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ROW SPACING AND PLANT DENSITY EFFECTS AT CASTOR BEAN

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Abstract

Castor bean is an important oil plant, which in Romania is cultivated on small areas for scientific, ornamental, industrial and medicinal purposes. Having into consideration the importance of the crop in the past, respectively up to 1989, when Romania was the sixth largest cultivator of castor bean in the world, and having in view the great importance of its oil, it can be said that in Romania the castor bean has a real potential to develop in the future.
Optimizing row spacing and plant density has a significant influence on seed yield. Therefore, our research focused on determining the optimal combination of row spacing and plant density to obtain the best yield under the environmental conditions specific to the South Romania and taking into account the phenotypic expression of the cultivated variety. Researches were performed in field conditions at the Agricultural and Development Research Station Teleorman located in Teleorman County in South Romania, in the years 2019 and 2020 and on cambic chernozem soil conditions. The experiment was placed according to the method of subdivided plots into 3 replications, with the following factors: Factor A - row spacing, with 4 graduations (30, 50, 70 and 90 cm); Factor B - plant density, with 3 graduations (40,000, 60,000 and 80,000 plants/ha); Factor C - castor bean variety, with 2 graduations (Teleorman and Rivlas). The results of the performed research proved that decreasing the row spacing is associated with decreasing of yield, while increasing the plant density is associated with increasing of yield. The Rivlas variety turned out to be more productive than the Teleorman variety.

Key words: *castor bean, row spacing, plant density, variety, plant characteristics, yield.*

INTRODUCTION

Castor bean (*Ricinus communis* L.) is one of the valuable oil plants. In Romania, up to 1989 it ranked fourth as cultivated area among oil crops, after sunflower, soybean and linseed. At that time, Romania was the sixth largest cultivator of castor bean at world level. At present, there are sporadic attempts to cultivate castor bean for ornamental, industrial and medicinal purposes, for entrepreneurs this proving to be an unpretentious crop, which is easily and very profitably cultivated, extraordinarily useful and, as a result, highly sought after.
In most castor bean growing regions, yields can be rapidly increased by using improved agronomic practices. Key technologies include selecting the right genotype combined with the use of good quality seeds, appropriate sowing date, irrigation, soil fertilization, weed, pest and disease management, optimized plant density, mechanical harvesting and post-harvest management (Severino et al., 2012).
Optimizing row spacing and plant density is a simple, low-cost procedure, but it has a significant influence on production (Severino et al., 2006a; 2006b; Soratto et al., 2012) and it is essential for maximizing seed production (Cox & Cherney, 2011). But, it has to be taken into consideration that increased plant density may result in overcrowded plants (Carvalho et al., 2010) prone to fall, while a small plant population may favor weed infestation, late flowering, broad lateral branches, and tall stems that affect mechanical harvesting (Lopes et al., 2008; Severino et al., 2012).
For castor bean, the nutrition space has a very important role due to the fact that the number of branches on plant depends on the nutrition area and in some cases, on the characteristics of the cultivated variety. The obtained results in this respect highlighted the differentiation of the optimal plant density according to the morpho-physiological peculiarities of the variety, the soil fertility and the water supply. Thus, for the southern conditions of Romania, in the past it was recommended that castor bean

must be sown at 80 cm between rows and 20-25 cm between plants per row, achieving optimal densities of 50-62 thousand plants per hectare (Vrânceanu & Stoenescu, 1970).

Most phytotechnical research has focused on establishing the optimal plant density, because this technological component together with the genetic potential is a determinant of the productive superiority of castor bean varieties. For the growing conditions in Romania, respecting the optimal sowing time and ensuring an appropriate density (80-90 thousand germinal seeds/ha) are leading to safe and good yields of castor bean, plants reaching maturity in time and harvest being performed in a single pass (Prodan & Prodan, 1993).

Research on plant density variation revealed that, compared to the old varieties, the optimal density for new varieties is higher, the optimal density underwent small variations, due to the manifestation of the phenomenon of compensation between productivity elements (Sturzu et al., 2014). It was also highlighted the dependence of yield on plant density in correlation with the reserve and soil moisture dynamics, as well as the relationships between the high plant density and the incidence of disease attack, and the correlation of row distance to weeds with weed control method (Sturzu et al., 2014).

