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Research Article

Productivity of Nontraditional Medicinal and Forage Crops in the Conditions of Dry Steppe of the Volga Region

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ABSTRACT:
The authors performed many years' studies aimed at increasing the productivity through selection and improvement of traditional and introduced crops' cultivation technologies in single-species and mixed agrophytocenoses. It has been found that one of the most productive medicinal and forage crops is amaranth both in single-species sowings, and in a mixture with the introduced crop — the Nakhodka cultivar of Nicandra physaloides, and maize. The biochemical, botanical, biological and agronomic characteristics of amaranth have been studied. The studies have shown high laboratory germination rate of amaranth (86.0 %), while the field germination rate, depending on the weather conditions and processing methods, varied from 71.2 to 89.5 %. Amaranth features low rate of leaf surface and above-ground biomass formation (0.4 – 3.4 t/ha) after shooting until the phase of branching, and the maximum values of the leaf surface (0.4 – 4.2 thousand m2/ha) and the above-ground biomass (39.0 – 48.1 t/ha) during the flowering stage. On the average for 2014 – 2017, the maximum accumulation of green (56.9 t/ha) and dry (12.0 t/ha) biomass, protein (1.98 t/ha) and fodder units (9.69 t/ha) was achieved in case of wide-row sowing (60 cm) and the seeding rate of 250 thousand pcs/ha. With this interaction of the seeding rate and the sowing method, the maximum seed yield (2.8 t/ha) had been obtained. Protein and oil accumulation amounted to 0.56 and 0.26 t/ha, respectively, which was by 8 – 12 % higher than in case of high and low seeding rate. The content of biologically active medicinal substance squalene increased with the increase in the seeding rate. This dependence of the content on the seeding rate was observed for all methods of sowing, and reached the maximum (6.2 %) at the seeding rate of 250 thousand pcs/ha with the wide-row method of sowing (60 cm). On the average for 2014 – 2017, high productivity of amaranth in the mixture with Nicandra was observed with the seeding rate of the components being equal to 75 % of the seeding rate adopted for single-species crops. It was by 8 – 12 % higher, compared to the lower seeding rates of the components (50 %), and by 14.2 – 38.6 % higher, compared to the single-species sowing of these crops.

Keywords: amaranth; Nicandra physaloides; field and laboratory germination rate; green biomass; vitamin complex; squalene; agrophytocenoses; yield

[I] NTRODUCTION
Despite the significant advances in creating synthetic medicinal preparations, medications from plants take an important place in the modern scientific medicine. Both in the global market and in Russia, every third medication has plant origin. The range of medicinal plant raw materials is

determined by the medicinal herbs adopted in the country, and by the standards for biologically active substances [1]. In Russia, medicinal plants, such as ginseng, Eleutherococcus, calendula, chamomile, and motherwort, as well as amaranth and Nicandra physaloides are widely spread. The last two are the most important. In pharmacology, all parts of amaranth and Nicandra are used, as well as the products of seed processing (oil, meal, cake). Seeds of amaranth contain squalene (up to 8.0 %). It reinforces the immune system, and is very important in tumor treatment. The medicinal properties of its oil help reinforce the immune system, efficiently purify the human organism of toxins, radionuclides and salts of heavy metals, etc. The content of protein in the seeds is up to 18 – 20 %, and its quality is better than that of milk protein. The total content of carotenoids in the aboveground mass and seeds is 34 – 79 mg/kg [2 – 5]. After heat treatment, amaranth grains are used in the confectionery industry. Vitamin E, squalene, phospholipids, choline, magnesium and phytosterols contained in amaranth flour contribute to improving the cardiovascular system by lowering the level of "bad" cholesterol in the blood, thus preventing the formation of dangerous atheromatous plaques on the walls of blood vessels. N. I. Vavilov recommended the use of amaranth for fodder purposes in 1932. In Russia, amaranth gained relative popularity as forage crops in the mid-1980s, and Nicandra — in the 2000s.

