UDC 595.799:633.31(477.52/.54) DOI: 10.36016/KhESG-2023-31-1-4

© 2023 M. O. FILATOV, I. P. LEZHENINA, V. L. MESHKOVA, N. Yu. POLCHANINOVA, S. V. STANKEVYCH

SOLITARY BEES — POLLINATORS OF SEED ALFALFA IN THE NORTH-EAST OF UKRAINE: CURRENT STATE AND USE IN POLLINATION

Філатов, М. О., Леженіна, І. П., Мєшкова, В. Л., Полчанінова, Н. Ю., Станкевич, С. В. Поодинокі бджоли — запилювачі насінної люцерни на північному сході України: сучасний стан і застосування на запиленні. *Вісті Харківського ентомологічного товариства*. 2023. Т. XXXI, вип. 1. С. 30–39. DOI: 10.36016/KhESG-2023-31-1-4.
Узагальнені дані стосовно видового складу запилювачів насінної люцерни, їхніх трофічних відносин, сезонної динаміки та впливу на насінну продуктивність люцерни. Серед 47 видів поодиноких бджіл з 15 родів 6 родин, виявлених на квітах насінної люцерни, 8 видів становили 87,9 % від усіх особин. Найвищу чисельність цих видів відзначено з другої декади червня до третьої декади липня включно, що збігається з періодом цвітіння жовтої люцерни після косіння на початку стадії бутонізації. Середній ступінь запилення квітів люцерни становив 25,4 %, що забезпечує фактичну врожайність насіння у виробничих умовах на рівні 7,6 ц/га.
1 рис., 3 табл., 57 назв.

Ключові слова: видове багатство, фенологія, ступінь запилення, урожай насіння.

Filatov, M. O., Lezhenina, I. P., Meshkova, V. L., Polchaninova, N. Yu., Stankevych, S. V. Solitary bees — pollinators of seed alfalfa in the north-east of Ukraine: current state and use in pollination. *The Kharkov Entomological Society Gazette* 2023. Vol. XXXI, iss. 1. P. 30–39. DOI: 10.36016/KhESG-2023-31-1-4.
The data on the species composition of seed alfalfa pollinators, their trophic links, seasonal dynamics, and influence on alfalfa seed productivity were generalized. Among 47 solitary bee species of 15 genera and 6 families, 8 species comprised 87.9% of all bees visiting alfalfa flowers. These species have the highest abundance from the second half of June to the third decade of July, which coincides with the yellow alfalfa flowering after moving at the beginning of the budding stage. The average degree of pollination of alfalfa flowers was 25.4%, which delivers an average of 7.6 centner/ha of actual seed yield in commercial crops. 1 fig., 3 tabs, 57 refs.
Keywords: species richness, phenology, pollination rate, seed yield.

Филатов, М. А., Леженина, И. П., Мешкова, В. Л., Полчанинова, Н. Ю., Станкевич, С. В. Одиночные пчелы — опылители семенной люцерны на северо-востоке Украины: современное состояние и использование на опылении. *Известия Харьковского энтомологического общества*. 2023. Т. XXXI, вып. 1. С. 30–39. DOI: 10.36016/KhESG-2023-31-1-4.
Обобщены данные относительно видового состава опылителей семенной люцерны, их трофических связей, сезонной динамики и влияния на семенную продуктивность люцерны. Среди 47 видов одиночных пчёл из 15 родов 6 семейств, обнаруженных на цветках семенной люцерны, 8 видов составляют 87,9 % всех особей. Наиболее высокая численность этих видов отмечается со второй декады июня до третьей декады июля включительно, что совпадает с периодом цветения жёлтой люцерны после кошения в начале фазы бутонизации. Средняя степень опыления цветов люцерны составляет 25,4 %, что обеспечивает фактическую урожайность семян в производственных условиях на уровне 7,6 ц/га. 1 рис., 3 табл., 57 назв.

Ключевые слова: видовое богатство, фенология, степень опыления, урожай семян.

I n t r o d u c t i o n . Successful farming requires deep knowledge of the underlying patterns. Ignoring one of these patterns, especially the one, on which the activity of the reproductive organs of plants depends, can lead to an unsatisfactory result, even if all other factors influencing the growth and development of plants are taken into consideration. Among these particular patterns are the state of pollinators and insect-pollinated agricultural plants (Ollerton, 2017; Kremen, 2018; Bänsch *et al.*, 2021). For example, in the USA, bees provide 11–15% of the gross agricultural product equal to 20 billion dollars annually (Morse, Calderon, 2000). Of this, at least 20% is provided by wild solitary bees, provided they have suitable nesting sites and an appropriate forage base in the blooming natural vegetation (Losey, Vaughan, 2006). Accordingly, as entomophilous crop acreage increases, so does the demand for pollinating services from agricultural producers (Calderone, 2012; Haedo *et al.*, 2022).

Filatov M. O. State Biotechnological University, 44, Alchevskikh str., 44, Kharkiv, 61002, Ukraine;
email: filatovhnau@gmail.com; ORCID: 0000-0003-2357-1853
Lezhenina I. P. State Biotechnological University, 44, Alchevskikh str., 44, Kharkiv, 61002, Ukraine;
email: iryna57lezhenina@gmail.com; ORCID: 0000-0001-8350-7496
Meshkova V. L. Ukrainian *Research Institute of Forestry and* Forest Melioration named after G. M. Vysotsky,
86, Pushkinska str., Kharkiv, 61024, Ukraine; e-mail: valentynameshkova@gmail.com, ORCID: 0000-0001-6483-2736
Polchaninova N. Yu. V. N. Karazin Kharkiv National University, Svobody sq., 4, Kharkiv, Ukraine, 61022;
e-mail: n.polchaninova@karazin.ua; ORCID: 0000-0003-4605-8788
Stankevych S. V. State Biotechnological University, 44, Alchevskikh str., 44, Kharkiv, 61002, Ukraine;
email: sergejstankevich1986@gmail.com; ORCID: 0000-0002-8300-2591

Received 27.04.2023 **Accepted 29.05.2023 by Dr. A. Shatrovskyi** **Published 30.06.2023**

Due to the decline in the abundance of honey bees and problems with their recovery (Aizen, Harder, 2009; Steinhauer *et al.*, 2014; Duchenne *et al.*, 2020), the role of wild solitary bees as the pollinators of many agricultural crops is increasing (Danforth *et al.*, 2019). The situation is particularly important for cross-pollinated crops, whose flowers are reluctant to be visited by honey bees due to their specific structure, such as red clover, seed alfalfa, etc. The area planted with these crops is limited by a great shortage of seeds and their very high price due to the low yields caused by the lack of pollination.

