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INFLUENCE OF SOME AGRO-TECHNICAL TREATMENTS ON THE DEVELOPMENT AND YIELDS OF AMARANTH

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Abstract

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This study was based on a field experiment conducted in 2010-2012 at the Experimental Station in Tomaszkowo near Olsztyn. The experiment was set up on light soil of very good rye complex, in a split-plot sub-block design with four replications. During the experiment, amaranth seeds were sown at a rate of 1.5 kg ha^{-1}, in rows spaced at 50 cm, in the last decade of May. The objective was to determine the effect of different doses of mineral fertilization (N + P + K) and fungicide treatments on the yield of seeds, protein and fat per field area unit and on some biometric traits: plants' height, length of inflorescences, 1000-seed weight, obtained from the amaranth cultivar Aztek. It was determined that mineral fertilization had a significant influence on all analyzed characteristics. The highest parameters of the tested traits were achieved from the plots with the highest mineral fertilization. The level of fungal control had a significant effect only on the protein yield.

Key words: amaranth, chemical composition, mineral fertilization, seed yield

Introduction

Amaranth is a pseudocereal crop, which used to be grown for food in ancient America. Both grains and green parts of this plant have remained an important component of a human diet in countries which suffer from food shortages. Stallknecht and Schulz-Schaeffer (1993) as well as Starczewski and Maksymiak (2001) report on a growing acreage of amaranth plantations owing to the high biological value of its seeds and leaves and to a great variety of uses of the plant. The total acreage under amaranth fields is growing in response to the demand stimulated by the food processing, pharmaceutical, cosmetics, electronics and energy generation industries. Penkov and Pavlov (2000) recommend includ in the compound feeds for animals, especially geese. Filipek and Bartnik (2000) highlight a very good chemical composition of amaranth seeds, which contain between 16 and 20% of protein, including an exceptionally high share of exogenous amino acids, from 3 to 9% of fat with very good biological quality, and high concentrations of macro- and micronutrients, such as potassium, magnesium and iron. In the food industry, because of their wholesome composition, amaranth seeds are used as an ingredient improving the nutritive value and dietary quality of food products made from grains of other cereal plants. Kościk (2003) underlines the fact that amaranth is increasingly often used as a renewable energy crop owing to its high biomass output, produced especially by fodder varieties. In the pharmaceutical industry, amaranth seeds are processed into anti-arteriosclerotic preparations as well as medicinal preparations fortifying the heart and cardiovascular system (Grajeta, 1997; Prokopowicz, 2001).

The purpose of this study has been to determine the effect of different mineral fertilization rates and anti-fungal preparations on the growth, development and yields as well as the protein and fat yields obtained from amaranth plants.

Materials and Methods

In 2010-2012, a strict, three-year, field experiment was conducted at the Experimental Station in Tomaszkowo near Olsztyn (north-west part of Poland; 53,7°N, 20,4°E). The experimental factors consisted of the following rates of mineral fertilizers:

- N+P+K1 – nitrogen 0 kg ha^{-1}, phosphorus 40 kg ha^{-1}, potassium 40 kg ha^{-1},
- N+P+K2 – nitrogen 30 kg ha^{-1}, phosphorus 40 kg ha^{-1}, potassium 40 kg ha^{-1},

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- N+P+K3 – nitrogen 60 kg ha^{-1}, phosphorus 50 kg ha^{-1}, potassium 50 kg ha^{-1},
- N+P+K4 – nitrogen 90 kg ha^{-1} (60+30), phosphorus 60 kg ha^{-1}, potassium 60 kg ha^{-1},
- N+P+K5 – nitrogen 120 kg ha^{-1} (60+60), phosphorus 70 kg ha^{-1}, potassium 70 kg ha^{-1},

and protection against diseases:

- without seed dressing,
- with an application of the seed dressing fungicide Funaben T (active substance: tiuram – tetramethylenethiuram disulphide + carbendazim-benzimidazol-2-yl methyl carbamate) + one treatment with Alert 375 SC (active substance: flusilazol + carbendazim) in a dose of 1 l.ha^{-1}, at the phase of 5-6 true leaves,
- the fungicide Funaben T + two treatments (Alert 375 SC in a dose of 1 l.ha^{-1}, at the phase of 5-6 of true leaves and Rovral FLO 500 SC – active substance: iprodion) in a dose of 0.7 l.ha^{-1}, given during the early budding phase.

