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RESEARCH ARTICLE

Legumes used for degraded haylands and pastures recultivation: initial stages of introduction

T.V. Kornievskaya[1], M.M. Silanteva[1]

[1]*Altai State University, pr. Lenina 61, Barnaul, 656049, Russia. E-mail: galtsovatw@yandex.ru*
[1]*Altai State University, pr. Lenina 61, Barnaul, 656049, Russia. E-mail: msilan@mail.ru*
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The article considers the six-year results of work on the introduction of legume herbs *Astragalus cicer, A. sulcatus, A. onobrychis* in the Kulunda dry steppe conditions. A comparative assessment of the success in the astragalus introduction was carried out. We identified the species that are prospective for introduction. The possibility of using astragali for the recultivation of haylands and pastures in the dry steppe area was evaluated.
Keywords: Introduction; recultivation; haylands and pastures; degradation; legumes; astragalus

One of the ways to restore disturbed and low-productive grasslands of the Russian steppe zone is biological recultivation using an assortment of forage grasses, resistant to drought, salinization, high soil density, soil trampling, and capable of producing aftergrowth within one growing season.
The European experience of creating and improving pastures in order to increase the production of meat and dairy products and to meet the growing world needs of the population has shown the enormous potential of legumes (Lüscher et al., 2014). Legumes contribute to the solution of some important problems in livestock sector: they replace inorganic nitrogen fertilizers with symbiotic fixation of atmospheric nitrogen, rise crop yields and increase the nutritional value of feed, and contribute to the effective transformation of the plant protein into the animal protein (Thornton, 2010).
In many phytocenoses of the Kulunda steppe, the growing conditions for legumes are quite favorable, but the legume species diversity is insignificant, since due to the existing forms of the steppe agricultural use (grazing, mowing) they are almost or not at all disseminated, and the seeds are brought in from the outside.
It is worth noting that the raw phytomass of some legumes contains proteinase inhibitors, alkaloids and tannins, which reduce the nutritional value of feed. These chemical compounds interfere with protein digestion, cause tympanites and poisoning of ruminants. Therefore, the study of the legume species assortment, prospective in terms of the steppe ecosystems restoration and the use of the Altai krai steppes in the agroindustrial complex is an important application.
One of the most prospective for the restoration of the perennial grasses food supply is the *Astragalus* L. genus. The primary speciation center of the Astragalus genus is concentrated in the Ancient Mediterranean flora, where the largest number of species grows (Ischenko, 1981). The astragalus is an extremely polymorphic genus with a large genotypic diversity and a wide ecological amplitude, which allows the genus to dwell in a variety of natural environmental conditions.
The species of the *Astragalus* genus combine valuable agricultural characteristics: high protein content and a wide range of amino acids in the aboveground phytomass, the absence of the substances harmful to animals in the aboveground parts, high crop yield and the highest percentage of the shoots leaf coverage (in comparison with other forage crops, such as *Medicago falcata* L.), drought and heat resistance, frost and winter hardiness (Johnston et al., 1975; Peterson et al., 1992; Loeppky et al., 1996). All these advantages allow us to consider astragali as a source material for creating new high-protein forage crops.

Materials and methods

The climate of the Kulunda steppe is sharply continental, characterized by cold winters with little snow and hot dry summers. The average monthly air temperature is + 3,7° C, the minimum winter temperature is –41,3° C, and the maximum summer temperature is +38° C. The average snow cover depth is 12,7 cm. The annual precipitation does not exceed 240–360 mm. Precipitation is distributed irregularly. In spring, its number does not exceed 20% of the annual amount. The high air temperature leads to its rapid evaporation; therefore, they have no effect on soil moistening. In July, up to 30% of the annual precipitation, mostly of heavy rain character, falls. The Kulunda steppe is characterized by strong winds, bringing dry air masses from the steppes and deserts of Kazakhstan, which has a drying effect on the atmosphere and soil. In spring, the wind speed can reach 15–40 m/s, causing the upper horizon to dry out, which leads to the "dust storm syndrome" (Paramonov et al., 2003).

The territory of the Kulunda steppe is characterized by the flatness of the relief with numerous depressions in the form of salt and fresh lakes. Soils are predominantly chestnut of light texture, characterized by an insignificant thickness of the humus horizon (20–30 cm).