The discovery that the key pollinators of seed alfalfa are wild solitary bees stimulated extensive research on pollination and fertilization of alfalfa flowers, as well as identification of the species composition of pollinators, study of their biology, ecology, ways of protection, and rational use. In particular, detailed assessment of the pollinating capability of solitary bees and the species composition of the main alfalfa pollinators in the territory of the former USSR are given in the reviews (Popov, 1951, 1956; Ponomarev, 1975) and dissertations (Zavgorodnyaya, 1952; Panfilov, 1952; Rymashevskaya, 1952; Filatov, 1997). For example, 161 species were recorded on alfalfa flowers in Central Asia (Popov, 1956), 60 species in the steppe part of the Right-Bank Ukraine (Osychnyuk, 1959), and 61 species in the Lower Don region (Pesenko, 1974a, 1974b). Over 30 publications on the species composition of alfalfa pollinators are known for the forest-steppe of Left-Bank Ukraine (Rabinovich *et al.*, 1975; Zharinov, Osychnyuk, 1976; Zinchenko, Korbetskaya, 1980).

The species composition and abundance of alfalfa pollinators presented in the above-mentioned works are somewhat different. Differences can be observed within the same field, depending on the sowing time and methods, agricultural technology application, mowing, etc. Nevertheless, pollination is provided by 5–10 key species. Other pollinator species are represented by single individuals on crops. Within the forest-steppe of Ukraine, the most important and numerous species that actively pollinate flowers are *Rophitoides canus* (Eversmann, 1852), *Melitta leporina* (Panzer, 1799), *Andrena ovatula* (Kiby, 1802), *A. flavipes* Panzer, 1799, *Meliturga clavicornis* (Latreille, 1806), *Halictus simplex* Bluthgen, 1923, *H. eurygnathus* Bluthgen, 1931, *Megachile centuncularis* (Linnaeus, 1758), *M. leachella* Curtis, 1828, *Eucera clypeata* Erichson, 1835. These species make up 80–90% of specimens of all bee species visiting flowers of seed alfalfa. The abundance of honey bees (*Apis meliffera* Linnaeus, 1758) in alfalfa crops varies from 4 to 60% of all bees visiting the flowers (Popov, 1956; Pesenko, 1982). However, due to the low proportion of opened alfalfa flowers per day (24–35%), the honey bee is a worse pollinator of alfalfa than a solitary bee. For comparison: one *Melitta leporina* female pollinates 4,320 flowers per day (Zharinov, 1975; Bänsch *et al.*, 2021).

The low abundance of solitary bees and, accordingly, the level of pollination of alfalfa flowers are the main reasons for low seed yields. There is a strong relationship between the level of pollination and yield, which is characterized by a high correlation coefficient: $r = 0.75$. Mathematical calculations, as well as analysis of observations, show that to ensure a 100% level of pollination, about 15,000 females of the major pollinator species should be present per 1 ha (Zharinov, 1975).

Many publications are devoted to specific aspects of the biology of the major alfalfa pollinators: seasonal and diurnal dynamics, habitat confinement, trophic links, the influence of various agrotechnical practices and alfalfa cultivation technology on the species composition and abundance of alfalfa pollinators (Pesenko, 1972a; Ponomarev, 1975; Zharinov, 1980; Zinchenko, 1977; Mukhin, Badulin, Ostrovskii, 1980; Zinchenko, Korbetskaya, 1980; Radchenko, 1982; Chen, Zhao, Zuo, 2018; Renzi *et al.*, 2022).

In alfalfa seed production, two complementary approaches exist and are evolving to increase flower pollination and alfalfa seed yield.

The first (industrial) approach is based on the mass rearing of several pollinator species. It includes specialized bee farms with a complex of refrigerating chambers and incubators, equipment for nest block production, etc. This approach is successfully developing in the countries of North and South America, Western Europe, and Australia (Bohart, Knowlton, 1967; Hobbs, 1973; Bohart, Nye, 1976; Pits-Singer, Cane, 2011; Pits-Singer, 2013; Leonard, Harmon-Threatt, 2019; Haedo *et al.*, 2022; Mirwan, 2023).

In the former USSR, artificial rearing of seed alfalfa pollinators began in the 1970s (Grebennikov, 1973; Lubenets *et al.*, 1974). The development of industrial rearing was further developed after the purchase of the first batches of cocoons of the alfalfa leaf-cutting bee (*Megachile rotundata* Fabricius, 1793) and related equipment abroad in 1979. The number of publications on this problem increased (Zhuravlev, 1980; Semin, Burmistrov, 1981). However, in the USSR, industrial seed production did not go beyond field experiments and it was limited to a few thousand hectares by a few farms in Kyrgyzstan (Ganagin, 1988), the Krasnodar Krai (Burmistrov, 1982), and the Saratov Region of Russia (Dobrynin, 1984).

The second (agrotechnical) approach is aimed at increasing the number of natural populations of solitary bees in the agricultural landscape and using them for pollination. Elements of the agrotechnical approach were developed back in the 1940s–1950s (Konakov, 1940; Travin, 1947; Popov, 1951; Panfilov, 1952; Bohart, 1952; Killewald *et al.*, 2019; Christman, Shaw, Hodsdon, 2022). Due to the low development of artificial pollinator

rearing in the USSR, the main interest was in agrotechnical methods of increasing pollinator populations, as evidenced by a large number of special studies (Mukhin, 1977; Gramma *et al.*, 1976; Mukhin, Badulin, Ostrovskii, 1980).

Despite extensive research on the development and improvement of agrotechnical methods for increasing the number of pollinators and the pollination of seed alfalfa, some important issues have been poorly studied. One of these is the species and numeric composition of solitary alfalfa-pollinating bees in the agricultural landscape as a whole, and, thus, their potential as pollinators. A rigorous assessment of bee populations in secondary biotopes and some entomophilous crops was carried out at the Lower Don steppe (Pesenko, 1972a, 1972b, 1972c, 1974a, 1974b), in fallow fields of three typical farms in the steppe zone of Ukraine (Donetsk Region) (Radchenko, 1982), and in the forest-steppe of Northeastern Ukraine (Filatov, 1997).

From the late 1990s to the present, no research on pollinators and seed alfalfa pollination has been conducted in Ukraine. In the last 20–25 years, there have been significant changes in the land use regime and cultivation technology of all agricultural crops. Moreover, the level of agrochemical load has changed which could not but affect the bee species composition and abundance in the agricultural landscape, as well as their ability to provide a high level of pollination and seed alfalfa yield.

The **aim of this research** was to generalize the data on the species composition of seed alfalfa pollinators, their trophic links, seasonal dynamics, and influence on alfalfa seed productivity, and to suggest the main agrotechnical methods to increase it.