Providing high-protein forage balanced in amino acids, vitamins, macro- and microelements for livestock breeding is one of the most urgent problems of modern agricultural production. Recently, as a result of changes in the climatic conditions and increased arid areas, the area of the land suitable for cultivation of traditional medicinal and forage crops has decreased. In this regard, there is a need for searching for and introducing new promising crops, such as amaranth, which is a highly valuable fodder and medicinal crop.

Expanding the varietal composition of forage crops by means of new high-protein (amaranth, Nicandra, woad) and nontraditional medicinal and oilseed crops (thistle, flax and false flax) [6 – 8] allows to increase in short time the productivity of fodder production and to significantly increase the quality of forage [5]. Searching for and rational use of indispensable ergotropic compounds in the rations of animals is a promising area of improving the efficiency of livestock production.

An important advantage of amaranth and Nicandra, compared to traditional forage crops, is their high biological activity [8]. The yield of green mass, depending on the type of plants, conditions and the region of cultivation, for amaranth ranges between 30 and 100 t/ha, and for Nicandra — between 20 and 50 t/ha. The seed yield is 2 – 5 t/ha, and 1 – 2.5 t/ha, respectively. In the arid conditions of the steppe zone, amaranth is 1.5 – 2.0 times superior to maize. Amaranth and Nicandra feature high recovery ability; they may be mowed 2 – 3 times.

The authors performed the research in accordance with the needs of the pharmaceutical industry and agricultural production. Amaranth is a new crop for the steppe zone of the Volga region, thus, the necessary information about the biological peculiarities and the technology of its cultivation in single-species and mixed crops is unavailable. In this regard, the research aimed at studying the biological peculiarities and the technology of cultivating amaranth in single-species and mixed sowing is relevant.

The purpose of the research is to form highly productive agrophytocenoses of amaranth in single-species and mixed sowing with Nicandra and maize, based on studying the biological features and on developing the basic methods of cultivation on the chernozems of the steppe zone in the Volga region.

[II] METHODS

Field experiments were performed in 2014 – 2017 in the experimental field of FSBSI RosNIISK (RosSorgo). The seeding rate (factor A — 100, 250, 300 thousand of viable seeds per 1 ha) and the methods of sowing – skip-row sowing (30 cm), and wide-row sowing (45 and 60 cm) – were studied. The experiment for studying amaranth in single-species and mixed sowing, depending on the seeding norm and the components' ratio, was performed according to the following scheme: 1 – amaranth, single-species sowing, seeding rate — 250 thousand viable seeds per 1 ha (100 %); 2 – Nicandra, seeding rate — 200 thousand pcs/ha (100 %); 3 — amaranth (75 %) + Nicandra (75 %); 4 — amaranth (50 %) + Nicandra (50 %); 5 —amaranth (75 %) + maize(75 %);and 6– seeding rate — 220 thousand pcs/ha (50 %).

High-yielding variety of amaranth Polyot, Nicandra variety Nakhodka (patent No. 6446, No. 8954188; publ. 17.02.2012, bull. No. 22) and corn of variety Sibiryachka were sown.

The climate in the region is sharply continental and severe. The sum of precipitation (hydrothermic factor) in humid years (2016, 2017) was 1.00 – 1.45 mm, and in arid years (2014, 2015) — 0.50 – 0.60 mm. The average annual amount of precipitation was 360 – 455 mm.

The soil of the experimental plot was southern black thin-humus loamy soil of medium thickness. The content of humus (by Tyurin) was 3.2 – 4.3 %, of mobile phosphorus — 18.2 – 22.6 mg/kg, and of exchange potassium (by Machigin) — 28.0 – 34.6 mg/100 g of soil. The water-physical properties of the 0 – 70 cm layer were the following: density was equal to 1.25 – 1.36 g/cm3, the lowest water-holding capacity (LWC) was 27.1 %, and the humidity sustainable wilting was 12.8 % by dry weight of soil. Field experiments were performed with 4 repetitions using the randomized method. The area of registration plots was 100 – 150 m2, that of the seeding plots 150 – 200 m2.

