VARIABILITY OF THE NUMBER AND ARRANGEMENT OF PLANTS IN A SUGAR BEET CANOPY UNDER ENVIRONMENTAL AND AGROTECHNICAL FACTORS

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In the years 1992–1994 a multifactorial experiment of type 2^7 with triploid sugar beet variety Kawejana was carried out to evaluate the number of plants and their arrangement over an area. Field emergence (FE) and number of plants were determined; the latter in phases: after emergence, BBCH 14–18 and at harvest. Then, arrangement in the rows as well as living area of individuals in the canopy were analyzed. Sowing date (two week difference) was a main factor determining field emergence. FE (varying from 55.5 to 77.5%) was mainly the result of weather conditions in a given year. With an early date, FE was on average 73%, while with a late one 64%. FE and natural losses during the growing season determined plant density at BBCH 14–18 phase and at harvest. Final plant density in treatments with the first sowing date was for different years of investigation: 106,100, 91,100 and 102,400 plants ha^{-1}, respectively, while with the late one 101,900, 84,000 and 97,800 plants ha^{-1}, respectively. Plant losses between emergence and BBCH 14–18 were on average 4.2% of the initial number, increasing by 10.3% up to the time of harvest. Living area of plants was highly differentiated, from 112.5 to 3667.5 cm^2. The share of plants with optimum living area (950–1250 cm^2) was small and varied 14.4 – 26.9%, depending on year of study and levels of experimental factors.

sugar beet canopy; plant density; plant arrangement; plant living area

INTRODUCTION

Root yield and the technological quality of sugar beet are determined in the field of growing plants. The plant population in the form a sugar beet canopy is affected by environmental factors, and also by the farmer, who applies a large amount of fossil energy (i.e. machines, fertilizers and pesticides), and various techniques in soil preparation and sowing, (e.g. targetted sowing) with a view to intervening in the processes occurring in the agrosystem population (Erjala, 1991; Wevers, 1992; Durrant et al., 1993; Durr, Boiffin, 1995). To increase the benefit plants drawn from these techniques and products, a farmer introduces the output of scientific progress with breeding, biology and technology (*inter alia* cultivars with a marked capacity to produce root growth or to generate a more effectively functioning leaf rosette, as well as genetically- and technically-improved sowing material). Plant metabolism is modified through changes in technologies of production, and especially through the use of factors that change the number of plants per plantation, duration of the growing season and conditions underpinning plant mineral nutrition (Er, Inan, 1989; Dunham, 1991; Smit, 1993; Draycott et al., 1997; Jozefyova et al., 2003). Plant number, density and arrangement in an area are canopy features that determine the spatial organization, within which there is dieoff, a specific age structure, different rhythms to the formation of the mass of individuals and different physical dimensions (Ramade, 1984; Zimny, 2002). A high density of uniform, evenly-arranged beet plants within the canopy, leaving little room for gaps, is the basis for the obtaining of maximum sugar yields per area unit (Neeb, Winner, 1969; Wiley, Heath, 1969; Märländer, 1989a, b; Cakmakci et al., 1998). Under Polish conditions in the years 1996–2001, the average plant density in production plantations varied from 73 300 to 79 300 plants ha^{-1} and was manifested by an upward trend (Jaworowski, 2002). In France in the years 1996–2000 plant densities in production plantations were greater, on average at about 102 000 plants ha^{-1}, and ranging in 2001 from 91 900–113 000 plants ha^{-1}, depending on the region of the country (Anonymous, 2001).

As it is very important to study the effect of factors in production technology, since these shape the changes are ongoing in the plant canopy, the aim of the investigation described here was to evaluate the sugar beet canopy under the conditions pertaining in Central Poland, as regards to the two most important parameters characterising a population, i.e. the number of plants and their arrangement over an area.