Materials and methods. The material was mainly collected from 1998 to 2021 in the Kharkiv and Dnipropetrovsk regions of Ukraine. The surveys were conducted in 23 agrarian landscape localities, similar in climatic, soil, and vegetative conditions. Stationary studies were carried out in three agricultural enterprises: APC 'Vostok' (Izium District, Kharkiv Region), LLC 'Borschahivske' (Balakliya District, Kharkiv Region), and PJS 'Agro-Soyuz' (Sinelnikove District, Dnipropetrovsk Region).

We investigated the following habitats, typical of the area in question: (1) fields of the seed alfalfa; (2) ravine and gully slopes, roadsides, field margins; (3) pastures; (4) hay fields.

Part of the material was collected by hand during excursions. Quantitative counts were made using the methods proposed by Pesenko (1972c): 16 to 20 10-minute counts in an area of 100×2 m in each habitat. Before each count, a short botanical description of the sampling plot was made, taking into account the ground cover and the number of flowering mellitophilous species. Totally, 164 counts were made in the natural and transformed habitats studied.

Trophic links of bees with the background species of mellitophilous vegetation of the agricultural landscape were analyzed according to Pesenko (1982). The relationship between the number of legume species and the main pollinators of alfalfa seed was evaluated using Pierson correlation coefficient *r*.

To study the dynamics of seed alfalfa pollination efficiency and its dependence on the bee species composition and abundance, we used a technique developed at the A. I. William Institute of Forage (Zhuravlev, 1980). In the evening, after 6 p. m., 100 clusters of alfalfa were collected from a 100×2 m sample plot. The total number of flowers that bloomed during the day and the number of pollinated flowers from them were counted. The pollination rate was evaluated according to the following formula:

$$y = \frac{a}{b} \times 100\%$$

where y — pollination rate, %;

a — number of pollinated flowers;

b — number of blossoming (pollinated and unpollinated) flowers.

To estimate the dependence of the seed yield on pollination rate, we evaluated the biological yield of seeds before mowing when 80–90% of the beans were browned, by threshing 10 sheaves of alfalfa taken randomly from ten $1m^2$-plots of the field.

Results and discussion. Species composition of the pollinators of seed alfalfa. During the research, we registered 47 solitary bee species belonging to 15 genera of 6 families on the seed alfalfa flowers. Forty species were represented by females and males or only by females, which opened alfalfa flowers and pollinated them. The other seven species did not take part in pollination. These are kleptoparasitic bees — three species of the genera *Coelioxys* and *Nomada*, whose females do not store pollen for their offspring, but visit opened flowers to feed on nectar. Males of *Halictus tumulorum* (Linnaeus, 1758) and *Anthidium manicatum* Linnaeus, 1758 also visited alfalfa flowers for nectar.

THE LIST OF SOLITARY BEES-POLLINATORS OF SEED ALFALFA IN THE STUDY AREA

Family Colletidae
Hylaeus communis Nylander, 1852;

Family Andrenidae
Andrena chrysopyga Schenck, 1853
A. dorsata Kirby, 1802
A. flavipes Panzer, 1799
A. labialis (Kirby, 1802)
A. ovatula (Kiby, 1802)
A. tibialis (Kirby, 1802)
A. variabilis Smith, 1853
A. wilkella (Kirby, 1802)
Melitturga clavicornis (Latreille, 1806)

Family Halictidae
Lasioglossum calceatum (Scopoli, 1763)
L. qriseolum (Morawitz, 1872)
L. interruptum (Panzer, 1798)
L. relativentre (Schenck, 1853)
L. malachurum (Kirby, 1802)
L. discum (Smith, 1853)
L. puncticolle (Morawitz, 1872)
L. villosulum (Kirby, 1802)
L. aeratum (Kirby, 1802)
L. xanthopus (Kirby, 1802)
Halictus rubicundus (Christ, 1791)
H. tetrazonius group (hardly identified by females)
H. quadricinctus (Fabricius, 1776)
H. maculatus Smith, 1848
Seladonia tumulorum (Linnaeus, 1758)
S. vestita (Lepeletier, 1841)
Rophitoides canus (Eversmann, 1852)
Nomiapis diversipes (Latreille, 1806)

Family Melittidae
Melitta leporina (Panzer, 1799)

Family Megachilidae
Anthidiun florentinum Fabricius, 1775
A. manicatum (Linnaeus, 1758)
A. punctatum Latreille, 1809
Osmia coerulescens Linnaeus, 1758
Megachile leachella Curtis,1828
M. centuncularis (Linnaeus, 1758)
M. rotundata Fabricius, 1793
Coelioxys inermis Kirby, 1802

Family Apidae
Anthophora plumipes (Pallas, 1772)
A. retusa Linnaeus, 1758
A. radoszkowskyi Fedtschenko, 1875
Eucera hungarica Friese, 1896
E. clypeata Erichson, 1835
E. interrupta Bar, 1859
E. longicornis Linnaeus, 1758
E. rufipes Smith, 1879
Nomada fulvicornis Fabricius, 1793
N. flavopicta Kirby, 1802

Using standard counting methods, 2,646 specimens of solitary bees were collected from alfalfa seed plants. Of these, 2,326 specimens belonged to the eight main species (*Rophitoides canus*, *Andrena ovatula*, *A. flavipes*, *A. dorsata*, *Melitturga clavicornis*, *Melitta leporina*, and species of the genus *Halictus* (*H. simplex* and *H. eurygnathus*), representing 87.9% of the total number of bees collected (Table 1).

Table 1. Abundance and trophic links of the key pollinators of seed alfalfa in the study area

Species	Trophic group	Number of specimens:		Part of the total bees, %
		total	females	
Rophitoides canus	oligolectic	651	475	24.6
Andrena ovatula	oligolectic	601	440	22.7
Melitta leporina	oligolectic	587	428	22.2
Halictus tetrazonius group	polylectic	193	143	7.3
Andrena flavipes	polylectic	90	68	3.4
Andrena labialis	polylectic	90	60	3.4
Andrena dorsata	polylectic	64	49	2.4
Melliturga clavicornis	oligolectic	50	35	1.9
Other 39 species	—	320	236	12.1
Total	—	2,646	1,934	100.0

On average, the most abundant species during the study period was *Rophitoides canus* (24.6%). In some years (2020, 2021), its abundance was lower than that of *Melitta leporina*. In general, our data on the species composition of seed alfalfa pollinators coincide with the results obtained in the nearby regions of Ukraine and the Russian Federation (Zharinov, 1975; Radchenko, 1982; Zinchenko, 1982; Filatov, 1997). Despite the changes in agricultural production in Ukraine over the past 20 years, as well as major climate changes associated with global warming, the species composition of the main alfalfa pollinators, and the ratio of individual species have not changed.

Ecological characteristics of the main pollinators of alfalfa. In trophic terms, half of the key pollinator species of seed alfalfa are represented by oligolects (Table 1) restricted to the family Leguminosae: *Rophitoides canus*, *Melitta leporina*, *Andrena ovatula*, and *Melitturga clavicornis*. The other species are polylects, equally successful in collecting pollen and nectar from plants of different families.