In order to conduct the research on the recultivation of low yield steppe phytocenoses in the surroundings of the Poluyamki village (Mikhailovsky district),we selected two pastures at different stages of pasture degradation – the beginning of the digression (wormwood stage) and the stage of intensified grazing (fescue stage).

The studies were conducted on specially fenced sites of 100 m2 in size; half of the site is natural grass stand, while another half has plots of seeded astragalus embedded in the turf. We used seeds obtained from the introduction site in the Poluyamki village in the experiments.

The introduction site performs several tasks: it is used as a nursery for seeds of forage plants, as well as for the detailed biomorphological observations of species, assessment of their introduction success and identification of promising species (Silanteva et al., 2015; Kornievskaya, Silanteva, 2017).

The introduction success was assessed by the method of R.A. Karpinosova (1978) during six years of plant life from 2013 to 2018. The comparative assessment was carried out according to the following criteria: generative development, vegetative reproduction, preservation of habitus in cultivation, survival rate during unfavorable seasons. Assessment of the seed productivity elements was carried out according to the generally accepted technique by I.V. Vaynagyy (1974).

The S.S. Kharkevich coefficient of seminification, which is the most important criterion for the introduced species assessment, reflecting the ratio of real to potential seed productivity, was calculated.

Three species were studied: *Astragalus cicer, A. sulcatus, A. onobrychis*.

Results and their discussion

***Astragalus cicer* L. (= syn. *A. mucronatus* DC.) cicer milk vetch** is a widespread Euro-Caucasian-Ural species; the area stretches from the Atlantic Ocean to the Urals (Heideman, 1954; Takhtajan, 1972). It is an adventitious species in Altai krai. It is an escapee from the experimental fields of the Altai Research Institute of Agriculture. It is found in the outskirts of Barnaul and Nauchniy Gorodok (Silanteva, 2013).

Generative development determining seed reproduction

Astragalus cicer L. plants bloom massively from the second summer. In the second year, few flowers are formed, seeds do not ripen. Starting from the third year, the plants bloom and bear fruit in large quantities, form seeds. The seeds have time to ripen and are characterized by high laboratory germination (Kornievskaya, Mikhailova, 2016). Ripening of beans stretches over time. The first beans begin to ripen when the side shoots still continue growing. The beginning of fruit formation often coincides with the period of mass blooming of plants and lasts until the first frost. The fruit of *A. cicer* L. is an indehiscent bean, therefore the spread of seeds is challenging. Some seeds germinate inside the bean when the fruit falls.

A. cicer L. plants grown on the introduction site in the Mikhailovskiy district in dry steppe conditions, and the seeds obtained from them are presented in Figure 1.

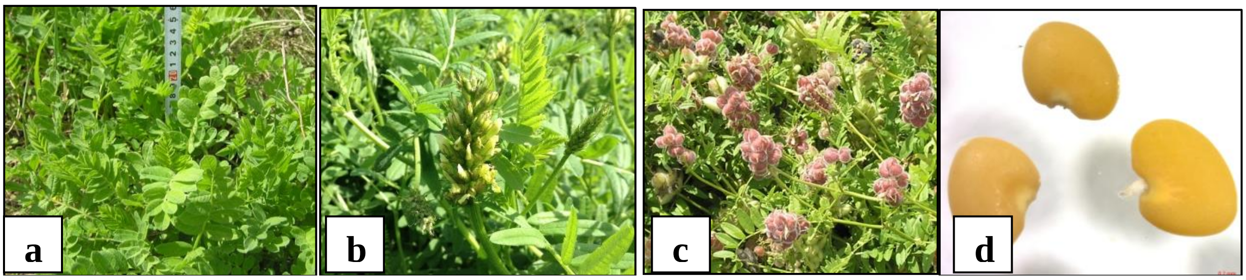

Figure 1. *Astragalus cicer* development in the dry steppe conditions of the Kulunda area:
a – vegetation, b – blossoming, c – fruit formation, d – mature seeds.

The main criterion reflecting the success of the species introduction is the productivity index, which shows the degree of the species adaptation to new conditions. Table 1 shows the analysis of the peculiarities of *A. cicer* generative development, the latter grown for six years in the dry Kulunda steppe. It should be noted that, in general, *A. cicer* is characterized by a high level of seminification, which does not decrease over the years.

