CROP PRODUCTION

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STUDY OF THE GROWTH AND DEVELOPMENT OF *AMARANTHUS CRUENTUS* L. AT DIFFERENT DATES AND METHODS OF SOWING IN THE CHUVASH REPUBLIC

Research article

Abstract

The article presents the results of studying the dates and methods of sowing one of the most studied species *Amaranthus cruentus* L. for growing green mass and for grain in the soil and climatic conditions of the Chuvash Republic. For this purpose, the theoretically possible productivity of amaranth was initially found based on such climate factors as temperature conditions and moisture reserves of the growing season, and the accumulation of incoming solar energy by the crop. Further, the biological and morphological plants characteristics in different years of vegetation according to meteorological conditions were studied in field experiments and the yield of *Amaranthus cruentus* L. under three methods and three dates of sowing were determined. It has been established that amaranth for growing green mass can be sown in all the testing methods and at all dates, up to the end of June. The advantages of wide-row sowing methods (75 cm) and earlier sowing dates (May 25) for growing grain were identified.

Keywords: *A cruentus* L.*,* methods of sowing, date of sowing, growing season, growth stages, green mass, grain.

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ИЗУЧЕНИЕ РОСТА И РАЗВИТИЯ *AMARANTHUS CRUENTUS* L. ПРИ РАЗЛИЧНЫХ СРОКАХ И СПОСОБАХ ПОСЕВА В ЧУВАШСКОЙ РЕСПУБЛИКЕ

Научная статья

Аннотация

В статье приводятся результаты изучения способов и сроков посева одного из наиболее изученных видов *Amaranthus cruentus* L. при выращивании на корм и зерно в почвенно-климатических условиях Чувашской Республики. Для этого первоначально определена теоретически возможная урожайность амаранта по основным факторам климата, а именно по температурным условиям и запасам влаги вегетационного периода, аккумулированию урожаем приходящей солнечной энергии. Далее в полевых опытах изучены фенологические и морфологические изменения растений по фазам вегетации в разные годы по метеорологическим условиям и определена продуктивность *Amaranthus cruentus* L. при трех способах и трех сроках посева. Установлено, что амарант для получения зеленой массы можно высевать всеми изучаемыми способами посева и в различные сроки, вплоть до конца июня. Также выявлено преимущество широкорядных способов посева (75 см) и более ранних сроков посева (25 мая) при выращивании амаранта на зерно.

Ключевые слова: *A cruentus* L., способы посева, сроки посева, вегетационный период, фазы развития, зеленая масса, зерно.

1. Introduction

Currently, fodder production is based on a narrow range of plants. These are mainly cereals and various legumes. Cereals, traditional for central Russia: rye, oats and barley, have two main drawbacks - low productivity and a relatively low content of protein and essential amino acids. Legumes without these disadvantages are characterized by the highest water consumption for the formation of a unit of dry matter [2]. Amaranth has a high biological yield of green mass (up to 100 t / ha) and seeds (up to 4 t / ha). The seeds contain 16-18% of the protein with a high-grade amino acid composition, much larger than that of wheat, maize, and even milk. The essential amino acid lysine contains twice as much as corn protein. The green mass of amaranth is well eaten by all types of animals. It is used to prepare pellets, briquettes, grass flour, and mixed with green mass of corn and sunflower – good combined silage, balanced in protein and other nutrients and has an antioxidant effect [12]. This heat-loving and drought-resistant crop belongs to the group of so-called C4 plants of subtropical and tropical origin. Due to the specific organization of the leaf photosynthetic apparatus, the plants have formed a mechanism for very economical water consumption and high photosynthesis intensity, while at the same time reducing photorespiration [1,10]. This combination of high-efficiency photosynthesis with active protein-synthesizing systems makes the amaranth promising for the development of a forage base in certain agro-ecological conditions.

The aim of the research is to study of the growth and development of *Amaranthus cruentus* L. at different dates and methods of sowing in the Chuvash Republic

2. Methods

Field experiments were held in 2016-2018 on the light gray forest soils of the university collection site located on the banks of the Volga in the town of Cheboksary. Soil pH is 5.5; humus content is 2.4 %; the content of phosphorus and potassium in the soil, respectively 123 and 122 mg / kg. Field experiments were fertilized with N60P80K90 before sowing of amaranth. The field plots area was 90 m^2 at 10 m^2 per each variant. Amaranth cultivation technology was generally accepted for the conditions of the Chuvash republic. It should be added that the soil of the experimental site on the bank of the Volga is polluted due to the action of a chemical factories, thermal power stations and hydroelectric power stations. Ecologists' studies have shown that the soil of the experimental site has exceeded the maximum permissible concentrations of Pb, formaldehyde and other harmful chemical elements. But no deviations in the vegetation of amaranth on polluted soils were observed. This proves that the crop is able to grow and develop normally on polluted soils, but our data need further study [3].