During the summer, seed alfalfa pollinators emerge and complete their activity at different dates (Fig. 1). Polylectic species of the genus *Andrena* appear the earliest: *A. flavipes* — 15.04. *A. dorsata* — 20.04. *A. ovatula* is an oligolect that appears in the second decade of May (12.05) when legumes begin to bloom *en masse* (*Vicia cracca* Linnaeus, 1753; *Robinia pseudoacacia* Linnaeus, 1753). The appearance of *Rophitoides canus* and *Melitta leporina* is associated with the beginning of the flowering of yellow alfalfa *Medicago falcata* Linnaeus, 1753; their greatest abundance is associated with the flowering peak of this plant. The bees with one generation per year have the shortest flight period. The end of activity of oligolectic *Melitturga clavicormis* is the first half of July and that of *Melitta leporina* and *Rophitoides canus* is the first half of August. The longest seasonal activity is characteristic of polylectic species of the genera *Andrena* and *Halictus*.

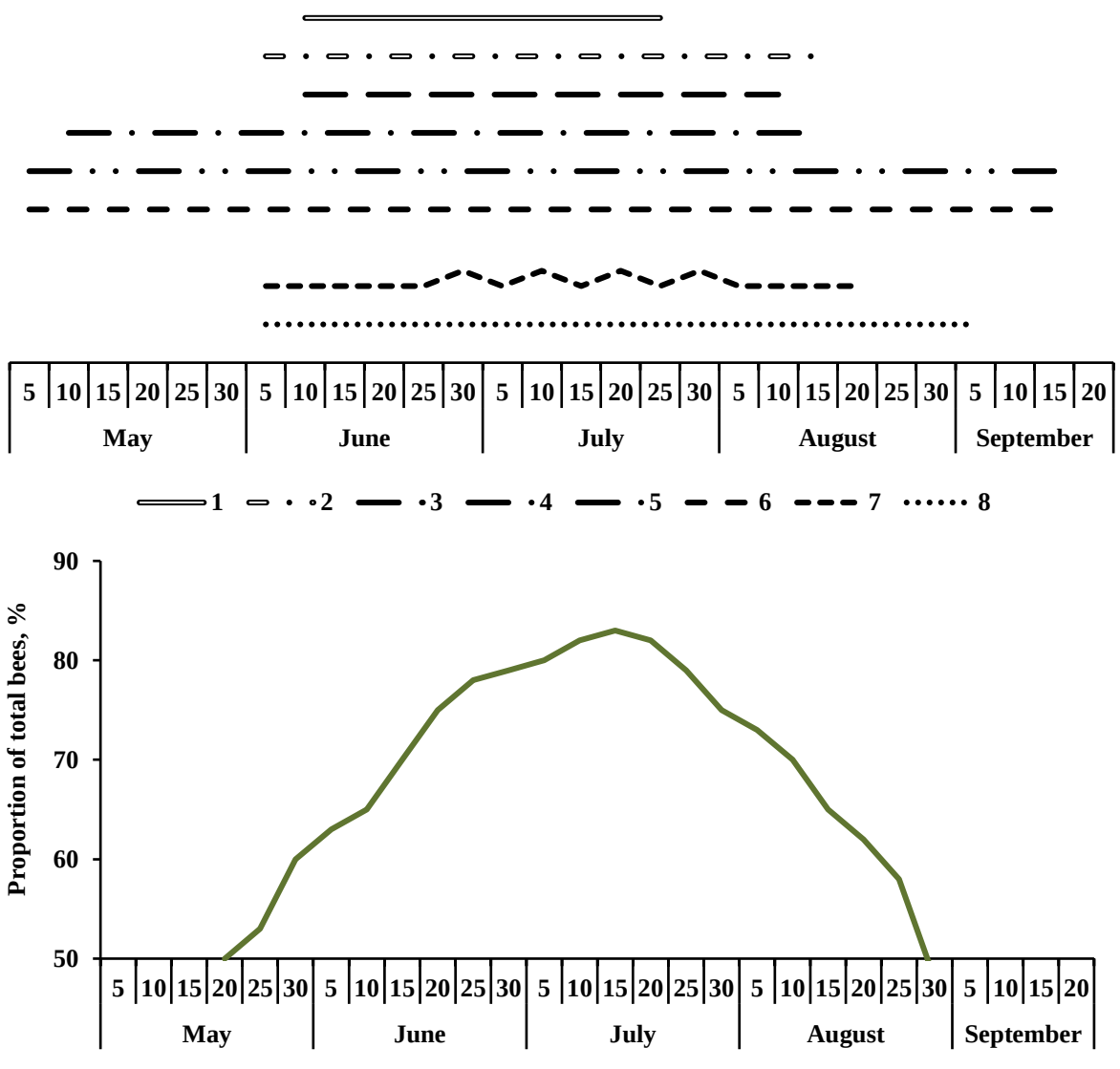


Fig. 1. Flight periods of main pollinators and alfalfa flowering (A); seasonal dynamics of relative abundance of the main alfalfa pollinators (B): 1–6 — flight periods of solitary bees: 1 — *Meliturga clavicornis*; 2 — *M. leporina*; 3 — *Rophitoides canus*; 4 — *Andrena ovatula*; 5 — *A. dorsata*; 6 — *A. flavipes*; 7–8 — alfalfa flowering; 7 — *Medicago sativa*; 8 — *M. falcata*. Three periods of alfalfa flowering are marked: without a cut, cut at the beginning of the budding stage, and cut after the end of the budding stage.

The comparison of the flight periods and individual abundance of the main pollinators with the flowering periods of seed alfalfa of different cuts shows that the maximum abundance of the main pollinators falls in the period from the second half of June to the third decade of July coinciding with the flowering of yellow alfalfa. This is also the flowering period of alfalfa after the cut at the beginning of the budding stage. The peak of pollinator activity lasts from the end of the pre-budding period to the beginning of the post-budding time.

The main pollinator bee species, *Andrena dorsata*, *A. flavipes*, *A. labialis*, and two species of the genus *Halictus*, are polylects and account for 16.5% of the number of all pollinators (Table 1). They appear in early spring long before alfalfa blossoms, and complete their flight period after alfalfa blossoms (Fig. 1). Their number in the agrarian landscape is in no way related to the presence of seed alfalfa or other legumes. Oligolect pollinators *Rophitoides canus*, *Andrena ovatula*, *Melitta leporina*, and *Melliturga clavicornis* (71.4% of all pollinators) collect pollen and nectar only from plants of the Leguminosae family. The presence of wild leguminous plants and their abundance determine the abundance and distribution of oligolectic pollinators in agrarian landscapes. Summarized data on bee abundance and its dependence on wild legumes is presented in Table 2.