The field experiments and research were organized and performed according to the generally adopted methods. The chemical composition of the seeds and the nutritional value were determined according to GOST 10842-91 and GOST 108-42-76. Statistical processing of the experimental data was performed by the variance and correlation analyses [9 – 14].

[III] RESULTS AND DISCUSSION

Botanical features and biochemical composition of amaranth plants. It is an annual branchy leafy plant. The stem is erect (diameter is up to 5 cm); the height is 180 – 200 cm. The leaves are alternate, ovate. The root is rachidian up to 120 cm long, branched in the arable layer, insufficiently powerful.

The fruits are nut-shaped, small (the weight of 1,000 seeds is 0.601 g), the number of seeds in one head may reach 500 thousand pcs. The flowers are small, telianthus or separate; they are collected in a large, complex inflorescence — a head. The plant is resistant to soil and air draughts. The crimson amaranth variety (Amaranthus cruentus) features high content of protein (17 %), fiber (11 %), and mineral substances (11 %) in the green mass. The seeds contain 21 % of protein with balanced amino acid composition, biologically anti-active substances, including squalene, macro- and microelements, and the vitamin complex.

Features of growth and development. The biological feature of amaranth is high laboratory germination rate (82.5 – 93.0 %); the average germination rate over the years of the research was 83.8 – 86.5 %. In addition, it features slow growth in the early vegetation season — 0.6 cm a day. From the phase of rosette formation (8 – 10 leaves), the growth accelerates, and in the flowering phase reaches 7.5 cm. The duration of the flowering period is 42 – 46 days, and from germination until seed ripening — 95 – 110 days. The plant has high recovery ability, which allows 2 – 3 mowings of the green mass; therefore, it is an important link in the green conveyor system.

Formation of the leaf apparatus. The regularity of leaf surface formation has been determined, depending on the phase of vegetation and plant density.

The leaf area, similar to the photosynthetic capacity, increased from germination until the flowering phase, reaching over the years of the research the average of 5.22 thousand m2/ha and 2,536.6 thousand m2/ha a day, respectively (Table 1).

Phase of vegetation	Leaf area, thousand m^2/ha				
	2014	2015	2016	2017	on average
Branching	3.82	3.52	3.92	4.96	4.17
Shooting	12.92	13.01	12.00	16.67	14.03
Head formation	28.11	24.20	30.20	36.27	29.90
Flowering	38.07	30.63	44.67	50.22	40.75
Fruit formation	48.82	36.07	58.01	62.75	52.88
During harvesting (fruit formation)	Photosynthetic capacity, thousand m^2/ha· a day				
	2,374.5	2,168.1	2,158.3	3,067.4	2,536.6

Table: 1. Dynamics of leaf surface and photosynthetic capacity growth

Amaranth develops large leaf surface, depending on the density of plant stand — in the phase of head formation from 38.5 up to 64.0 thousand m2/ha. From the flowering phase, the leaf area is significantly influenced by the sowing method. The maximum leaf area (70.5 thousand m2/ha) was in case of wide-row sowing (60 cm), which was by 15 % and 25 % higher, compared to skip-row sowing (30 cm) and wide-row sowing with interrow spacings (45 cm) with the same seeding rate of 250 thousand of viable seeds per 1 ha.

The dynamics of green and dry biomass formation. In the early amaranth growing season, the rate of vegetative mass accumulation was moderate, the maximum value was noted closer to the phase of fruit formation, which, depending on the seeding rate and the methods of sowing, reached 42.5 – 61.0 t/ha. With the increase in the seeding rate from 100 to 300 thousand seeds/ha, the rate of biomass accumulation increased by 15 – 22 % (Table 2). With the same plant density (250 thousand per ha), increased by 15 – 18 % biomass accumulation was noted in case of wide-row sowing (60 and 45 cm), compared to skip-row (30 cm) sowing.

