second layer according to cultivar shade tolerance.
6. Conducted researches essentially added information about phytogenous field of some plant cultivars. They are possible to use for theoretical base development in plant ecology and ecology of forest phytocenoses.
7. Results of the given research can be applied during planning and creation of single and group tree plantations in landscape and other compositions under conditions of introduction on South Coast of the Crimea.

The study was funded by research grant № 14-50-00079 of the Russian Scientific Foundation.

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The article was received at editors 12.08.2015

Plugatar Yu.V., Kovalev M.S., Ilnitsky O.A., Korsakova S.P., Pashtetsky A.V. Peculiarities of light conditions in undercrown space with woody plants in terms of Arboretum of Nikita Botanical Gardens // Bull. of the State Nikit. Botan. Gard. – 2015. – № 116. – P. 5-14.

Light conditions of undercrown space where woody plants grow (15 cultivars) were analyzed in terms of Arboretum of Nikita Botanical Gardens. As a result of crown shady effect created by overwood plants, specific light conditions are formed in undercrown space, that causes formation of zones with permanent and variable shadow in phytogenous field of *Cedrus atlantica, Sequoiadendron giganteum, Cupressus macrocarpa, Pinus pinea, Abies numidica, Sequoia sempervirens.* In frost-free season light stream of study alien plants, besides *Sequoia sempervirens,* ranges from 8 up to 27% from total illumination supply, what is favorable for growth of shrubby plants. Light pellucidity which characterizes light climate in undercrown space, is mainly determined by environmental factors, genotypical features of the cultivar with its typical architectonics of crown. Transformation character of the light stream in undercrown space is a possible criterion for selection of the second layer plants according to cultivar shadow tolerance.

Key words: *light conditions; phytogenous field; undercrown space; overwood trees*.