The experiment on the amaranth cultivar Aztek (bred at the Institute of Plant Breeding and Acclimatization in Radzikowo in Poland) was set up on light soil, classified as very good rye complex, with the following content of basic nutrients appeared in (in 2010, 2011 and 2012, respectively): 48 mg.kg^{-1}, 61 mg.kg^{-1} and 59 mg.kg^{-1} of phosphorus, 130 mg.kg^{-1}, 119 mg.kg^{-1} and 128 mg.kg^{-1} of potassium, and 52 mg.kg^{-1}, 47 mg.kg^{-1}, and 58 mg.kg^{-1} of magnesium. The preceding crops were cereals: spring triticale (twice, in the first and second year) and spring barley (once, in the third year of the experiment). The experiment was run in a split-block design with four replications. Each year, amaranth was sown in the last decade of May, with 1.5 kg seeds ha^{-1} sown in rows spaced at 50 cm. The most optimal plant stand for amaranth is said to be 22 plants per 1 m^{-2}. The actual plant stand in our experiment ranged from 19 to 21 plants per m^{-2}. Amaranth seeds were harvested during the wax maturity phase.

Before harvest, a sample of randomly chosen 10 plants from each plot was taken to measure the height of plants and the length of inflorescences. After harvest, the volume of seed yield was expressed in t·ha^{-1}, at the seed humidity equal 13%. The content of crude fat in seeds was determined with the Soxhlet's method, while the content of protein was assessed according to Kjeldahl. The results were submitted to analysis of variance with the Tukey's test (at p = 0.05).

Results

The course of the weather conditions during the whole experiment is presented according to the data collected by the Meteorological Station in Tomaszkowo (Poland) (Table 1). During the three years of the experiment, the weather conditions were highly changeable. The first year was characterized by a higher mean air temperature than the multi-year average in June, July and August. Significantly higher temperature than the multi-year mean temperature was recorded especially in July and August: 3.4° and 2.1°C higher, respectively. In May and September that year, the mean air temperature was lower than the multi-year value. In the second year of the trial, the air temperature was higher than the multi-year mean throughout the whole plant growing season, thus being the closest to the optimum temperature required by amaranth. The third year was the coolest. It was characterized by a lower air temperature during the whole vegetative season. April and May were particularly cold, while July was the warmest one, with the highest air temperature.

Amaranth needs much water, and during the three years of the experiment the supply of water was insufficient. The

Table 1
Temperatures and rainfall in the vegetation period of amaranth according to Meteorological Station in Tomaszkowo

Years	Average monthly temperatures						
	IV	V	VI	VII	VIII	IX	X
2010	8.1	12.0	16.4	21.1	19.3	12.0	5.0
2011	9.1	13.1	17.1	17.9	17.6	14.1	8.3
2012	7.8	13.4	15.0	19.0	17.7	13.5	7.4
Average 1961-2000	6.9	12.7	15.9	17.7	17.2	12.5	7.8
Years	Monthly rainfall, mm						
	IV	V	VI	VII	VIII	IX	X
2010	18.2	131.9	84.8	80.4	95.3	40.5	24.1
2011	22.5	51.1	81.7	202.8	82.1	67.5	29.5
2012	73.1	51.7	103.2	121.0	45.1	45.7	68.5
Average 1961-2000	36.1	51.9	79.3	73.8	67.1	59.0	43.4

highest average sum of rainfall was recorded in July in the second year of the study and the lowest – in April and October in the first year. The sum of precipitations during the three-year experiment was higher than the multi-year sum in each period of the intensive growth of amaranth. However, during every year of the experiment, there were shorter or longer periods of water deficits.