Table 2. Species richness and abundance of solitary bees at different species richness of wild legumes (the average number per count)

Legume species	Bee species	Bee individuals:	
		total	alfalfa pollinators
3.9 ± 0.9	7.0 ± 2.1	17.3 ± 5.2	8.3 ± 3.1
2.7 ± 0.5	11.2 ± 3.3	18.3 ± 6.1	7.3 ± 2.7
2.5 ± 0.5	5.3 ± 1.9	12.8 ± 3.4	4.5 ± 1.8
1.0 ± 0.3	3.6 ± 0.9	7.2 ± 2.6	2.2 ± 0.8

Alfalfa is pollinated mainly by oligolectic bee species, whose abundance depends on the presence of leguminous plants, such as *Medicago falcata* Linnaeus, 1753; *Lotus corniculatus* Linnaeus, 1753; *Melilotus officinalis* (Linnaeus) Lam., 1779; *Coronilla varia* (Linnaeus) Lassen, 1989 (Table 2).

In the study area, a high dependence of alfalfa pollinator abundance on legume species richness was found (r = 0.93). In agricultural crops (sunflower, horticultural crops), which are mainly pollinated by polylectic species, there was no significant correlation between plant diversity and bee abundance (r = 0.18).

Pollination rate and yield of seed alfalfa. Analysis of the available publications and our own experimental data gives us the possibility to identify the main agricultural practices that can provide the increase of pollination rate of alfalfa flowers.

1. Plant alfalfa seed crops near places of natural concentration of solitary bees in the agricultural landscape (agricultural inconvenience).

2. Limit field sizes to 25 hectares.

3. Ensure the contour of the seed alfalfa field in maximum contact with the places of natural concentration of bees in the agricultural landscape.

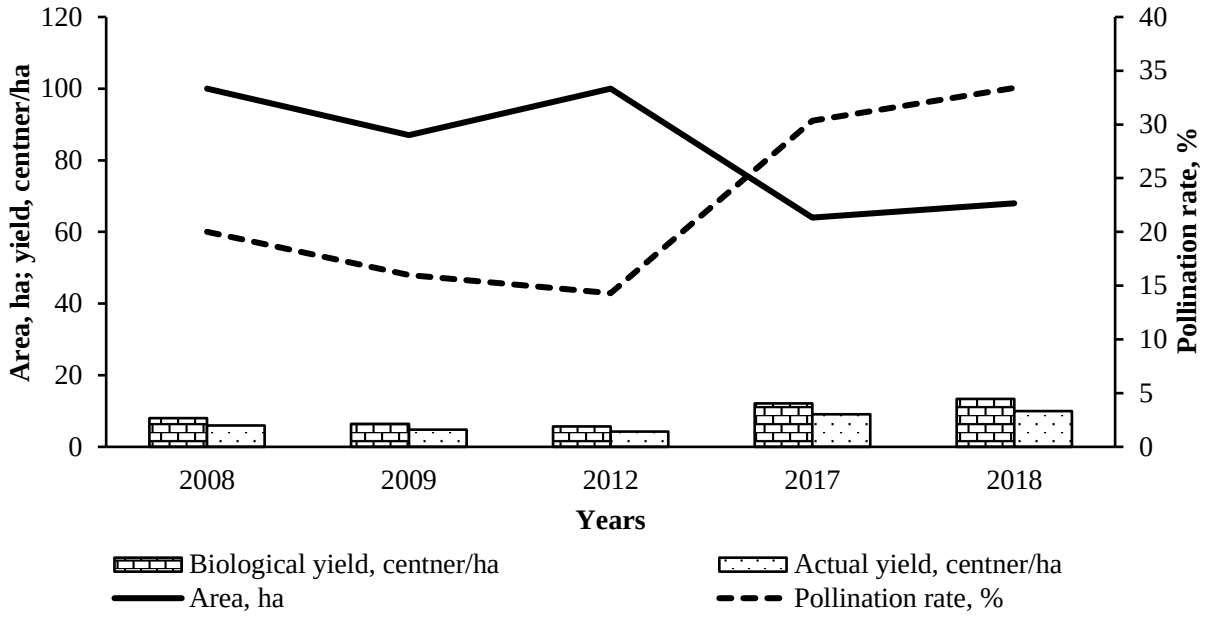
4. Use additional mowing to synchronize the maximum alfalfa flowering with the maximum flight of its main pollinators. (In our conditions, at the beginning of the budding start).

5. Create a mellitophilous ‘flowering conveyor’ that provides alfalfa pollinators with food during the period when alfalfa does not bloom.

6. Protect natural habitats for bee concentration in the agricultural landscape, and create micro-reserves.

7. Attract pollinators to alfalfa seed plants using artificial bait nests.

The joint effect of all existing techniques and their combinations were tested during the contractual and consulting work in 2008–2018 in the APC ‘Vostok’, LLC ‘Borschahivske’, and PJS ‘Agro-Soyuz’ (Fig. 2). The average pollination level in the given fields for all cuts was 25.4%. The average biological yield was 10.1 centner/ha or 1% of the pollination level giving us an average of 10.1 ÷ 25.4 = 0.39 centner/ha. The average actual yield was 7.6 centner/ha. The difference between the average biological yield and the average actual yield is caused by losses during the harvesting of seed alfalfa by a combine and subsequent cleaning of the collected heap. That is, in real production conditions, 1% of the pollination rate of alfalfa flowers gives 0.3 centner of seeds per 1 hectare after harvesting and final cleaning: (17% of 7.6 centner/ha = 0.3 centner/ha) instead of 0.39 centner/ha before harvesting. An analysis of the species and individual composition of solitary bees showed that currently the main pollinators of seed alfalfa are among the most widespread species in the agricultural landscape and are capable of providing an average pollination rate of 25.4% and a yield of 7.6 centner/ha. The total losses during the harvesting and cleaning of seeds, on average, amounted to 2.5 centner/ha (24.7%). This is three times less (71.2%) losses that were in the seed farms of Ukraine until the 1990s (Filatov, 1997).



F i g . 2 . Seed alfalfa yield and the pollination rate in different years.

C o n c l u s i o n s . 1. During the research, we registered 47 solitary bee species of 15 genera of 6 families on the flowers of seed alfalfa.

2. The proportion of eight main species — *Rophitoides canus*, *Andrena ovatula*, *A. flavipes*, *A. dorsata*, *Melitturga clavicornis*, *Melitta leporina*, and a group of species of the genus *Halictus* (*H. simplex* and *H. eurygnathus*) indistinguishable by females, comprise 87.9% of all bees visited the flowers of seed alfalfa.

3. Half of the main alfalfa-pollinating bee species are oligolectic, associated with plants of the legume family.

4. The main pollinators of seed alfalfa reach maximum abundance in the period from the second half of June to the third decade of July which coincides with the yellow alfalfa flowering after the cut at the beginning of the budding stage.