For the pedoclimatic conditions in the Burnas Plain in South Romania, following the studies carried out, Sărdan (2003) recommends a density of 60,000 or 70,000 plants/ha to reduce the degree of branching and increase yields on the main raceme, depending on the climatic conditions of the year.

Attempts to define an optimal plant density of the castor bean crop fail because this optimal density depends on many factors such as plant architecture, soil characteristics, crop management (fertilization, weed control etc.) and environmental conditions during growing period (rainfall, temperature, solar radiation, and air humidity) (Severino et al., 2017).

The complex interaction of plant density factors is reflected in the fact that it is not a widely accepted optimal plant density defined even for major crops such as maize (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), peanuts (*Arachis hypogaea* L.) and soybean (*Glycine max* L.) (Boquet, 2005; Egli, 1988; Rossini et al., 2011; Wells, 1991).

Castor bean has a considerable ability to adjust its yield so that a certain change in plant density is compensated by adjusting the number of racemes, the number of seeds per raceme and the weight of the seeds.

For this reason, it is common to consider negligible or inconsistent the effect of plant density on castor bean production (Bizinoto et al., 2010; Diniz et al., 2009; Petinari et al., 2012; Severino and Auld, 2013; Soratto et al., 2011; 2012; Souza-Schlick et al., 2011; 2012).

The optimal combination of row spacing and plant density can lead to economic maximization of castor bean yield.

Thus, the best economic results were obtained when a smaller space between rows was used (0.45 m).

The highest production cost was for the density of 70,000 plants/ha, due to the use of a larger amount of seeds and fungicide applications. The best profitability index (27.46%) was obtained by combining the distance between rows of 0.45 m and the density of 55,000 plants/ha (Petinari et al., 2012).

In drought conditions, for castor bean crop, the height of the main raceme is positively and directly correlated to plant density. But, the number of racemes per plant and the diameter of the stem are inversely proportional to the plant density. However, yield was not influenced by the number of plants per hectare (Severino et al., 2012).

The use of the optimal combination of row spacing and plant density among a crop allows the best use of light, water and nutrients by plants (Henderson et al., 2000; Tourinho et al., 2002).

The ideal arrangement of plants in the planting area depends on the intrinsic characteristics of the cultivar, such as size, growth habits and architecture of the plants (Bezerra et al., 2009), as well as on the pedo-climatic conditions and management system (Severino et al., 2006a; 2006b; Bizinoto et al., 2010).

Optimizing row spacing and plant density has a significant influence on seed yield. Therefore, our research focused on determining the optimal combination of row spacing and plant density to obtain the best yield under the environmental conditions specific to the South Romania and taking into account the phenotypic expression of the cultivated variety.

MATERIALS AND METHODS

Researches were carried out in field experiments at the Agricultural and Development Research Station Teleorman (ADRS Teleorman) located in South Romania (Teleorman County) in the years 2019 and 2020.

The researches were performed under rainfed conditions on a soil of cambic chernozem type, the vertical subtype, having a loam-clay texture on the depth of the ploughed layer (0-25 cm). From the point of view of the physical and chemical properties, the soil is characterized by a clay content of 45%, humus content of 3.1%, weakly acid reaction (pH varies between 6.1 and 6.5), total nitrogen content of 0.166%, phosphorus mobile of 40-60 ppm, and mobile potassium of 250 ppm.

The main hydro-physical indices of the soil on the horizon 0-80 cm have the following average values: bulk density of 1.43 t/m^3, field capacity of 27.3% (310.4 mm), and permanent wilting point of 15.0% (171.0 mm).

Experimental design. The experiment was based on the method of subdivided plots into 3 replications, with the following factors:

- Factor A - row spacing, with 4 graduations:
  - a1 = 30 cm;
  - a2 = 50 cm;
  - a3 = 70 cm;
  - a4 = 90 cm.
- Factor B - plant density, with 3 graduations:
  - b1 = 40,000 plants/ha;
  - b2 = 60,000 plants/ha;
  - b3 = 80,000 plants/ha.
- Factor C - castor bean variety, with 2 graduations:
  - c1 = Teleorman variety;
  - c2 = Rivlas variety.

The small plot was represented by the variety, the medium plot by the plant density and the large plot by the row spacing.

The biological material consists of two varieties of castor bean, creations of SCDA Teleorman, respectively Teleorman variety, which is an early variety, with 1-3 secondary racemes per plant and with average drought resistance, and achieved seed yields of 1050-1720 kg/ha, and Rivlas variety, which is a semi-late variety, with 0.1-0.2 secondary racemes per plant and with average drought resistance, and achieved seed yields of 1534-2540 kg/ha.