Table 1. Peculiarities of *A. cicer* generative development in the conditions of introduction (Mikhailovskiy district, Altai krai, 2014–2018)

Species	Year	Age, years old	Average number of fruits on a generative shoot, pcs.	Number of seeds in a bean, pcs.	PSP, pcs.	RSP, pcs.	Productivity index, %
	2014	2	48	5 ± 0.4 / 49.0	28 315	25 425	0.90
	2015	3	178	6 ± 0.4 / 31.8	628 029	350 663	0.56
A. cicer	2016	4	133	8 ± 0.3 / 20.3	210 166	189 185	0.89
	2017*	5	33	7 ± 0.4 / 35.8	80 643	42 213	0.52
	2018	6	58	7 ± 0.4 / 30.4	173 022	144 808	0.84

Note: hereinafter PSP – potential seed productivity; RSP – real seed productivity; the numerator represents the arithmetic mean ± the error of the arithmetic mean, the denominator represents the standard deviation; 2017* is the year when the astragali on the introduction site were severely damaged by pests.

Seed productivity largely depends on the moisture supply of plants. The smallest number of fruits on a generative shoot of *A. cicer* formed in 2017 (33 pcs.) and in 2014 (48 pcs.).

Based on the Klyuchi weather station data, the amount of precipitation during the summer months and the amount of precipitation of the growing season for 2014–2018 were calculated (Table 2).

Table 2. Precipitation distribution during the growing seasons of 2014–2018 according to the weather station No. 36021 data (Klyuchi, Mikhailovsky district, Altai krai)

	Years of observation				
	2014	2015	2016	2017	2018
May	35	21	27	34	68
June	7.1	30	65	50	42
July	51	49	67	47	35
August	31	25	9	60	14
Precipitation total, mm	**124.1**	**125**	**168**	**191**	**159**

The year of 2014 was the driest for 5 years in a row (the total precipitation of the summer season equaled 124,1 mm). In June, 7,1 mm of precipitation fell (Fig. 2). June is a critical month in the development of legumes, since the plants enter the period of budding (the beginning of the flower buds formation). Insufficient soil moistening causes the buds to fall, leading to a decrease in the seed productivity of the plants.

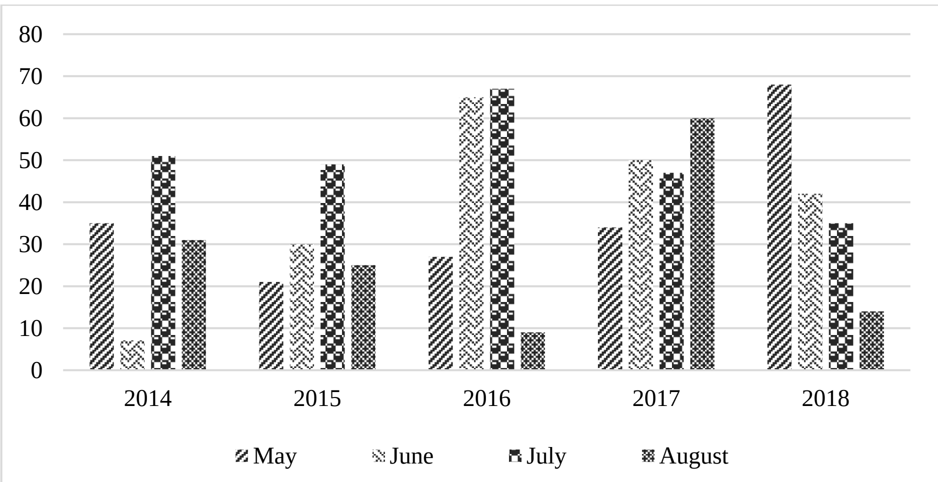

Figure 2. Precipitation distribution during the growing seasons of 2014–2018 according to the weather station No. 36021 data (Klyuchi, Mikhailovsky district, Altai krai)

In 2017, despite the greatest water availability during the season, the plants suffered from phytophagous insects. Massive development of insects coincided with the period of plants blossoming.

Vegetative reproduction

A. cicer is a burr plant. Depending on the amount of precipitation, from 10 to 25 new vegetative shoots can be formed per season. Vegetative reproduction is carried out by root suckers, which begin to form intensively in the third or fourth year. Table 3 outlines detailed biomorphological characteristics of the vegetative shoots.