5. In the study area, the number of alfalfa pollinators was highly dependent on the species richness of wild legumes in the agricultural landscape near the seed alfalfa fields (r = 0.93).

6. The average pollination rate of alfalfa flowers during the study period was 25.4%, resulting in an average biological yield of 10.1 centner/ha, or 1% of the pollination rate provided, an average of 0.39 centner/ha of alfalfa seeds.

7. The average actual yield was 7.6 centner/ha, or under actual production conditions, 1% of the pollination rate of alfalfa flowers gives 0.3 centner of seeds per 1 hectare after harvesting and final cleaning.

8. On average, the total losses during harvesting and seed cleaning in our practice amounted to 2.5 centner/ha (24.7%), which is three times (71.2%) less than the losses in the seed farms of Ukraine until the 1990s.

R E F E R E N C E S

Aizen, M. A, Harder L. D. 2009. The global stock of domesticated honey bees is growing slower than agricultural demand for pollination. *Current Biology*, **19**(11), 915–918. DOI: https://doi.org/10.1016/j.cub.2009.03.071.

Bänsch, S., Tscharntke, T., Gabriel, D., Westphal, C. 2021. Crop pollination services: Complementary resource use by social vs solitary bees facing crops with contrasting flower supply. *Journal of Applied Ecology*, **58**(3), 476–485. DOI: https://doi.org/10.1111/1365-2664.13777.

Bohart, G. E. 1952. Pollination by native insects. In: United States Department of Agrculture. *Insects: Yearbook of Agriculture*. U. S. G. P. O., Washington, D. C., 107–121. URL: https://archive.org/details/insectsyearbooko00unit/page/106/mode/2up.

Bohart, G. E., Knowlton, G. F. 1967. Managing the alfalfa leaf-cutting bee for higher alfalfa seed yields. *Utah State University Extension Service Leaflet*, **104**. 1–8. URL: https://digitalcommons.usu.edu/piru_pubs/89.

Bohart, G. E., Nye, W. P. 1976. Insect pollinators of alfalfa grown for seed. In: Davis, D. V., ed. Insects and nematodes associated with alfalfa in Utah. *Utah Agricultural Experiment Station Bulletin*, 494, 33–45. URL: https://digitalcommons.usu.edu/piru_pubs/288.

Burmistrov, F. N. 1982. Research on bee pollination in USSR [Научные исследования по пчелоопылению в СССР]. *Bee pollination of entomophilous cultures and honey base of beekeeping* [*Пчелоопыление энтомофильных культур и медоносная база пчеловодства*]. Apimondia, Bucharest, 60–63. [in Russian].

Calderone, N. W. 2012. Insect pollinated crops, insect pollinators and US agriculture: Trend analysis of aggregate data for the period 1992–2009. *PLoS One*, **7**(5), e37235. DOI: https://doi.org/10.1371/journal.pone.0037235.

Chen, M., Zhao, X. Y., Zuo, X. A. 2018. Pollinator activity and pollination success of *Medicago sativa* L. in a natural and a managed population. *Ecology and Evolution*, **8**(17), 9007–9016. DOI: https://doi.org/10.1002/ece3.4256.

Christman, K., Shaw, R., Hodsdon, L. 2022. The Bee Brick: Building habitat for solitary bees. *International Journal of Sustainable Design*, **4**(3–4), 285–304. https://doi.org/10.1504/IJSDES.2022.128532.

Danforth, B., Minckley, R., Neff, J., Fawcett, F. 2019. *The Solitary Bees: Biology, Evolution, Conservation*. Princeton University Press, Princeton, 1–488. DOI: https://doi.org/10.1515/9780691189321.

Dobrynin, N. D. 1984. Propagation of *Megachile rotundata* F. for pollination of alfalfa in the Central-Chernozem zone [Разведение пчёл-листорезов *Megachile rotundata* F. для опыления люцерны в Центральном Черноземье]. *9th Congress of the All-Union Entomological Society* (Kiev, October 1984): abstracts [*9-й съезд Всесоюзного энтомологического общества* (Киев, октябрь 1984 г.): тезисы докладов. Naukova dumka, Kiev, **1**, 144. [in Russian].

Duchenne, F, Thébault, E, Michez, D. M., Elias, M, Drake, M, Persson, M, Rousseau-Piot, J. S., Pollet, M, Vanormelingen, P, Fontain, C. 2020. Phenological shifts alter the seasonal structure of pollinator assemblages in Europe. *Nature Ecology and Evolution*. **4**(1), 115–121. DOI: https://doi.org/10.1038/s41559-019-1062-4.

Filatov, M. O. 1997. *Solitary bees (Hymenoptera, Apoidea) of the agricultural landscape of northeastern Ukraine: fauna, ecology and practical importance* [*Поодинокі бджолині (Hymenoptera, Apoidea) агроландшафту північного сходу України: фауна, екологія та практичне значення*]. The dissertation thesis for the scientific degree of the candidate of biological sciences. Kharkiv State Pedagogical University, Kharkiv, 1–20. [in Ukrainian].

Ganagin, A. V. 1988. Some aspects of use of *Megachile rotundata* F. in Kirghizia [Некоторые аспекты технологии использования пчелы-листореза (*Megachile rotundata* F.) в Киргизии]. *Entomological Researches in Kirghizia [Энтомологические исследования в Киргизии]*, Ilim, Frunze, **19**, 103–109. [in Russian].

Gramma, V. N., Zagovora, A. V., Beletskiy, E. N., Kirilenko, V. A., Bartenev, A. F., Gritsay, V. P. 1976. *Methodical Recommendations for Increase in Abundance of Wild Bee Pollinators of Alfalfa [Методические рекомендации по увеличению численности диких пчёл-опылителей люцерны]*, Ukrainian Research Institute for Plant Growing, Genetics, and Selection, Kharkov, 1–21. [in Russian].

Grebennikov V. S. 1973. Sectional shelters of trap-nests for solitary bees [Разъёмные гнездоблоки для одиночных пчёл]. *Beekeeping* [*Пчеловодство*], **9**, 39–41. [in Russian].

Haedo, J. P., Martínez, L. C., Graffigna, S., Marrero, H. J., Torretta, J. P. 2022. Managed and wild bees contribute to alfalfa (*Medicago sativa*) pollination. *Agriculture, Ecosystems & Environment*, **324**, 107711. https://doi.org/10.1016/j.agee.2021.107711.

Hobbs, G. A. 1973. Alfalfa leaf-cutter bees for pollinating alfalfa in Western Canada. *Publication Canada Department of Agriculture*, **1495**, 1–30.