The surface of the experimental plot, the sowing density, the distance between rows, the number of plants/plot, the number of plants/row, the distance between plants/row varied depending on the combination of experimental factors (Table 1).

Crop management. The preceding crop was common autumn wheat. After harvesting the preceding crop, there was performed a harrowing work, and after that the ploughing was performed at a depth of 30 cm. In the autumn, 100 kg of nitrocalcar (27% nitrogen) were applied, being incorporated with the disc harrow work. In the spring, complex chemical fertilizers of the 15:15:15 type were applied, in a dose of 200 kg commercial product on ha. For the preparation of the germination bed, two perpendicular works made with a combinator were performed. After preparing the germination bed, the sowing rows were marked with the SPC-8 seed drill. The sowing was done manually with the planter at a depth of 6 cm. To ensure the number of plants on the plot, 2-3 seeds were sown in the nest. After plant emergence, the plants were thinned, leaving only one plant in the nest.

The control of the weeds was performed by the application immediately after sowing of the herbicides Dual Gold 960 EC (S-metolachlor 960 g/l) at a rate of 1.5 l/ha and Roundup (glyphosate 360 g/l) at a rate of 2.0 l/ha. For controlling in the vegetation period of the monocotyledonous weeds, the herbicide Leopard 5 EC (quizalofop-P-ethyl 50 g/l) was applied in a rate of 0.75 l/ha in the growth stage of 5-6 leaves. Unfortunately, for the control of dicotyledonous weeds there is not yet an herbicide for the castor bean crop with application in the vegetation period. As a consequence, in our field experiments the control of dicotyledonous weeds in the vegetation period was done by a mechanical weeding followed by a manual correction weeding. After the growth stage of appearance of the main raceme, the weeds are no longer a problem for the castor bean crop, because they no longer have favorable conditions for development (light, water and nutrients), the land being well covered by the canopy of the castor bean plants.

Table 1. Experimental factors of the castor bean field experiments in the years 2019 and 2020, at ARDS Teleorman

Fild no.	Combination of experimental factors	Experimental factors			Plots surface (m^2)	No of plants/ plots	No of plants/ row	Distance between plants/row (cm)
		Row spacing (cm)	Plant density (plants/ha)	Castor bean variety				
1	a1b1c1	30	40,000	Teleorman	10	40	10	50.0
2	a1b1c2	30	40,000	Rivlas	10	40	10	50.0
3	a1b2c1	30	60,000	Teleorman	10	40	10	50.0
4	a1b2c2	30	60,000	Rivlas	10	40	10	50.0
5	a1b3c1	30	80,000	Teleorman	14	56	14	35.7
6	a1b3c2	30	80,000	Rivlas	14	56	14	35.7
7	a2b1c1	50	40,000	Teleorman	14	56	14	35.7
8	a2b1c2	50	40,000	Rivlas	14	56	14	35.7
9	a2b2c1	50	60,000	Teleorman	10	60	15	33.3
10	a2b2c2	50	60,000	Rivlas	10	60	15	33.3
11	a2b3c1	50	80,000	Teleorman	10	60	15	33.3
12	a2b3c2	50	80,000	Rivlas	10	60	15	33.3
13	a3b1c1	70	40,000	Teleorman	14	84	21	23.8
14	a3b1c2	70	40,000	Rivlas	14	84	21	23.8
15	a3b2c1	70	60,000	Teleorman	14	84	21	23.8
16	a3b2c2	70	60,000	Rivlas	14	84	21	23.8
17	a3b3c1	70	80,000	Teleorman	10	80	20	25.0
18	a3b3c2	70	80,000	Rivlas	10	80	20	25.0
19	a4b1c1	90	40,000	Teleorman	10	80	20	25.0
20	a4b1c2	90	40,000	Rivlas	10	80	20	25.0
21	a4b2c1	90	60,000	Teleorman	14	112	28	17.8
22	a4b2c2	90	60,000	Rivlas	14	112	28	17.8
23	a4b3c1	90	80,000	Teleorman	14	112	28	17.8
24	a4b3c2	90	80,000	Rivlas	14	112	28	17.8

All experimental variants were sown on the same day and benefited from the same technological elements applied from sowing to harvesting.