Seeding rate, thousand pcs. pf viable seeds per hectare	The method of sowing and the width of interrow spacings	The actual plant density before harvesting, thousand pcs/ha	Phase of vegetation				
			branching	shooting	head formation	flowering	fruit formation
100	Skip-row, 30 cm	91.0	0.49	5.82	15.82	39.50	39.01
	Wide-row, 45 cm	89.2	0.56	6.28	18.40	42.81	42.20
	Wide-row, 60 cm	88.6	0.66	6.95	20.81	43.90	42.10
150	Skip-row, 30 cm	133.5	1.01	6.40	20.50	41.21	39.20
	Wide-row, 45 cm	136.1	1.38	7.12	22.81	43.60	41.11
	Wide-row, 60 cm	130.5	1.51	7.81	24.60	45.99	42.22
200	Skip-row, 30 cm	186.1	4.69	8.98	23.90	44.80	43.15
	Wide-row, 45 cm	184.5	2.61	8.01	26.01	48.51	45.21
	Wide-row, 60 cm	183.1	2.75	7.92	21.94	51.01	48.12
250	Skip-row, 30 cm	232.1	3.01	10.21	24.50	46.82	43.50
	Wide-row, 45 cm	230.5	3.82	10.68	26.30	49.62	47.60
	Wide-row, 60 cm	231.0	3.95	10.92	27.90	51.93	50.12
300	Skip-row, 30 cm	280.5	2.81	9.82	23.71	43.10	42.10
	Wide-row, 45 cm	278.1	3.21	2.92	24.15	44.60	42.60
	Wide-row, 60 cm	276.5	3.41	10.01	23.81	42.28	41.50

Table: 2. The influence of the methods of sowing and the seeding rate on the dynamics of amaranth green biomass accumulation, t/ha (the average over 2014 – 2017)

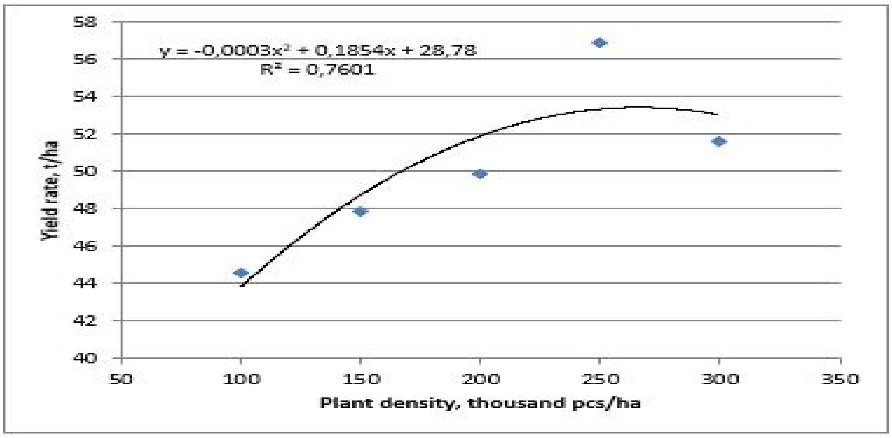
The maximum amount of biomass was formed at the seeding rate of 250 thousand pcs/ha in case of wide-row sowing (60 cm) — 51.90 t/ha in the phase of head flowering. A similar regularity was observed in the matter formation as well, which at all seeding rates was higher by 8 – 12 % in case of wide-row sowing, compared to skip-row sowing (30 cm).

The yield of the above-ground biomass and seeds. The yield of green and dry biomass of amaranth significantly increased with the increase in the seeding rate. This regularity was observed for all methods of sowing (Table 2). On the average for 2014 – 2017, the maximum yields of green biomass (56.9 t/ha), dry biomass (12.0 t/ha), fodder units (9.65 t/ha), and protein (of 1.98 t/ha) were reached in the variant with the seeding rate of 250 thousand germinating seeds per 1 ha in case of wide-row sowing (60 cm). It was by 48 – 61 % higher, compared to the low seeding rate – 100 thousand germinating seeds per 1 ha – and skip-row sowing (30 cm). The same regularity was observed in the formation of the yields of inflorescences, seeds, and other elements of amaranth harvest structure. With the increase in the seeding rate from 100 to 300 thousand germinating seeds per 1 ha in case of the skip-row (30 cm) and wide-row (60 cm) sowing methods, the share of inflorescences reduced from 51 % to 27 % and from 44 % to 35 % of the total aboveground mass of plants, respectively.