The control of plant stem height, stem diameter, number of leaves on the plant, leaf area was carried out in all vegetative stages: seeding, vegetative phase, flowering, seed maturation.

The analyzed species was *Amaranthus cruentus* L. with a seed purity of 96 % and a seed germination of 90 %. It should be noted that amaranth belongs to small-seeded plants (mass of 1000 seeds is 06 g), and often there are difficulties when sowing to a depth of 1.5 cm. It is also important that this plant has a long period of preservation of seed germination up to 20-25 years [13].

The dates and methods of sowing of *A. cruentus* L on green mass and grain were compared in the field experiment (table 1.)

Table 1 – Field experiment scheme (2016-2018)

Seeding date	Sowing method	Row spacing, cm	Plant density per ha	Seeding rate, kg / ha	Harvest date	
					green mass	grain
25.05.	Drill sowing Broadcasting Broadcasting	15 45 70	600.000 300.000 200.000	1.8 0.9 0.6	25.08.	15.09.
5.06.	Drill sowing Broadcasting Broadcasting	15 45 70	600.000 300.000 200.000	1.8 0.9 0.6	5.09.	25.09.
15.06.	Drill sowing Broadcasting Broadcasting	15 45 70	600.000 300.000 200.000	1.8 0.9 0.6	15.09.	-

The method of analysis of variance (ANOVA) was used to process experimental data in the program Statistica 12.0.

3. Results

Biological climatic potential (BCP) is an indicator with which it is possible to calculate the productivity of a plant in the specific climatic conditions of any region. Therefore, it is the basis for agro-climatic zoning of plants [7]. It is calculated using the following formula:

$$\mathrm{BCP} = \frac{\mathrm{f} \cdot \Sigma\mathrm{T} > 10^{0}\mathrm{C}}{1000^{0}} \quad (1)$$

BCP -biological climatic potential of crop productivity, points;
f - humidification factor of climatic conditions of region;
$\Sigma T > 10\ ^{0}$C - sum of temperatures >10 ^{0}C during the amaranth growth;

1000^0C - sum of temperatures during growing season on the border of open agriculture.

The yield of green mass and grain is calculated according to the following formula:

$$Y = \beta \cdot BCP \qquad (2)$$

Y - Yield of green mass and grain, t / ha;

β - Coefficient of productivity, t / ha. β is calculated from the experimental data.

The sum of temperatures ($\Sigma T > 10\ ^0$C) during amaranth growth for fresh mass and grain was different in the years of experiments, since the biomass harvesting began 90 days after sowing, and grains - 110 days after sowing (table 2).

Table 2 – Bioclimatic potential (BCP), points and coefficient β, t / ha of amaranth green mass and grain (2016-2018)

Seeding date	Σt>10⁰C		Humidification factor of climatic conditions						
	Green mass	Grain	0,7	0,75	0,8	0,85	0,9	0,95	1,0
BCP, points									
25.05.	1542		1,08	1,15	1,23	1,30	1,38	1,46	1,54
		1813	1,27	1,36	1,45	1,54	1,63	1,72	1,81
5.06.	1539		1,08	1,15	1,23	1,31	1,38	1,46	1,54
		1808	1,27	1,36	1,45	1,54	1,63	1,72	1,81
15.06.	1513	-	1,06	1,13	1,21	1,29	1,36	1,44	1,46
β, t / ha									
25.05.	1542		61	57	53	50	48	45	43
		1813	1.4	1.3	1.2	1.1	1.0	0.9	0.8
5.06.	1539		63	60	56	53	49	47	44
		1808	1.4	1.3	1.2	1.1	1.0	0.9	0.8
15.06.	1513	-	59	54	51	48	46	43	41

Amaranth BCP points are higher in more favorable weather conditions. It is the main cause for harvesting higher yields of amaranth mass and seeds [5]. The most optimal years in terms of temperature for amaranth were 2016 and 2017, when the sum of temperatures was 100-200^0C higher, and the BCP scores were higher by 0.1-0.2 points.