All variants were sown on 26 of April in 2019, respectively on 19 of April in 2020. The plants emerged on 8 of May in 2019, respectively on 11 of May in 2020. Harvesting was done manually. After harvesting, the seeds were peeled by hand on each variant.

The calculation and interpretation of the results were made based on the analysis of variance for the experiments placed according to the method of subdivided plots (Ceapoiu, 1968).

Climatic data. In terms of temperature in the experimental years, castor bean benefited throughout the vegetation period from temperatures higher than the multiannual average (Figure 1).

In terms of rainfall, in 2019, castor bean benefited from 376.6 mm of rainfall over the entire vegetation period, being 76.6 mm more than the crop's requirements for moisture, but their distribution was unfavorable to the castor bean crop. Thus, in the first part of the vegetation period the rainfall was quantitatively higher than the multiannual average by +27.2 mm in April, +48.1 mm in May and +99.3 mm in June. During the yield formation period, respectively in July and August there was an accentuated water deficit of - 27.1 mm in July and - 47.2 mm in August (Figure 2).

In 2020, there were excess rainfall in May (+7.8 mm) and June (+11.6 mm), while in April (-21.8 mm), July and August a cumulative deficit of -92.9 mm was registered, compared to the multiannual averages of the area. Practically, it can be said that in July the total drought was installed, when only 2.8 mm of rainfall was recorded, the rainfall being practically absent, and the deficit of the month being of 58.6 mm. The drought continued in August, when only 12.6 mm of rainfall was registered, of which 12.2 mm in the second decade, and the deficit was of 34.4 mm.

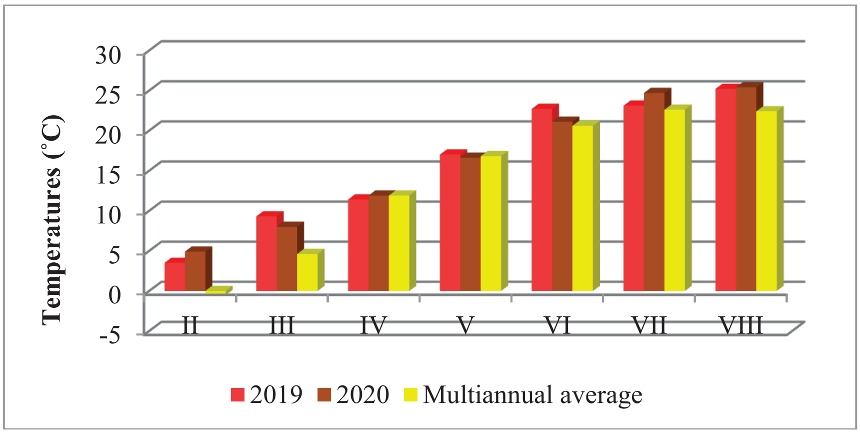

Figure 1. Evolution of average monthly temperatures at ARDS Teleorman in the years 2019 and 2020

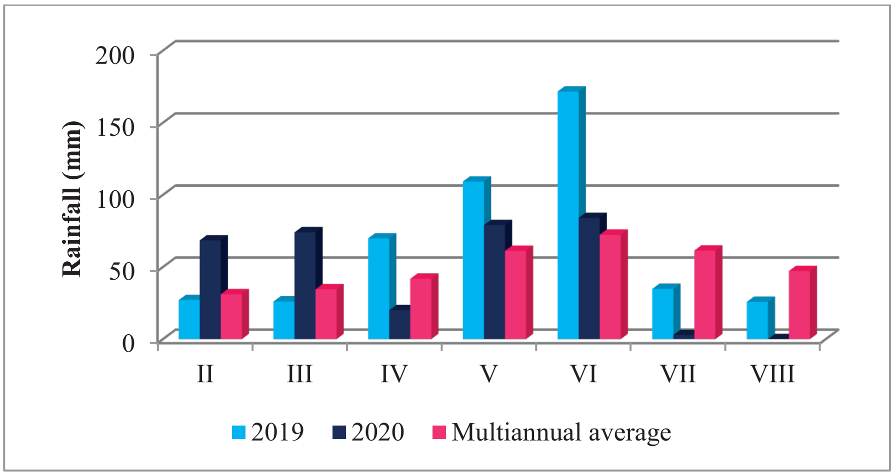

Figure 2. Evolution of rainfall at ARDS Teleorman in the years 2019 and 2020

RESULTS AND DISCUSSIONS

The sum of the temperature degrees from sowing to maturity was different, with values between 2448ºC and 2699ºC in 2019.