Killewald, M. F., Rowe, L. M., Graham, K. K., Wood, T. J., Isaacs, R. 2019. Use of nest and pollen resources by leafcutter bees, genus Megachile (Hymenoptera: Megachilidae) in central Michigan. *The Great Lakes Entomologist*, **52**(1), 8. DOI: https://doi.org/10.22543/0090-0222.2338.

Konakov, N. N. 1940. Works directed to the increase in the diversity and abundance of pollinators of fodder plants [Работы по расширению и улучшению контингента опылителей кормовых растений]. *The Voronezh Scientific Conference on the Study and Development of Productive Forces in the Region*: abstracts *[Воронежская научная конференция по изучению и развитию производительных сил в области*: тезисы докладов*]*, Voronezh, 118–119. [in Russian].

Kremen, C. 2018. The value of pollinator species diversity. *Science*, **359**(6377), 741–742. DOI: https://doi.org/10.1126/science.aar7614.

Leonard, R. J., Harmon-Threatt, A. N. 2019. Methods for rearing ground-nesting bees under laboratory conditions. *Apidologie*, **50**(5), 689–703. DOI: https://doi.org/10.1007/s13592-019-00679-8.

Losey, J. E, Vaughan, M. 2006. The economic value of ecological services provided by insects. *Bioscience*, **56**(4), 311–323. DOI: https://doi.org/10.1641/0006-3568(2006)56[311:TEVOES]2.0.CO;2.

Lubenets, P. A., Ivanov, A. I., Pesenko, Yu. A., Osytshnjuk, A. Z. 1974. *Guidelines for the Breeding of Leafcutter Bees (Megachile rotundata) and Their Use to Pollinate Alfalfa [Методические указания по разведению пчелы-листореза (Megachile rotundata) и использование её для опыления семенников люцерны]*. All-Union Research Institute of Plant Growing, Leningrad, 1–33. [in Russian].

Mirwan, H. B. 2023. Nesting traps to collect solitary cavity-nesting Hymenoptera. *Al-Mukhtar Journal of Sciences*, **38**(2), 160–172. DOI: https://doi.org/10.54172/mjsc.v38i2.1247.

Morse, R. A, Calderone, N. W. 2000. The value of honey bees as pollinators of U.S. crops in 2000. *Bee Culture*, **128**(3), 1–15.

Mukhin, Yu. P. 1977. Bees of forest-shelter belts, their conservation and attraction [Пчелиные полезащитных насаждений, их охрана и привлечение]. *State and Conservation of Biological Resources in Volgograd Region*: abstracts of the Inter-Departmental Scientific-Practical Conference *[Состояние и охрана биологических ресурсов Волгоградской области*: тезисы докладов межотраслевой научно-практической конференции*]*, Volgograd State Pedagogical Institute, Volgograd, 54–56. [in Russian].

Mukhin, Yu. P., Badulin, A. V., Ostrovskii, F. N. 1980. *Recommendations for the protection, attraction and resettlement of wild bees-pollinators of seed alfalfa in collective farms and state farms of Volgograd Region [Рекомендации по охране, привлечению и расселению диких пчелиных-опылителей семенной люцерны в колхозах и совхозах Волгоградской области]*. Volgograd, 1–20. [in Russian].

Ollerton, J. 2017. Pollinator diversity: Distribution, ecological function, and conservation. *Annual Review of Ecology, Evolution, and Systematics*, **48**(1), 353–376. DOI: https://doi.org/10.1146/annurev-ecolsys-110316-022919.

Osychnyuk, G. Z. 1959. *The Bees (Apoidea) of the Right-Bank Steppe of the Ukraine* [*Бджолині (Apoidea) правобережного степу України*]. Publishing of the Academy of Sciences of the Ukrainian SSR, Kyiv, 1–92. [in Ukrainian].

Panfilov, D. V. 1952. *Insect Pollinators of Alfalfa in the Stalingrad Province* [*Насекомые-опылители люцерны Сталинградской области*]. The dissertation thesis for the scientific degree of the candidate of biological sciences. Moscow State University, Moscow, 1–13. URL: https://search.rsl.ru/ru/record/01005858834. [in Russian].

Pesenko, Yu. A. 1972a. *Bees (Hymenoptera, Apoidea) of the Lower Don basin (fauna, trophic links, biocenology)* [*Пчелиные (Hymenoptera, Apoidea) Нижнего Дона (фауна, трофические связи, биоценология)*]. The dissertation thesis for the scientific degree of the candidate of biological sciences. Zoological Institute of the Academy of Sciences of the USSR, Leningrad, 1–22. URL: https://search.rsl.ru/ru/record/01007322269. [In Russian].

Pesenko, Yu. A. 1972b. Contributions to the fauna and ecology of bees (Hymenoptera, Apoidea) in the Lower Don basin. Report 3. Phenology and trophic links of the Andrenidae [Материалы по фауне и экологии пчелиных (Apoidea) Нижнего Дона. Сообщение 3. Фенология и трофические связи Andredidae]. *Zoological Journal [Зоологический журнал]*, **51**(8), 1196–1200. [in Russian].

Pesenko, Yu. A. 1972c. On methods of quantitative counts of insect pollinators [К методике количественных учётов насекомых-опылителей]. *Ekologiya [Экология]*, **1**, 89–95. [in Russian].

Pesenko, Yu. A. 1974a. Contributions to the fauna and ecology of bees (Hymenoptera, Apoidea) in the Lower Don basin. Report 5. The biotopic distribution and formation of wild bee populations in secondary (suburb) biocoenoses [Материалы по фауне и экологии Нижнего Дона (Hymenoptera, Apoidea). Сообщение 5. Стациальное распределение и формирование населения пчелиных вторичных стаций]. *Zoological Journal [Зоологический журнал]*, **53**(6), 882–887 [in Russian].

Pesenko, Yu. A. 1974b. Pollination of entomophilous plants by bees (Hymenoptera, Apoidea) in the Lower Don and a discussion of their possible significance in speciation of the angiosperms [Опыление энтомофильной растительности пчелиными (Hymenoptera, Apoidea) на Нижнем Дону и обсуждение их возможной роли в видообразовании цветковых растений]. *Reports in the 26th Annual Readings to the Memory of Prof. N. A. Kholodkovskiy, Leningrad, 6 April 1973 [Доклады на 26-м ежегодном чтении памяти Н. А. Холодковского, Ленинград, 6 апреля 1973 г.]*. Nauka, Leningrad, 3–48. [in Russian].

Pesenko, Yu. A. 1982. *Principles and Methods of Quantitative Analysis in Faunal Researches* [*Принципы и методы количественного анализа в фаунистических исследованиях*]. Nauka, Moscow. 1–287. [in Russian].

Pits-Singer, T. L. 2013. Intended release and actual retention of alfalfa leafcutting bees (Hymenoptera: Megachilidae) for pollination in commercial alfalfa seed fields. *Journal of Economic Entomology*, **106(**2), 576–586. DOI: https://doi.org/10.1603/ec12416.