On average, over the years of experiments, the BCP of amaranth for grain increased by 0.21-0.26 points than for mass, and ranged from 1.27 to 1.81 points, depending on the moisture factor due to a longer vegetation period, and as result a greater amount of accumulated temperatures. BCP didn't change from early to late sowing dates, both when cultivated for grain in the first two seeding dates, and in all three tested seeding dates for fresh mass. Thus, the BCP was 1.09-1.56 points when seeding on May 25; 1.08-1.54 – June 5 and 1.06-1.51 points – June 15 in various humidification conditions harvesting for biomass. BCP had the same indicators from 1.27 to 1.81 points when sowing on May 25 and June 5 in the case of harvesting for grain. The less favorable climatic conditions of amaranth vegetative season the grater the coefficient β corresponds to each BCP point. On average, 41-63 t / ha of mass and 0.8-1.4 t / ha of grain corresponded to each BCP point for three seeding dates.

In general, BCP amaranth points did not significantly change from the early seeding dates to the later ones, which lead to the conclusion that the weather conditions of Chuvash Republic are suitable for producing of biomass and grain of *A. cruentus* sowing from the end of May to the middle of June.

Plant biomass consists of 90-95% organic matter produced during photosynthesis. Therefore, the theoretical basis for plant productivity is yield based on accumulated photosynthetic active radiation (PAR the portion of the light spectrum utilized by plants for photosynthesis) [6].

The yield according to the level of photosynthetic active radiation (Y_{PAR}) is calculated with the formula:

$$Y_{PAR} = \frac{10^4 \cdot f_{PAR} \cdot C \cdot Q_{PAR}}{q} \qquad (3)$$

Y_{PAR} - yield according to PAR, t / ha;

f_{PAR} - Plant solar utilization factor, %;

C - Coefficient for converting biological yields into green mass (5.556) and grain (0.118) yield;

Q_{PAR} – Sum of plant accumulated PAR for growing season, kJ / cm^2;

q – Caloric value of amaranth green mass (20110) and grain (21771), kJ / kg.

The total PAR for amaranth green mass during growing period was 90 kJ / cm2, for grain-101.4 kJ / cm2 at sowing on May 25; respectively, 84 and 95 kJ / cm2 – on June 5; 79 kJ / cm2-on June 15 (seed maturation in climatic conditions of the experiment was not observed due to higher temperature requirements). The biological theoretically possible yield of amaranth green mass and grain at different levels of accumulation and use of PAR in climate conditions of Chuvash Republic are presented in table 3.

Table 3 – Yield of amaranth green mass under using accumulated PAR, t / ha (2016-2018)

Seeding date	Seeding method	Row spacing, cm	PAR for growing season, kJ / cm^2	Plant solar utilization factor (f_{PAR}), %;				
				1%	2%	3%	4%	5%
25.05.	Drill sowing	15	90.0	24.6	49.2	73.8	98.4	123.0
	Broadcasting	45						
	Broadcasting	70						
5.06.	Drill sowing	15	84.3	23.3	46.6	69.9	93.2	116.5
	Broadcasting	45						
	Broadcasting	70						
15.06.	Drill sowing	15	78.9	21.6	43.2	64.8	86.4	108.0
	Broadcasting	45						
	Broadcasting	70						

Table 3 shows that amaranth yield of green mass with a 4% use of the accumulated PAR (high agro background, optimal conditions) were 98.4, 93.2 and 86.4 t/ha, respectively, for three sowing dates. This means that amaranth has a high potential to form green mass when sown at different dates, up to the end of June in the climatic conditions of Chuvash Republic, which is associated with the fact that amaranth belongs to short-day plants from the C4 plants with more active photosynthetic reactions [8].

The growing period of *A. cruentus* includes stages: seedlings, vegetative state, flowering, seed maturation [4]. The lasting of amaranth growth phases are shown in table 4.