The experimental variants sown in the combinations of factors that resulted in a narrower nutritional space required a sum of degrees of lower temperature to reach maturity compared to variants with more space for nutrition. In the case of the number of days from sowing to maturity, the situation is the same, variants whose combinations of factors determined a smaller area of nutrition reached maturity faster than those with a larger area of nutrition. In 2020, in June, there was a drought that affected the castor bean plants so that the differences in the sum of temperature degrees and the number of days from sowing to maturity did not differ.

Due to the architecture of the castor bean plant, breaking strength is a phenomenon that can cause significant production losses. The use of a smaller distance between rows and an increased plant density can result in overcrowded plants prone to falling and breaking, while a larger distance between rows and a lower plant density can favor weed infestation, late flowering, lateral branches and tall stems that affect mechanical harvesting, prolongs the vegetation period and consequently reduces productivity. On average, the lowest percentage of broken plants (6.6%) was recorded at 70 cm between rows and the highest percentage of broken plants at 30 cm between rows (10.9%) (Table 2). On average per plant density at the row spacing of 30 cm, it is observed that with the increase of plant density increased the percentage of broken plants, while at the row spacing of 50 cm, the increase in plant density decreased the percentage of broken plants. At row spacing of 70 cm, the increase in plant density did not affect the percentage of broken plants, and at the row spacing of 90 cm, the increase in plant density from 40,000 to 80,000 plants/ha led to almost a triple increase in the percentage of broken plants (from 3.4 to 9.6%) (Table 2).

For the growing conditions of Romania, as the maturity of secondary racemes is attributed to uncertainty, due to their later appearance, a safe production of castor bean is achieved only from the main racemes. The percentage of monoracemal plants (plants with only one raceme) was influenced by the experimental factors studied, the most visible influence being the row spacing. Thus, the reduction of the distance between the rows to 30 cm led to the overcrowding of the plants and to the reduction of the number of secondary branches, so the increase of the number of monoracemal plants (92.2%). Increasing of the distance between rows determined the decreasing of the percentage of monoracemal plants, the lowest percentage being registered at the row spacing of 90 cm (71.7%) (Table 2). On average, the Teleorman variety has the lowest number of secondary branches of the two studied varieties.

Table 2. Influence of experimental factors on the percentage of broken plants and the percentage of monoracemal plants (ARDS Teleorman, 2019-2020)

Row spacing (cm)	Plant density (plants/ha)	Percentage of broken plants						Percentage of monoracemal plants					
		Variety				Average		Variety				Average	
		Teleorman		Rivlas		Plant density	Row spacing	Teleorman		Rivlas		Plant density	Row spacing
		2019	2020	2019	2020			2019	2020	2019	2020		
30	40,000	11.1	1.3	18.7	0.5	**7.9**		89.3	96.2	86.5	92.5	**91.1**	
	60,000	14.4	1.2	17.7	0.8	**8.5**		87.2	92.3	89.0	91.9	**901**	
	80,000	15.6	1.0	17.4	1.2	**8.8**		97.4	92.1	97.3	94.3	**95.3**	
Average 30		**13.7**	**1.2**	**17.9**	**0.8**		**10.9**	**91.3**	**93.5**	**90.9**	**92.9**		**92.2**
50	40,000	18.0	1.7	19.7	0.5	**10.0**		91.7	90.3	87.5	84.2	**88.4**	
	60,000	17.0	1.3	14.7	0.4	**8.3**		86.9	89.7	83.3	80.3	**85.1**	
	80,000	10.3	1.2	7.8	0.5	**4.9**		93.8	91.2	83.2	80.3	**87.1**	
Average 50 cm		**15.1**	**1.4**	**14.1**	**0.5**		**10.2**	**90.8**	**90.4**	**84.7**	**81.6**		**86.9**
70	40,000	9.1	0.6	10.2	0.5	**5.1**		57.1	83.2	55.7	80.2	**69.1**	
	60,000	9.8	0.5	9.4	0.5	**5.0**		69.8	80.3	65.7	79.5	**73.8**	
	80,000	10.0	1.2	8.7	0.5	**5.1**		91.3	82.7	89.2	80.3	**85.9**	
Average 70 cm		**9.6**	**0.8**	**9.4**	**0.5**		**6.6**	**72.7**	**82.1**	**70.2**	**80.0**		**76.3**
90	40,000	7.1	0.5	4.9	1.2	**3.4**		55.4	70.3	56.0	70.0	**62.9**	
	60,000	7.6	0.5	7.1	0.5	**3.9**		66.9	78.9	57.7	73.1	**69.2**	
	80,000	20.7	1.0	16.2	0.5	**9.6**		89.8	76.3	90.4	75.6	**83.0**	
Average 90 cm		**11.8**	**0.7**	**9.4**	**0.7**		**7.3**	**70.7**	**75.2**	**68.0**	**72.9**		**71.7**
Average variety		**12.5**	**1.0**	**12.7**	**0.6**			**81.4**	**85.3**	**78.5**	**81.9**		
		6.75		**6.65**				**83.4**		**80.2**			