Pits-Singer, T. L., Cane, J. H. 2011. The Alfalfa leafcutting bee, *Megachile rotundata*: The world's most intensively managed solitary bee. *Annual Review of Entomology*, **56**, 221–237. DOI: https://doi.org/10.1146/annurev-ento-120709-144836.

Ponomarev, A. N. 1975. The ecology of pollination of alfalfa (*Medicago sativa* L.) by insects [Экология энтомофильного опыления посевной люцерны (*Medicago sativa* L.)]. *Pollination Ecology [Экология опыления]*. Perm State University, Perm, **1**, 5–36. [in Russian].

Popov, V. B. 1951. On the role of bees (Hymenoptera, Apoidea) in lucerne pollination [О значении пчелиных (Hymenoptera, Apoidea) в опылении люцерны]. *Proceeding of All-Union Entomological Society [Труды Всесоюзного энтомологического общества]*, **43**, 65–82. [in Russian].

Popov, V. B. 1956. The bees, their associations with angiosperm plants and the problem of alfalfa pollination [Пчелиные, их связи с цветковой растительностью и вопрос об опылении люцерны]. *Entomological Review [Энтомологическое обозрение]*, **35**(3), 582–598. [in Russian].

Rabinovich, V. M., Kiselev, A. N., Zharinov, V. I., Shuplik, P. P., Pipko, A. S., Radchenko, V. G., Kalmykov, V. R., Ivanov, S. P. 1975. *A Complex of Measures for Alfalfa Growing* [*Комплекс мероприятий по выращиванию люцерны*]. Prapor, Kharkov, 1–24. [in Russian].

Radchenko, V. G. 1982. A method for the accumulation and maintenance of abundance of alfalfa pollinators at the nature conditions [Методика накопления и поддержания численности опылителей люцерны в естественных условиях]. *Insect Pollinators of Agricultural Plants [Насекомые-опылители сельскохозяйственных культур]*. Siberian Branch of the V. I. Lenin All-Union Academy of Agricultural Sciences, Novosibirsk, 132–135. [in Russian].

Renzi, J. P., Coito, C., Reinoso, O., Quintana, M., García, F., Cantamutto, M. A. 2022. *Megachile rotundata* (Fab.) as a potential agro-environmental conservation strategy for alfalfa seed production in Argentina. *Journal of Applied Entomology*, **146**(1–2), 44–55. DOI: https://doi.org/10.1111/jen.12953.

Rymashevskaya R. S. 1952. *The role of bees (Apidea) in alfalfa pollination in Alma-Ata Region* [*Роль пчелиных (Apidea) в опылении люцерны в Алма-Атинской области*]. The dissertation thesis for the scientific degree of the candidate of biological sciences. Alma-Ata. 1–12. [in Russian].

Semin, A. S., Burmistrov, A. N. 1981. The pollination of alfalfa by leaf-cutter bees in Canada [Опыление люцерны пчёлами-листорезами в Канаде]. *Beekeeping [Пчеловодство]*, **1**(2), 62–63. [in Russian].

Steinhauer, N. A., Rennich, K., Wilson, M. E., Caron, D. M., Lengerich, E. J., Pettis, J. S., Robyn, R., Skinner, J. A., Tarpy, D. R., Wilkes J. T., van Engelsdorp, D. 2014. A national survey of managed honey bee 2012–2013 annual colony losses in the USA: Results from the Bee Informed Partnership. *Journal of Apicultural Research*, **53**(1), 1–18. DOI: https://doi.org/10.3896/IBRA.1.53.1.01.

Travin, I. S., 1947. *Seed Production of Perennial Grasses [Семеноводство многолетних трав]*. OGIS-SelkhozGIZ, Moscow, 1–264. [in Russian].

Zavgorodnaya, V. K. 1952. *Bees (Hymenoptera, Apoidea) and Their Role in Alfalfa Pollination under Conditions of Grassland Agriculture [Пчелиные (Hymenoptera, Apoidea) и их роль в опылении люцерны в условиях травопольной системы земледелия]*. The dissertation thesis for the scientific degree of the candidate of biological sciences. Voronezh State University, Voronezh, 1–12. [in Russian].

Zharinov, V. I. 1975. The fauna of alfalfa pollinators in the forest-steppe of the Ukrainian SSR [Видовой состав опылителей люцерны в Лесостепи УССР]. *Proceeding of the Kharkov Agricultural Institute [Труды Харьковского сельскохозяйственного института]*, **206**, 87–91. [in Russian].

Zharinov, V. I. 1980. *A System of Means for Reservation of Pollinators and Increasing Their Populations in Seed Alfalfa Plantations [Система мероприятий по сохранению и увеличению опылителей семенных посевов люцерны]*. V. I. Lenin All-Union Academy of Agricultural Sciences, Moscow, 1–46. [in Russian].

Zharinov, V. I., Osychnyuk, A. Z. 1976. Medick pollinators in the forest-steppe of the Left-Bank Ukraine [Опылители люцерны в лесостепи Левобережной Украины]. *Vestnik Zoologii [Вестник зоологии]*, **2**, 6–9. URL: http://mail.izan.kiev.ua/vz-pdf/1976/2/VZ%201976-2-02-Zharinov.pdf. [in Russian].

Zhuravlev, A. A. 1980. *Methodical Instructions for Pollination of Seed Alfalfa Plantations by Wild Bees and Honey Bees* [*Методические указания по опылению семенных посевов люцерны дикими одиночными и медоносными пчёлами*]. V. I. Lenin All-Union Academy of Agricultural Sciences, Moscow, 1–30. [in Russian].

Zinchenko, B. S. 1977. Pathways for rational use of pollinators in plantations of seed alfalfa [Пути рационального использования опылителей на семенниках люцерны]. *Selection and Seed Growing [Селекция и семеноводство]*, **37**, 72–76. [in Russian].

Zinchenko, B. S. 1982. On the fauna, attraction and management of alfalfa pollinators in the forest-steppe of the Ukraine [О видовом составе, привлечении и размножении опылителей люцерны в Лесостепи УССР]. *Insect Pollinators of Agricultural Plants [Насекомые-опылители сельскохозяйственных культур]*. Siberian Branch of the V. I. Lenin All-Union Academy of Agricultural Sciences, Novosibirsk, 129–132. [in Russian].

Zinchenko, B. S., Korbetskaya, L. A. 1980. Wild pollinators of seed alfalfa [Дикие опылители посевной люцерны]. *Beekeeping [Пчеловодство]*, **6**, 18–19. [in Russian].

Ukrainian Research Institute of Forestry and Forest Melioration named after G. M Vysotsky,
State Biotechnological University,
V. N. Karazin Kharkiv National University