Table 4 – Duration of amaranth growth stages, days (2016-2018)

Seeding date	Seeding method	Row spacing, cm	Growth stages					
			Seedlings	Vegetative state	Flowering	Growing season (biomass)	Seed maturation	Growing season (grain)
25.05.	Drill sowing	15	13	46	33	92	-	-
	Broadcasting	45	13	43	27	83	27	110
	Broadcasting	70	13	40	26	79	26	105
5.06.	Drill sowing	15	11	44	30	85	-	-
	Broadcasting	45	11	40	26	77	26	103
	Broadcasting	70	11	38	24	73	26	99
15.06.	Drill sowing	15	10	43	25	79	-	-
	Broadcasting	45	10	38	25	73	-	-
	Broadcasting	70	10	36	24	70	-	-

Table 4 shows that two amaranth phases of growth are distinguished by the longest duration: 36-46 days (vegetative stage) and 24-33 days (flowering). Finally, *A. cruentus* formed biomass for silage in 85-92 days with drill sowing method and for 70-79 days with broadcasting methods during the season of growing. Comparing the methods of sowing, it had been established that amaranth passed the growth phases 9-11 days faster in broadcasting sowing then in drill sowing due to the lower plant density. Since amaranth is a short-day plant, the lasting of growth stages and growing seasons were 10 days less in June seeding dates when solar activity is more optimal for plants growth. *A. cruentus* L. didn't have enough time to rich the maturation of seeds in drill sowing methods and later sowing dates [8]. Generally, the weather conditions of region are suitable for growing of *A. cruentus* L. for fodder and grain purposes in all testing dates and methods of sowing but the early beginning of sowing and lower plant density can lead to full ripeness of seeds.

Experiments included the determination of changes in plant height; stem diameter, leaves number and leaf area depending on seeding dates and seeding methods. Results of green mass and productivity, growing indicators are presented in the table 5.

Table 5 – Yield, t / ha; height and stem diameter, cm; number of leaves and leaf area, cm^2 of amaranth (2016-2018)

Seeding date	Seeding method	Plant height, cm	Stem diameter, cm	Number of leaves	Leaf area, cm^2	Yield, t / ha	
						green mass	seeds
25.05.	Drill sowing (15)	155.2a	1.7a	57.6a	2122a	54.3a	-
	Broadcasting (45)	166.7b	2.3b	58.2a	3912b	60.2b	12.1
	Broadcasting (70)	175.3c	2.6c	59.5b	5710c	69.2c	14.3
5.06.	Drill sowing (15)	160.9a	1.9a	55.9a	2273a	53.0a	-
	Broadcasting (45)	174.3b	2.4b	57.4a	3948b	61.6b	13.3
	Broadcasting (70)	180.8c	2.7c	60.2b	5849c	72.4c	15.7
15.06.	Drill sowing (15)	159.6a	2.2a	57.3a	2298a	55.0a	-
	Broadcasting (45)	170.5b	2.5b	58.1a	4020b	61.5b	-
	Broadcasting (70)	179.5c	2.8c	60.8b	5943c	71.9c	-

Values with different letters are especially different at $p < 0.05$.

In the beginning of vegetation amaranth growths very slow (stem and leaves) because of the small seeds. After 30-35 days, active growth and height reached 40-45 cm. The stem growth and its diameter increase were very intensive and reached maximum at the end of flowering. Being a heat-loving and short-day plant the amaranth of the second- and third-seeding dates was faster in growth processes and formed the longest stems (170-180 cm) with a diameter 2.3-2.5 cm due to higher temperatures and shorter days in June and July during the experiment. The maximum increase in the number of leaves and the leaf area per plant was established in the experiments with broadcasting methods. In comparison, the wider the distance between rows of plants (45, 70 cm), the greater the number of leaves (58, 60) and the leaf area (3950, 5943) as a result of the increased plant area due to less plant density in all seeding dates of the experiment. Green biomass yield showed that all testing amaranth methods and dates of sowing resulted in a high biological productivity from 54 to 70 t / ha. In comparison, amaranth broadcasting methods of sowing with less dense plants yielded 7-10 t / ha more than drill sowing due to increased height and diameter of the stem and increased leaf formation with good sunlight of the plants. Seed productivity showed that only broadcasting sowing in earlier seeding dates on May 25 and June 5 had time to form seeds in full maturity in all years of the experiment. In later date, on June 15 and with drill sowing method seed ripening was not observed due to shorter growing season and denser sowing of plants in the field experiments [4], [11], [13].

Analyzing the research results of growth and development of *A. cruentus*, it was found that the weather conditions of Chuvash Republic are able for growing of plant for green biomass (silage) in various dates (May 25, June 5 and June15) and with all studied methods (drill, broadcast) of cultivation. It had been established that the broadcast sowing of *A. cruentus* L. is more suitable than drill sowing for seed ripening in climate conditions of the region.

Conflict of Interest

None declared.

Конфликт интересов

Не указан.

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