MATERIALS AND METHODS

A series of multifactorial experiments of type 2^7 to evaluate the effect of agrotechnical factors upon number and arrangement of plants in a sugar beet canopy were run with one full replication in the years 1992–1994. The experiments were conducted in the experimental field of WAU Department of Crop Management in Chylice (20^0 33' E and 52^0 05'30" N). The variety Kawejana was used for investigation. Factors characterised by a high level of variability in production plantations were chosen for the experiments. They were: sowing date, harvest date, plant density, rate of N, timing of N fertilization, division of N rate and foliar fertilization with Insol 4. Their levels were selected in such a way as to be either what was considered optimal (denoted as higher level of factor *"1"*) or "permissible" (denoted as a lower level *"0"*) in sugar-beet production technology. The aim of such a choice was a desire to obtain agrotechnical systems that ensure quantitatively and qualitatively better root yields and a consequently large technological sugar yield. Analyzed factors and their letter codes are presented in Table 1.

Sugar beet was cultivated after winter cereals (triticale and wheat) on degraded black earth, soil of very good rye complex of valuation class IIIb and IVa. The field was cultivated, then a skimming with harrowing and winter ploughing at the depth 25–30 cm were done. Farmyard manure 35 t ha^{-1} was applied at winter ploughing. During fallow ploughing, 35 P kg ha^{-1} and 130 K kg ha^{-1} were added. At springtime the field was harrowed and prepared for sowing through aggregated treatment using cultivator and Campbell roller. Germinating ability of sowing material was above 90%. Their sowing was made with a pneumatic point seeder according to the experimental design. Their distance in the row was 6 and 13.7 cm, sowing depth 3 cm. The interrow distance was 45 cm. A manual thinning was made in the treatments with sowing every 6 cm, to obtain distance between plants 20–25 cm, while in treatments sown every 13.7 cm no intervention was made. Weed control was performed using foliar spraying with herbicides: Betanal Tandem (3 l ha^{-1}), Goltix (1.5 kg ha^{-1}) and Fusilade (1.5 l ha^{-1}).

In the whole investigation, i.e. on 128 plots, analysis centred on the field emergence (%)(FE) and plant density ('000 plants ha^{-1}) in the phases: after emergence, prior to canopy closure (BBCH 14–18) and at harvest. At the end of the growing season, the 64 plots subject to targeted sowing (every 13.7 cm) were described in terms of the distribution of beet plants in the row and the living area of individual plants within the overall cover (Fig. 1), the latter being an area of a rectangular shape taken as the product of the sum of two half-distances from neighbouring plants on the left and right side in the row and inter-row width (45 cm).

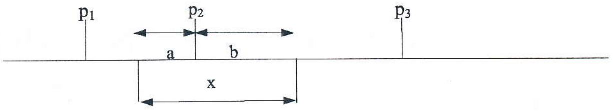

Fig. 1. Living area $x = (a + b) \cdot 45$ cm of sugar beet plants in the row

p_1, p_2, p_3 – successive plants

To evaluate plant density after emergence and prior to canopy closure (BBCH 14–18), plants in 3 rows of each plot (15 current meters) were counted, with measurements of the arrangement of plants in the row and their living area being performed on one row of 5 m in length. At harvest time, sugar beet plants were manually stripped of their leaves, the roots being dug up, cleared and counted. After recalculation, the number of plants was presented in terms of '000 individuals ha^{-1}.

In line with the requirements of sugar beet, the soils in which the experiments were conducted were characterized by a nearly neutral pH, high content of phosphorus, moderate content of magnesium and low potassium content. They also showed low levels of iron and medium levels of boron, copper, manganese and zinc (Table 2). The total amounts of precipitation and its distribution across the experimental period were varied (Table 3). In 1992 and 1993 rainfall across the growing season was about 100 mm lower than the multi-year average, and 150 mm lower than the 408 to 430 mm sugar beet growing in moderately cohesive soils is said to require (Dzieżyc et al., 1987). The distribution of rainfall in 1993 was more favourable. In July, when shortages of water limit sugar beet yielding most severely, rainfall did conform to the developmental needs of plants. In 1994,

Table 1. Factors of experiment

Factor	Level *"1"*	Level *"0"*
Sowing date	14.04	28.04
Harvest date	26.10	12.10
Plant density*	controlled	not controlled
Rate of N	130 kg ha^{-1}	80 kg ha^{-1}
Timing of N fertilization**	BS. BBCH-12	BBCH-12. BBCH-16
Division of N rate	60 + 40%	100%
Foliar fertilization***	Insol 4 – 1+1.5 l ha^{-1}	0