It was demonstrated that the applied mineral fertilization had a significant effect on the height of amaranth plants (Table 2). Significantly the highest plants were observed after an application of the second mineral fertilization level. The highest plants were grown in 2011 and under the highest level of anti-fungal protection (where no significant differences were determined).

The climatic conditions during the experiment and mineral fertilization had a significant effect on the length of inflorescences (Table 3). The longest ones were found in 2010 and on plots with the highest dose of mineral fertilization. The application of fungicides had no significant influence on the length of amaranth inflorescences.

Although the 1000-seed weight was varied during the three years of the experiment, no statistically significant differences were observed in this trait, which confirms a considerable dispersion of the results achieved (Table 4). The most robust seeds were obtained in 2010, but the smallest 1000-seed weight was recorded in 2011, which was 17% lower than in 2010. The statistical analysis did not demonstrate any significant effect of the fungicide treatments on the weight of 1000-seed, although a growing tendency in the value of the trait was observed.

The year of the experiment and the applied rate of mineral fertilization had significant impact on the seed yield produced by amaranth (Table 5). The highest yield was achieved in 2010, where it reached an average of 2.17 t ha^{-1} and was 15% higher than the lowest seed yield, harvested in 2011. As the dosage of mineral fertilization increased, a significant increase in seed yields was observed. The application of fungicides did not differentiate significantly seed yields. However, a rising tendency was noticed with regard to this trait in response to a more intensive anti-fungal protection.

The analyzed factors had a significant effect on the level of protein yield (Table 6). As the mineral fertilization rate and level of applied fungicides went up, the protein yield increased as well. To a large extent, the yield of protein depended on the seed yield volume. The highest protein yield was noticed in 2010 (356.4 kg.ha^{-1}). On the other hand the lowest protein yield was recorded in 2011 (302.6 kg.ha^{-1}). The application of fungicides contributed to a significant increase in the protein yield, which became evident already after the application of seed dressing or just one fungicide treatment.

Table 2
Plant hight of amaranth (cm)

Years	Protection method	Mineral fertilization					Mean
		N+P+K1	N+P+K2	N+P+K3	N+P+K4	N+P+K5	
2010	a	127.0	139.0	148.5	155.0	176.0	149.1
	b	126.5	142.0	146.0	157.0	177.0	149.7
	c	133.5	142.0	147.0	159.0	179.0	152.1
2011	a	137.0	145.0	158.0	169.0	182.0	158.2
	b	137.0	147.0	156.0	167.0	188.0	159.0
	c	138.0	147.0	157.0	168.0	189.0	159.8
2012	a	135.0	148.0	154.0	161.0	175.0	154.6
	b	137.0	148.0	155.0	164.0	177.0	156.2
	c	137.0	149.0	157.0	164.0	178.0	157.0
2010	-	129.0	141.0	147.2	157.0	177.3	150.3
2011		137.3	146.3	157.0	168.0	186.3	159.0
2012		136.3	148.3	155.3	163.0	176.7	155.9
-	a	133.0	144.0	153.5	161.7	177.7	154.0
	b	133.5	145.7	152.3	162.7	180.7	155.0
	c	136.2	146.0	153.7	163.7	182.0	156.3
Mean		134.2	145.2	153.2	162.7	180.1	-
LSD (0.05) for: years – 3.2; mineral fertilization – 4.9; other interactions – ns*							

*- not significant difference

Mineral fertilization had a significant effect on the fat yield (Table 7). The average fat yield ranged from 96.4 to 174.3 kg.ha^{-1}. The highest fat yield (analogously to the protein yield) was found in 2010, when it equaled 142.8 kg.ha^{-1}.