Table 3. Biomorphological characteristics of the *A. cicer* vegetative parts in the conditions of introduction (Mikhailovskiy district, Altai krai, 2014–2018)

Year	Stem height, cm	Number of shoots, pcs./m^2	Number of nodes with median leaves, pcs.	Length of the median leaf, cm	Width of the median leaf, cm	Number of nodes with bracts, pcs.	Length of the bract, cm	Width of the bract, cm
2015	80±2.6	312	2±0.2	14.5±1.1	6.2±0.6	3±0.1	14.3±0.5	6.4±0.2
	17.7		52.5	42.0	54.3	26.3	18.1	20.1
2016	85±2.9	360	3±0.2	12.5±0.6	5.3±0.2	6±0.4	10.6±0.4	5.2±0.2
	18.5		32.2	27.6	25.1	38.3	22.3	18.5
2017*	71±2.4	198	4±0.2	7.2±0.4	2.4±0.2	5±0.3	5.9±0.4	2.2±0.1
	18.8		27.5	33.3	34.7	29.0	39.2	29.3
2018	88±3.0	372	5±0.3	15.8±0.6	6±0.3	4±0.2	12.7±0.5	5.1±0.2
	18.4		35.1	18.7	23.1	26.9	20.8	26.4

Note: the numerator represents the arithmetic mean ± the error of the arithmetic mean; the denominator represents the standard deviation.

The shoots of *A. cicer* are well foliated. On average, 5–9 nodes of pinnatisected leaves 5–15(8) cm long, 1–6,5(3,7) cm wide are formed on a shoot in the budding phase.

Preservation of habitus in cultivation

In the sixth year, the plants reach a height of (88) 18–118 cm, which corresponds to a natural size.

Plants survival rate during unfavorable seasons

Six years of observation witnessed no plants mortality from the collection site. During the period of drought and mass flowering of plants (June–July 2017), the vegetative and generative organs of *A. cicer* were severely damaged by pest insects (*Epicauta erythrocephala* Pallas, *Lytta vesicatoria* L., *Mylabris frolovi* German). At the end of August, complex pinnatisected leaves re-grew and formed a powerful aboveground phytomass, and the generative shoots bore fruits.

***Astragalus onobrychis* L. (onobrychis milk vetch)**. The species area covers the south of central Europe, the north of the Balkan Peninsula, Turkey, Iran, the west of the Russian European part, the Crimea, the North Caucasus, and Western Siberia. The species is rather variable. Its various ecotypes from different sites in Europe were described as species (Flora of Kazakhstan, 1961; Sytin, 1982). The species is widespread in Altai krai (Silanteva, 2013).

Generative development determining seed reproduction

Separate individuals of *A. onobrychis* bloomed from the first summer. Mass flowering of plants was observed in the third year. Seed production is abundant. Seeds ripen, have good germination capacity. The external appearance of the plant, its fruits and seeds are shown in Figure 3.

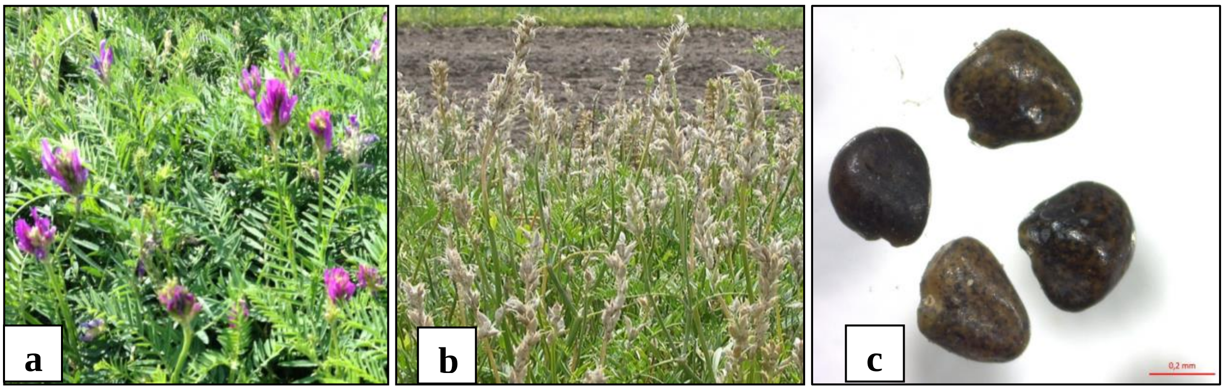

Figure 3. *Astragalus onobrychis* development in the dry steppe conditions of the Kulunda area:
a – blooming, b – fruiting, c – mature seeds.