The plant height is influenced by the distance between the rows. It increases with increasing distance between rows and does not show significant differences in different plant densities. On average per variety, Rivlas has the highest height, of 144.6 cm (Table 3).

On average for row spacing, the length of the main raceme had the highest value (34.3 cm) at 50 cm between rows and the smallest value (30.7 cm) at 30 cm between rows. At all graduations of factor A, the decrease of the length of the main raceme is observed with the increase of the plant density. On average per variety, the Rivlas variety had the longest main raceme (34.0 cm) (Table 3).

Table 4 shows how the row spacing and plant density influence the number of seeds on the main raceme. The highest number of seeds on the main raceme (131.6) was obtained at 50 cm between rows, and the smallest number of seeds (101.3) was obtained at 30 cm between rows. On average per variety, Rivlas had the highest number of seeds on the main raceme (120.4).

The weight of the seeds on the main raceme was influenced more by the row spacing than by the plant density. Thus, at 90 cm between rows, the weight of the seeds was of 29.9 g, 31.6 g at 70 cm between rows, 32.5 g at 50 cm between rows, and 25.7 g at 30 cm between rows. On average per variety, Rivlas had a higher seed weight on the main raceme than Teleorman variety (Table 4).

Table 3. Influence of experimental factors on plant height and main raceme length (ARDS Teleorman, 2019-2020)

Row spacing (cm)	Plant density (plants/ha)	The plant height (cm)						The length of the main raceme (cm)					
		Variety				Average		Variety				Average	
		Teleorman		Rivlas		Plant density	Row spacing	Teleorman		Rivlas		Plant density	Row spacing
		2019	2020	2019	2020			2019	2020	2019	2020		
30	40,000	143	113	156	109	**130.3**		37	23	40	21	**30.3**	
	60,000	147	117	154	100	**129.5**		40	19	40	20	**29.8**	
	80,000	149	105	158	100	**128.0**		38	20	40	30	**32.0**	
Average 30		**146.3**	**111.7**	**156.0**	**103.0**		**129.3**	**38.3**	**20.7**	**40.0**	**23.7**		**30.7**
50	40,000	148	115	160	131	**138.5**		42	26	46	32	**36.5**	
	60,000	150	110	164	103	**131.8**		44	22	53	25	**36.0**	
	80,000	148	123	161	135	**141.8**		40	21	41	20	**30.5**	
Average 50		**148.7**	**116.0**	**161.7**	**123.0**		**137.3**	**42.0**	**23.0**	**46.7**	**25.7**		**34.3**
70	40,000	147	144	162	131	**146.0**		40	20	49	23	**33.0**	
	60,000	159	119	164	144	**146.5**		43	20	46	21	**32.5**	
	80,000	156	122	167	131	**144.0**		38	24	47	20	**32.3**	
Average 70		**154.0**	**128.3**	**164.3**	**135.0**		**145.5**	**40.3**	**21.3**	**47.3**	**21.3**		**32.6**
90	40,000	160	112	167	148	**146.8**		36	21	45	23	**31.3**	
	60,000	153	136	169	144	**150.5**		40	23	46	26	**33.8**	
	80,000	159	94	167	145	**141.3**		36	24	41	21	**30.5**	
Average 90		**157.3**	**114.0**	**167.7**	**146.0**		**146.2**	**37.3**	**22.7**	**44.0**	**23.3**		**31.8**
Average variety		**151.6**	**117.5**	**162.4**	**126.8**			**39.5**	**21.9**	**44.5**	**23.5**		
		134.6		**144.6**				**30.7**		**34.0**			