The maximum seed yield (2.02 t/ha) was obtained in the variant with the wide-row (60 cm) method of sowing and the seeding rate of 250 thousand pcs/ha (Table 3, see the figure 1).

Seeding rate, thousand pcs. of viable seeds per 1 ha	The method of sowing and the width of interrow spacings	Seed yield, t/ha					The yield from 1 ha, t, average for 2014-2017	
		2014	2015	2016	2017	average	oil	protein
100	Skip-row, 30 cm	0.70	0.69	0.76	0.77	0.73	0.16	0.28
	Wide-row, 45 cm	0.78	0.80	0.86	0.84	0.82	0.18	0.34
	Wide-row, 60 cm	0.90	0.87	1.13	1.19	1.03	0.20	0.40
150	Skip-row, 30 cm	0.78	0.78	1.38	1.40	1.09	0.19	0.42
	Wide-row, 45 cm	0.87	0.90	1.48	1.57	1.18	0.20	0.49
	Wide-row, 60 cm	1.01	0.98	1.78	1.80	1.39	0.22	0.52
200	Skip-row, 30 cm	1.00	1.06	1.40	1.61	1.26	0.20	0.44
	Wide-row, 45 cm	1.20	1.18	1.68	1.58	1.41	0.23	0.49
	Wide-row, 60 cm	1.33	1.24	1.65	2.04	1.64	0.23	0.52
250	Skip-row, 30 cm	1.12	1.26	1.94	1.80	1.53	0.24	0.45
	Wide-row, 45 cm	1.21	1.40	2.27	1.78	1.74	0.25	0.49
	Wide-row, 60 cm	1.46	1.60	2.56	2.44	2.02	0.26	0.56
300	Skip-row, 30 cm	1.25	1.30	1.55	1.50	1.40	0.20	0.43
	Wide-row, 45 cm	1.31	1.43	1.85	1.73	1.58	0.23	0.47
	Wide-row, 60 cm	1.37	1.16	2.07	2.28	1.72	0.23	0.49
LSD_{05} Actual A		0.033	0.039	0.045	0.049			
Actual B		0.039	0.041	0.048	0.043			
Actual AB		0.042	0.049	0.051	0.050			

Table: 3. The influence of the seeding rate and the sowing methods on the yield and quality of amaranth seeds



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The correlation coefficient between the seeding rate (plant density) and the seed yield was 0.87 (r = 0.87). The coefficient of determination was 0.7601, i.e. 76 % of the yield, and correlated with plant density. The weight of seeds per plant, on the contrary, decreased with the increase in the seeding rate. Thus, the maximum weight of the head (136.90 g) and seeds per plant (16.20 g) was in the variant with the plant density of 100 thousand of plants per 1 ha with the wide-row (60 cm) method of sowing. It was by 85 % and 81 % more than in the case of plant density of 300 thousand plants and the skip-row method of sowing (30 cm). The influence of the seeding rate on the harvest structure was observed in all methods of sowing. It should be noted that the seeding rate affected the seed yield and its structure more significantly than the methods of sowing. Accumulation of protein and oil in amaranth seeds was the highest in the variant with the seeding rate of 250 thousand viable seeds per 1 ha and wide-row sowing (60 cm), and was, respectively, 0.56 and 0.26 t/ha, which was by 8 – 10 % higher than in case of lower seeding rates. With the increase in the seeding rate from 100 to 300 thousand viable seeds per 1 ha, the content of squalene naturally increased from 5.1 to 6.2 %. This dependence was observed in all methods of sowing and reached the maximum of 6.2% in the combination of the wide-row method of sowing (60 cm) and the seeding rate of 250 thousand pcs/ha. These data were confirmed by the studies performed in Azerbaijan [15, 16].