By the fourth and fifth years, plants formed noticeably fewer seeds. In the fifth year, the *A. onobrychis* individuals were 80% damaged by phytophages (at the budding stage). Leaves and buds were completely destroyed. The astragalus failed to re-

grow, therefore in 2017, it did not bear fruits and form seeds (Table 4). The productivity index decreases from the fourth year and later, which indicates the transition of the plants into the senile period.
The fruit of *A. onobrychis* is an indehiscent bean. Mature seeds remain inside the fruit and have a high percentage of seed hardness. The regeneration of plants from seeds on the introduction site was not observed.

Table 4. Peculiarities of *A. onobrychis* generative development in the conditions of introduction (Mikhailovskiy district, Altai krai, 2014–2018)

Species	Year	Age, years old	Average number of fruits on a generative shoot, pcs.	Number of seeds in a bean, pcs.	PSP, pcs.	RSP, pcs.	Productivity index, %
A. onobrychis	2014	2	–	–	–	–	–
	2015	3	116.3	7.5 ± 0.4 / 26.3	463 565	462 293	1.00
	2016	4	80.2	7.8 ± 0.4 / 31.3	1 010 533	932 084	0.92
	2017*	5	–	–	–	–	–
	2018	6	35.1	7.3 ± 0.5 / 34.8	141 025	110 337	0.78

* See note to Table 1.

Vegetative reproduction
A. onobrychis has a multicipital, well-developed taproot with numerous lateral ones. When blooming, the tuft has a semi-slouchy or slouchy form. On average, there are 8 shoots on a plant. Stems are well foliated, the number of leaf nodes on one shoot is 5–7 pcs. Median leaves are (8,6) 4–12 cm long and (3,8) 1,5–5,0 cm wide (Table 5).

Table 5. Biomorphological characteristics of the *A. onobrychis* vegetative parts in the conditions of introduction (Mikhailovskiy district, Altai krai, 2014–2018)

Year	Stem height, cm	Number of shoots, pcs./m^2	Number of nodes with median leaves, pcs.	Length of the median leaf, cm	Width of the median leaf, cm	Number of nodes with bracts, pcs.	Length of the bract, cm	Width of the bract, cm
2015	66±1.0 / 8.6	729	4±0.2 / 28.6	3.1±0.1 / 16.2	3.2±0.1 / 18.4	6±0.1 / 30.5	4.3±0.1 / 17.9	2.4±0.1 / 20.5
2016	54±1.3 / 11.7	1490	2±0.1 / 35.0	6.2±0.3 / 26.9	2.1±0.1 / 35.5	3±0.2 / 38.1	6.0±0.2 / 21.9	2.3±0.1 / 22.6
2017*	55±2.4 / 23.6	130	2±0.1 / 49.1	3.6±0.2 / 30.0	1.4±0.1 / 33.3	7±0.1 / 26.7	4.4±0.2 / 21.4	1.6±0.1 / 33.9
2018	56±1.0 / 9.9	486	2±0.1 / 38.2	8.6±0.4 / 28.4	3.8±0.1 / 20.1	2±0.1 / 42.1	8.4±0.3 / 16.8	3.8±0.2 / 26.1

Note: the numerator represents the arithmetic mean ± the error of the arithmetic mean; the denominator represents the standard deviation.