Table 4. Influence of experimental factors on the number of seeds and their weight on the main raceme (ARDS Teleorman, 2019-2020)

Row spacing (cm)	Plant density (plants/ha)	Number of seeds on the main raceme						Seed weight on the main raceme (g)					
		Variety				Average		Variety				Average	
		Teleorman		Rivlas		Plant density	Row spacing	Teleorman		Rivlas		Plant density	Row spacing
		2019	2020	2019	2020			2019	2020	2019	2020		
30	40,000	90	74	154	77	**98.8**		23.8	20.7	46.3	21.4	**28.1**	
	60,000	98	68	129	75	**92.5**		26.1	16.4	38.4	18.9	**25.0**	
	80,000	80	89	130	75	**93.5**		21.3	17.9	38.9	18.8	**24.2**	
Average 30		**89.3**	**77.0**	**137.7**	**75.7**		**101.3**	**23.7**	**18.3**	**41.2**	**19.7**		**25.7**
50	40,000	155	98	58	78	**97.3**		41.2	23.5	38.0	24.7	**31.9**	
	60,000	166	86	72	112	**109.0**		41.9	17.6	45.8	31.1	**34.1**	
	80,000	139	90	119	107	**113.8**		32.3	21.4	46.1	26.5	**31.6**	
Average 50		**153.3**	**91.3**	**150.0**	**99.0**		**131.6**	**38.5**	**20.8**	**43.3**	**27.4**		**32.5**
70	40,000	106	120	122	102	**112.5**		29.2	26.2	37.9	30.5	**31.0**	
	60,000	164	87	135	140	**131.5**		40.9	24.4	41.6	31.3	**34.6**	
	80,000	93	93	122	112	**105.0**		26.8	22.9	39.1	28.0	**29.2**	
Average 70		**121.0**	**100.0**	**126.3**	**118.0**		**115.8**	**32.3**	**24.5**	**39.5**	**29.9**		**31.6**
90	40,000	130	96	134	126	**121.5**		33.8	30.7	40.6	36.3	**35.4**	
	60,000	121	103	133	122	**119.8**		34.1	26.0	42.8	29.1	**33.0**	
	80,000	133	111,0	134	120,0	**124.5**		32.2	24.4	43.3	30.4	**32.6**	
Average 90		**128.0**	**103.3**	**133.7**	**122.7**		**121.7**	**33.4**	**27.0**	**42.2**	**31.9**		**29.9**
Average variety		**122.9**	**92.9**	**136.9**	**103.8**			**32.0**	**22.7**	**41.6**	**27.3**		
		107.9		**120.4**				**27.4**		**34.5**			

For all biometric productivity elements one can say that they are largely influenced by factor A (row spacing) and factor C (variety).

Factor B (plant density) to a lesser extent influences the differences between the experimental variants.

Analyzing the yields obtained for the experimental variants one can observe that the increase of the distance between rows from 30 cm to 50 cm, 70 cm and 90 cm determines a progressive increase of the yields in both years of experimentation (Table 5).

Table 5. Influence of experimental factors on castor bean yields (ARDS Teleorman, 2019-2020)

Row spacing (cm)	Plant density (plants/ha)	Yields (kg/ha)					
		Variety				Average	
		Teleorman		Rivlas		Plant density	Row spacing
		2019	2020	2019	2020		
30	40,000	740	620	1408	713	**870.3**	
	60,000	788	846	1188	946	**942.0**	
	80,000	665	1107	1230	1314	**1079.0**	
Average 30 cm		**731.0**	**857.7**	**1275.3**	**991.0**		**954.7**
50	40,000	1320	845	1174	839	**1044.5**	
	60,000	1741	914	2276	1462	**1598.3**	
	80,000	1722	1474	2448	1645	**1822.3**	
Average 50 cm		**1594.3**	**1077.7**	**1966.0**	**1315.3**		**1488.3**
70	40,000	1564	936	1945	1001	**1361.5**	
	60,000	2185	1257	2224	1522	**1797.0**	
	80,000	1882	1605	2730	1740	**1989.3**	
Average 70 cm		**1877.0**	**1266.0**	**2299.7**	**1421.0**		**1814.2**
90	40,000	2410	1143	2643	1370	**189.5**	
	60,000	1766	1442	2707	1699	**1903.5**	
	80,000	1870	1874,0	2556	1945,0	**2061.3**	
Average 90 cm		**2015.3**	**1486.3**	**2635.3**	**1671.3**		**2045.7**
Average variety		**1554.4**	**1171.9**	**1590.1**	**1349.7**		
		1363.2		**1469.9**			