Table 3
Inflorescence lenght of amaranth (cm)

Years	Protection method	Mineral fertilization					Mean
		N+P+K1	N+P+K2	N+P+K3	N+P+K4	N+P+K5	
2010	a	46.0	52.1	55.0	58.0	63.0	54.8
	b	48.0	53.0	55.0	57.0	63.0	55.2
	c	49.2	54.0	56.1	57.5	64.0	56.2
2011	a	41.0	44.0	48.0	51.0	53.0	47.4
	b	42.0	46.0	47.0	52.0	55.0	48.4
	c	42.0	46.0	48.0	53.0	55.0	48.8
2012	a	44.0	47.0	52.0	53.0	56.0	50.4
	b	44.0	48.0	52.0	54.0	57.0	51.0
	c	44.0	48.0	52.0	54.0	57.0	51.0
2010	-	47.7	53.0	55.4	57.5	63.3	55.4
2011		41.7	45.3	47.7	52.0	54.3	48.2
2012		44.0	47.7	52.0	53.7	56.7	50.8
-	a	43.7	47.7	51.7	54.0	57.3	50.9
	b	44.7	49.0	51.3	54.3	58.3	51.5
	c	45.1	49.3	52.0	54.8	58.7	52.0
Mean		44.5	48.7	51.7	54.4	58.1	-
LSD (0.05) for: years – 1.8; mineral fertilization – 3.6; years x mineral fertilization – 0.40; other interactions – ns							

Table 4
Weight of 1000 seeds of amaranth (g) relative humidity of 13%

Years	Protection method	Mineral fertilization					Mean
		N+P+K1	N+P+K2	N+P+K3	N+P+K4	N+P+K5	
2010	a	0.611	0.634	0.652	0.675	0.737	0.662
	b	0.643	0.681	0.695	0.764	0.813	0.719
	c	0.659	0.692	0.736	0.849	0.877	0.763
2011	a	0.551	0.563	0.578	0.583	0.611	0.577
	b	0.554	0.569	0.581	0.598	0.627	0.586
	c	0.561	0.586	0.597	0.613	0.694	0.610
2012	a	0.572	0.583	0.598	0.619	0.646	0.604
	b	0.575	0.591	0.614	0.631	0.678	0.618
	c	0.587	0.609	0.629	0.648	0.691	0.633
2010	-	0.638	0.669	0.694	0.763	0.809	0.715
2011		0.555	0.573	0.585	0.598	0.644	0.591
2012		0.578	0.594	0.614	0.633	0.672	0.618
-	a	0.578	0.593	0.609	0.626	0.665	0.614
	b	0.591	0.614	0.630	0.664	0.706	0.641
	c	0.602	0.629	0.654	0.703	0.754	0.669
Mean		0.590	0.612	0.631	0.664	0.708	-
LSD (0.05) for: mineral fertilization – 0.067; other interactions – ns							

The highest mean fat yield was obtained from the plots with the highest mineral fertilization. The research results did not verify a significant effect of the application of fungicides on the volume of fat yield. Nonetheless, an increasing tendency

Table 5
Yield seeds of amaranth ($t \cdot ha^{-1}$) relative humidity of 13%

Years	Protection method	Mineral fertilization					Mean
		N+P+K1	N+P+K2	N+P+K3	N+P+K4	N+P+K5	
2010	a	1.50	1.57	2.01	2.18	2.49	1.95
	b	1.72	1.78	2.22	2.70	2.66	2.22
	c	1.84	2.13	2.18	2.73	2.80	2.34
2011	a	1.17	1.37	1.55	2.20	2.46	1.75
	b	1.24	1.58	1.83	2.23	2.50	1.88
	c	1.42	1.58	1.92	2.28	2.49	1.94
2012	a	1.49	1.75	2.10	2.34	2.53	2.04
	b	1.51	1.61	1.90	2.55	2.73	2.06
	c	1.63	1.75	1.95	2.61	2.68	2.12
2010	-	1.69	1.83	2.14	2.54	2.65	2.17
2011		1.28	1.51	1.77	2.24	2.48	1.85
2012		1.54	1.70	1.98	2.50	2.65	2.08
-	a	1.39	1.56	1.89	2.24	2.49	1.91
	b	1.49	1.66	1.98	2.49	2.63	2.05
	c	1.63	1.82	2.02	2.54	2.66	2.13
Mean		1.50	1.68	1.96	2.42	2.59	-
LSD (0.05) for: years – 0.18; mineral fertilization – 0.34; years x mineral fertilization – 0.40; other interactions – ns							