Analyzing Table 5, we can note the predominance of the vegetative shoots number in *A. onobrychis* in the third year (2016 – 1490 shoots per m^2). From the third year on (2017), there was a considerable decrease in the number of shoots on the survey sites, which is due to the vulnerability of the species to pests and the senescence of the *A. onobrychis* population in general. Vegetative reproduction of the species is absent.
Preservation of habitus in cultivation
A. onobrychis plants retain their natural size (30–80 cm), reaching the height of 27–50 cm.
Plants survival rate during unfavorable seasons
During three years of the object observation in cultivation, the absence of plants mortality was noted in the crops. In 2017, in the period of mass flowering, *A. onobrychis* (mostly generative organs – inflorescences and buds) suffered from phytophages. It was noted that single specimens are capable of re-blooming, but at the same time, mature fruits were not formed.
Astragalus sulcatus **L.** is a species spread in Central Europe, in the European part of the former USSR, in Western and Eastern Siberia, and in the Balkans (Flora of Kazakhstan, 1961). It is typical in the flora of the steppe area of Altai krai (Silanteva, 2013).
Generative development determining seed reproduction
A. sulcatus blooms from the second summer. *A. sulcatus* plants grown in the conditions of introduction – flowering individuals, fruits and mature seeds – are depicted in Figure 4.

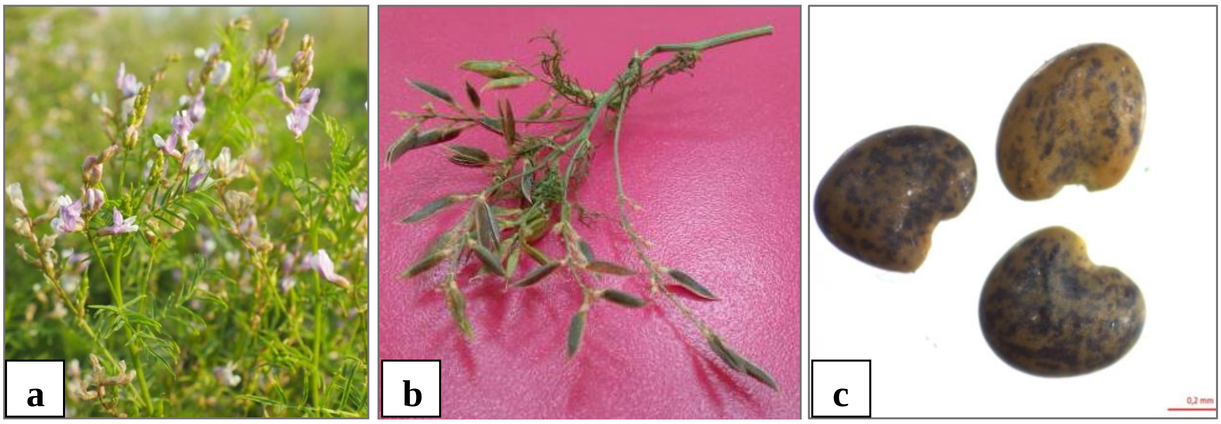

Figure 4. *Astragalus sulcatus* development in the dry steppe conditions of the Kulunda area: a – blooming, b – fruiting, c – mature seeds.

Numerous flowers collected in racemous inflorescences have a light purple color of the corolla. Massive blooming and abundant seed production of plants were observed from the third to the sixth years. Ripe seeds have high laboratory germination capacity. The seeds spread autochorically, however, self-regeneration from seeds was not noticed on the survey sites.

A. sulcatus forms great quantities of mature seeds in the dry steppe conditions. The year of 2014 saw the maximum number of fruits on a generative shoot – 430 pcs., the seed productivity index being 0,98% (Table 6).

Table 6. Peculiarities of *A. sulcatus* generative development in the conditions of introduction (Mikhailovskiy district, Altai krai, 2014–2018)

Species	Year	Age, years old	Average number of fruits on a generative shoot, pcs.	Number of seeds in a bean, pcs.	PSP, pcs.	RSP, pcs.	Productivity index, %
	2014	2	–	–	–	–	–
	2015	3	262.4	6.4 ± 0.4 34.3	586 380	453 427	0.77
A. sulcatus	2016	4	430.6	7.5 ± 0.4 26.4	1 148 175	1 130 325	0.98
	2017*	5	168.3	6.9 ± 0.4 34.1	244 770	148 643	0.61
	2018	6	180.4	5.0 ± 0.3 33.5	276 000	208 362	0.76

* See note to Table 1.

With aging of plants, the real seed productivity and the seminification coefficient decrease from the fourth year and on.

Vegetative reproduction

A. sulcatus is a herbaceous taproot polycarpic. 2–14 upright stems are formed per plant and they do not lodge throughout the whole summer. Biomorphological characteristics of vegetative shoots are shown in Table 7.