Table 6. Limit differences for all combinations of factors (ARDS Teleorman, 2019-2020)

LSD (kg/ha)	For row spacing		For plant density		For variety		a1b2-a1b1		a2b2-a1b1		a1c2-a1c1	
	2019	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**
5%	137.7	92.98	130.5	30.36	119.4	30.71	260.9	70.14	236.8	105.17	206.8	61.45
1%	208.5	140.79	172.4	41.81	162.3	41.75	344.8	106.22	325.4	155.70	281.1	83.52
0.01%	334.9	226.18	237.3	5757	217.4	55.91	476.6	170.63	470.5	241.90	376.5	111.86
-	**b1c2-b1c1**		**b2c2-b1c2**		**a2c2-a1c2**		**a1b1c2-a1b1c1**		**a1b2c1-a1b1c1**		**a2b1c1-a1b1c1**	
5%	238.8	53.21	195.9	43.49	86.1	42.67	391.8	86.05	386.6	52.21	82.19	128.88
1%	324.6	72.32	263.1	59.42	121.8	48.63	526.2	116.96	527.8	59.31	139.33	185.02
0.01%	434.8	96.86	356.4	80.45	175.6	56.28	712.9	156.64	729.8	68.92	296.56	273.58

Comparing the average yields one find that there are statistically assured differences between the yields obtained at the four row spacing. The strongest growth is recorded with the increase of row spacing from 30 cm to 90 cm (+ 1091 kg/ha). The increasing trend is maintained and it is still strong with each increase in row spacing from 50 cm to 70 cm and 90 cm, adding an increase of about 300 kg/ha, statistically increase being distinctly significant (Table 5).

Analyzing the average yields by plant density, one finds that there are differences depending on this factor.

Yields increase with increasing of density from 40,000 plants/ha to 60,000 plants/ha and to 80,000 plants/ha.

Regardless of the row spacing and plant density, the Rivlas variety exceeds the Teleorman variety in average by 106.7 kg/ha, a statistically assured difference being very significant.

By analyzing the influence of plant density at the same row spacing one find that at the same row spacing one can obtain yield increases by increasing the plant density (Table 7). The increases are statistically ensured for both varieties by increasing the density from 40,000 plants/ha to 60,000 plants/ha and 80,000 plants/ha.

Table 7. Analysis of variance for experience with row spacing x plant density x variety (ARDS Teleorman, 2019-2020)

Source of Variation	Sum of Squares (SS)		Degrees of Freedom (DF)	Mean Squares (MS)		F-test	
	2019	2020		2019	2020	2019	2020
Row spacing	17898.12	4058932	3	59660.71	1352977.3	209.9***	104.4***
Plant density	8051.20	5142410	2	4025.60	2571204.9	9.6**	1044.9***
Row spacing x plant density	32181.95	84163,25	6	5363,66	14027.2	12.8***	5.7*
Variety	43134.74	570312	1	43134.74	570312.0	71.3***	142.5***
Row spacing x variety	179004.86	27330	3	59668.29	9110.0	98.6***	2.3^{NS}
Plant density x variety	5367.92	127422.8	2	2683.96	63711.4	4.4^{NS}	15.9**
Row spacing x plant density x variety	10300.89	186392.3	6	858.41	31065.4	1.4^{NS}	7.8**

CONCLUSIONS

Considering the architecture of the plant and the way the plant growth and develop, it is very important to find for castor bean the optimal nutrition space. An optimal nutrition space can be obtained by reducing the branching capacity and obtaining high yields on the main raceme. The use of narrow rows and an increased plant density results in overcrowded plants prone to falling and breaking, while the wide rows and a lower plant density favors weed infestation, late flowering, branching and tall stems that affect mechanical harvesting, prolongs the growing season and consequently reduces productivity.

Increasing of row spacing and plant density is associated with increasing of grain yield. The highest average yield of 2061.3 kg/ha was obtained at row spacing of 90 cm and density of 80,000 plants/ha, but a close yield with a difference of only 72 kg was obtained at row spacing of 70 cm and density of 80,000 plants/ha.

The Rivlas variety turned out to be more productive than the Teleorman variety.

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