Table 6
Protein yield of amaranth ($kg \cdot ha^{-1}$) of relative humidity of 13%

Years	Protection method	Mineral fertilization					Mean
		N+P+K1	N+P+K2	N+P+K3	N+P+K4	N+P+K5	
2010	a	234.0	252.8	329.6	364.1	418.3	319.8
	b	270.0	286.6	361.9	453.6	446.9	363.8
	c	290.7	345.1	359.7	461.4	473.2	386.0
2011	a	181.4	216.5	251.1	363.0	410.8	284.5
	b	193.4	251.2	296.5	370.2	420.0	306.3
	c	221.5	251.2	313.0	380.8	418.3	317.0
2012	a	229.5	274.8	340.2	388.4	425.0	331.6
	b	232.5	251.2	311.6	425.9	461.4	336.5
	c	254.3	278.3	319.8	435.9	452.9	348.2
2010	-	264.8	294.7	350.4	426.2	446.1	356.4
2011		198.7	239.6	286.8	371.3	416.4	302.6
2012		238.7	268.0	323.9	416.7	446.4	338.7
-	a	214.9	248.0	306.9	371.8	418.0	312.0
	b	231.9	262.9	323.3	416.4	442.7	335.4
	c	255.4	291.2	330.7	425.9	448.1	350.3
Mean		234.1	267.5	320.4	404.8	436.3	-
LSD (0.05) for: mineral fertilization – 32.2; protection method – 22.9; other interactions – ns							

Table 7
Fat yield of amaranth (kg.ha-1) of relative humidity of 13%

Years	Protection method	Mineral fertilization					Mean
		N+P+K1	N+P+K2	N+P+K3	N+P+K4	N+P+K5	
2010	a	96.3	101.4	130.7	143.7	167.3	127.9
	b	110.3	115.0	144.5	178.5	180.3	145.7
	c	119.0	138.5	142.8	181.3	193.5	155.0
2011	a	73.9	86.7	99.2	142.3	161.1	112.7
	b	78.4	100.6	117.7	144.7	164.8	121.2
	c	90.2	100.3	124.0	148.9	165.6	125.8
2012	a	96.6	113.8	137.6	154.9	170.3	134.6
	b	97.4	105.0	124.6	169.1	184.3	136.1
	c	105.8	114.5	128.5	174.1	181.4	140.9
2010	-	108.5	118.2	139.3	167.8	180.3	142.8
2011		80.8	95.9	113.6	145.3	163.8	119.9
2012		99.9	111.1	130.2	166.0	178.7	137.2
-	a	88.8	100.5	122.3	146.9	166.2	125.0
	b	95.3	106.9	128.9	164.0	176.4	134.3
	c	104.9	117.6	131.8	168.0	180.0	140.5
Mean		96.4	108.4	127.7	159.7	174.3	-
LSD (0.05) for: mineral fertilization – 13.6; other interactions – ns							

for fat yield was noticed on plots where the anti-fungal protection was on more intensive.

Discussion

The vegetative period for amaranth is from 95 to 130 days. Espitia (1992) claims than on average it lasts for about 160 days. In the authors' own studies, the growing season for amaranth plants was much longer, lasting from 178 to 181 days.