The productivity of amaranth and Nicandra physaloides in single-species and mixed cenoses. The years of research in the Lower Volga region have shown the higher productivity of forage crops in mixed sowings, compared to single-species sowing [7, 14]. Mixed cenoses of these crops differ significantly in the quantity and the quality of the above-ground biomass, compared to single-species cenoses. During the many years of experiments, the comparative analysis of productivity of single-species and mixed cenoses of amaranth with Nicandra and maize has shown the higher productivity of mixed sowings, compared to single-species sowings (Table 5).

The highest yields of green mass (46.0 t/ha), and dry biomass (9.60 t/ha), fodder units (7.7 t/ha), and digestible protein (1.50 t/ha) were obtained in mixed sowings of amaranth with Nicandra. With that, the seeding rate of the component was 75 % of the adopted rate in single-species sowings, which was by 15 % and 14 %, respectively, higher than at lower seeding rates. Amaranth not only has high medicinal properties, but is also a valuable forage crop, since it forms in single-species and mixed sowings with Nicandra and maize high and stable yields of green mass with balanced sugar-to-protein ratio, the vitamin-and-mineral complex, and biologically active substances [9, 14, 19, 20].

One should also note the high processability of the green mass of amaranth and its mixtures with Nicandra physaloides and maize, given the diversity of its use as forage and raw material for haylage and silage. Amaranth and Nicandra feature recovery ability, ensuring 2 – 3 mowings of the green mass. The aftergrowth of these crops is used for grazing. Similar data were obtained by researchers in Western Europe and in China [5, 18].

Nonconventional crops amaranth and Nicandra physaloides are plastic crops that respond well to deep tillage, introduction of mineral fertilizers, mainly nitrogen. The use of fertilizers (60 – 90 kg of active substance per 1 ha) allows obtaining high yields: in humid years — up to 48.1 – 60.0 t/ha, in arid years — up to 27.5 – 32.5 t/ha. The powerful root system of these crops with high content of nitrogen, micro- and macrominerals and carbohydrates contributes to increasing the humus content and improves soil fertility [5, 17, 18, 21].

[IV] CONCLUSION

1. Successful introduction and implementation of nontraditional crops at the farms in the Volga area is possible with the creation of adaptive cultivation methods for various purposes. The agroclimatic resources ensure their high productivity in boharic conditions as a medicinal raw material, and for feeding purposes.

2. It has been found that amaranth seeds feature high laboratory germination (82.5 – 91.0 %). Field germination in humid years (2016 – 2017) was the

highest — up to 86.5 %, and in arid years, it was by 17.5 – 24.0 % lower. The seeding rate had greater impact on the germination rate than the method of sowing.

3. The dependency was found for the rates of biomass and leaf surface formation. The maximum values of biomass and leaf surface were observed in the phase of full flowering in case of the wide-row (60 cm) sowing method, and the seeding rate of 250 thousand pcs/ha.

4. With the increase in the plant density, the yield of green and dry biomass increased in the case of all sowing methods. The maximum yield of green (56.9 t/ha) and dry (12.0 t/ha) biomass on the average over the years of research was achieved with the seeding rate of 250 thousand pcs/ha with the wide-row method of sowing (60 cm).

5. The maximum amaranth seed yield was obtained in case of the wide-row (60 cm) sowing method, and the seeding rate of 250 thousand pcs./ha, and amounted to 2.02 t/ha, while the yield of protein and oil amounted to 0.56 t/ha and 0.26 t/ha, respectively; the content of squalene amounted to 6.2 %.

6. In the mixed sowings of amaranth, the maximum yields of green biomass (46.0 t/ha), fodder units (7.7 t/ha), protein (1.50 t/ha) were obtained in the mixtures of amaranth with Nicandra physaloides at the seeding rate of the components equal to 75 % of the seeding rate adopted for single-species sowings.

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