Table 7. Biomorphological characteristics of the *A. sulcatus* vegetative parts in the conditions of introduction (Mikhailovskiy district, Altai krai, 2014–2018)

Year	Stem height, cm	Number of shoots, pcs./m^2	Number of nodes with median leaves, pcs.	Length of the median leaf, cm	Width of the median leaf, cm	Number of nodes with bracts, pcs.	Length of the bract, cm	Width of the bract, cm
2015	98±3.6 20.4	461	2±0.1 75.8	5.2±0.4 51.8	2.8±0.3 60.4	14±0.1 36.8	5.7±0.2 19.5	3.1±0.2 30.9
2016	78±0.1 9.1	349	4±0.1 42.3	3.8±0.2 30.7	2.2±0.2 42.7	7±0.1 24.4	3.4±0.2 28.6	2.3±0.1 31.3
2017*	62±0.1 10.3	117	4±0.1 30.6	2.7±0.1 21.7	1.1±0.1 36.1	8±0.1 34.8	2.7±0.1 24.2	1.0±0.1 30.3
2018	64±0.2 16.2	222	5±0.1 28.4	5.4±0.3 28.7	3±0.2 30.9	10±0.1 31.8	4.1±0.1 19.8	1.6±0.1 38.7

Note: the numerator represents the arithmetic mean ± the error of the arithmetic mean; the denominator represents the standard deviation.

The stems of *A. sulcatus* are (54)43–70 cm tall, foliated. The average number of leaf nodes per shoot was 11. The number of shoots decreases annually, which is well traced in Table 7. The increase in the number of shoots in 2018 is associated with the aboveground phytomass destruction by phytophagous insects in 2017, which was mentioned above. *A. sulcatus* does not reproduce in a vegetative way.

Preservation of habitus in cultivation

The average height of plants is (54) is 43–70, which corresponds to natural sizes (30–80 cm).

Plants survival rate during unfavorable seasons

Astragalus sulcatus is a frost- and drought-resistant species. Six years of the species observations in cultivation did not reveal any plants mortality. When damaged by pests, it re-grows and blooms massively. The result of the work on the introduction of the legumes, used for the recultivation of degraded haylands and pastures, is the score of the legumes introduction success (Table 8).

Table 8. The score of the astragali introduction stages success by R.A. Karpinosova (1978)

Species name	Characters				Total score	Overall estimate
	Generative development	Vegetative reproduction	Preservation of habitus in cultivation	Plants survival rate		
Astragalus cicer	2	3	3	3	12	VP
Astragalus onobrychis	1	0	2	1	4	UP
Astragalus sulcatus	2	0	3	3	9	P

Note: UP– unpromising (4–8 points); P – promising (9–11 points); VP – very promising (12–13 points).

Thus, according to the integral scale of rare perennials (Table 8), *Astragalus cicer* is a very promising species in terms of introduction into cultivation (12 points), *Astragalus sulcatus* is promising for introduction (9 points). *Astragalus onobrychis* is an unpromising species for cultivation (4 points). *A. onobrychis* is not resistant to pests, is not capable of vegetative reproduction, and has the worst seed quality in comparison with other astragalus species.

Conclusion

The studied astragali species are resistant to dry steppe conditions. In the conditions of introduction in the South Kulunda, *A. cicer, A. sulcatus* and *A. onobrychis* pass through all the stages of ontogenetic development and form mature seeds.

The most promising species for introduction into cultivation is *A. cicer*, which is capable of re-growth, regenerated by root suckers in a vegetative way and having a high seed productivity index (0,52–0,91%). *A. cicer* can be used to improve pastures and haylands.

A. sulcatus is promising for the recultivation of haylands. The species is not suitable for improving pastures, since it is a tall plant, is not capable of vegetative reproduction and re-grows worse after grazing. However, it forms a sufficient number of seeds, having a seminification coefficient of 0,76–0,98%. *A. sulcatus* is promising in seed production.

A. onobrychis is not a stable species in cultivation. Despite the high rate of semenification (0,78–1,0%), the seeds of *A. onobrychis* are characterized by low quality. The species does not reproduce in a vegetative way, is not capable of re-growth after grazing and damage, and is not resistant to pests.

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