Starczewski and Maksymiak (2001) reported that by the soil and climatic conditions as well as the applied agronomic treatments the growth and development of amaranth are significantly affected. Amaranth is a thermophilic plant, which requires between 2 000 to 2 600°C of the temperature sum during its vegetation. Edwards (1980) and Songin (1999) indicate that an optimum temperature for the proper growth and development of amaranth should be from 25 to 28°C. Nalborczyk et al. (1994) report that amaranth grows and develops well at a temperature from 16 to 35°C. Ladińska-Górko (2007) and Szot (1999) identify amaranth as a xerothermic plant, which tolerates well periodic water shortages, although a sufficient amount of rainfall in August has very good influence on its growth and development. Songin (1999) adds that although amaranth has good water management, it grows and yields very well in these parts of the world where the sum of rainfall during the plant growing season is above 300 mm. In the authors' own investigations, the sum of rainfall was higher than indicated by Songin (1999).

Pospisil et al. (2006) did not find any significant effect of nitrogen fertilization on the height of amaranth plants. Nalborczyk (1994) claims that given proper agronomic treatments and conditions amaranth can grow as high as 2.5 m. Gontarczyk (1993) underlines that amaranth develops very well at higher rates of mineral fertilization.

In the experiment reported herein, the length of inflorescences depended significantly on the level of mineral fertilization. Similarly, in an experiment conducted by Pospisil et al. (2006), the value of this trait increased with a higher rate of nitrogen.

A significant increase in the amaranth seed yield appeared in response to the mineral fertilization applied in our experiment. The highest yield was obtained from the plots nourished with the highest dose of mineral fertilizers. Similar results were reported by Myers (1998), Schulte auf'm Erley et al. (2005) and Pospisil et al. (2006). On the other hand, Bressani et al. (1987), Olaniyi et al. (2008) and Skwaryło-Bednarz et al. (2011) noticed a decline in seed yield following an application of a highest dose of mineral fertilization.

Roszewski (1994) and Songin (1999) underline the fact that fertilization, and nitrogen nutrition in particular, significantly affects the growth and development of amaranth. Elbehri et al. (1993) recorded an increase of up to 5% in the content of protein in amaranth seeds in response to nitrogen fertilization.

Also, Bressani et al. (1987) and Meyers (1998) demonstrated an increase in the protein concentration in seeds under the influence of increasing rates of mineral fertilization.

Roszewski (1994) and Skwaryło-Bednarz (2010) emphasize the fact that amaranth plants grow very intensively and produce better yields in response to higher rates of mineral fertilizers. Amaranth produces seed yields between 1.5 to 3.5 t.ha^{-1} (Nalborczyk et al., 1994; Malicki and Sobczak, 1999).

Skwaryło-Bednarz (2010) reports that the NPK fertilization in a dose of 130 kg.ha^{-1} N, 70 kg.ha^{-1} P and 70 kg.ha^{-1} K has a significant effect on the content of fat in amaranth seeds. More fat in seeds under the influence of mineral fertilization was also observed by Bressani et al. (1987).

Conclusions

Under the climatic and soil conditions typical of north-eastern Poland, cultivation of amaranth can bring satisfying results. The analyzed plantation of amaranth was established on light soil but produced seed yield was 2.80 t.ha^{-1}, when was fertilized with N 120 + P70 + K70 kg.ha^{-1} and provided intensive anti-fungal protection. Mineral fertilization had a positive influence on the analyzed traits of amaranth. Significant differentiation was noticed in the seed yield, 1000-seed weight, and plant height, length of inflorescences, protein yield and fat yield. The fungal control did not have any significant influence on the analyzed characteristics although they tended to increase when amaranth plants were treated with fungicides. The highest yield was obtained in 2010 (2.17 t.ha^{-1} on average), although that vegetative season had the lowest sum of rainfall. The protein and fat yields were strongly affected by the seed yield.

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