* Not controlled plant density was obtained from target sowing (every 13.7 cm), while controlled one was obtained where plots were sown every 6 cm with a manual thinning such that the distance between plants was 20–25 cm

** Timing of fertilization denotes: BS – before sowing (about 10 days), BBCH-12 and BBCH-16 – developmental stages of plants according to BBCH scale

*** Insol 4 (Mg 4.0, B 0.5, Cu 0.1, Fe 0.35, Mn 0.65, Mo 0.005 and Zn 0.35 % mass) applied twice at BBCH 16 – 1 l ha^{-1} and prior to canopy closure – 1.5 l ha^{-1}

Table 2. Soil chemical characteristics in the trial years

Years	pH_{KCl}	P	K	Mg	Cu	Fe	Mn	Zn	B
		mg.kg soil^{-1}							
1992	6.4	81.2	110.8	41.6	2.8	378	180	7.6	1.9
1993	6.0	90.4	83.3	34.9	3.0	438	148	7.0	1.1
1994	6.4	93.4	62.5	35.5	2.5	612	86	7.1	1.0

Table 3. Monthly precipitation (mm) and average temperature (°C) totals in the trial years. Agricultural Experimental Station Chylice as compared to water requirements after Dzieżyc et al. (1987)

Years	Months							Total
	April	May	June	July	August	September	October	
Precipitation (mm)								
1992	44	26	25	40	36	80	41	292
1993	26	28	31	76	38	55	19	273
1994	96	125	32	23	80	76	74	506
Means 1953–1982	39	56	86	87	66	46	40	418
Water requirements after Dzieżyc et al. (mm)								
	18	65	74	85	78	54	34	408
Temperature (°C)								
1992	251	461	595	667	725	414	201	3314
1993	301	564	516	566	565	401	256	3169
1994	296	422	493	810	609	461	222	3313
Means 1953–1982	246	434	531	583	561	426	288	3069

total rainfall exceeded the multi-year average, as well as the requirements of sugar beet as regards water, on account of excess precipitation at both the beginning of the growing season (April, May) and the end (September, October). However, the rainfall in July of that year was the lowest recorded in the investigated period. All years of study were characterized by adequate totals for temperature that surpassed the optimum values needed for normal growth of plants. As compared to the other years, 1993 was characterised by higher temperatures at the beginning and end of the growing season (April, May and October), while the lowest ones were observed in the summer months (July, August). During the whole period of investigation, July 1994 was the hottest month, the mean daily temperature exceeding 26 °C.

RESULTS AND DISCUSSION

In the studies carried out, plant emergence was determined to the greatest degree by the set of weather factors (Table 4). From year to year, field emergence (FE) varied from 64 to 79% with the first sowing date and from 47 to 80% with the second. Among all the factors investigated, only sowing date affected FE significantly. On average over the three years FE was of 73% for the first sowing and 64% for the second. In the years 1992 and 1993 (with their lower precipitation totals in spring), better emergence of sugar beet was to be observed with the first sowing date, whereas in 1994 (when total rainfall during the springtime months was high), the second sowing date was more favourable. The importance of an early sowing date for field emergence is greater in a dry and warm spring. The largest differences for comparable sowing dates occurred in 1993, the year with the lowest precipitation totals and high springtime temperatures (FE – 64 and 47%). It was not possible to note any significant effect on FE of the rate of application of nitrogenous fertilizer (in the range 80–130 kg N ha^{-1}), or the timing and means thereof. These data are confirmed by the works of other authors (Kalinowska-Zdun, Podlaska 1984).

Plant number after emergence was determined by FE. The number of plants in the period of canopy closure (BBCH 14–18) and at harvest in the treatment with targeted sowing reflected natural plant losses during the growing season. It further reflected density corrections where plots were sown every 6 cm (Table 4). In all years of investigation for the above-mentioned phases, plant numbers were significantly greater on the plots featuring the first sowing date, in the dry year 1992 with the treatments using 80 kg N ha^{-1} and in 1993 (where FE was the lowest) on plots with targeted sowing. Losses of sugar beet plants in the period from emergence to canopy closure (as evaluated for plots with targeted sowing) amounted to 4.2% on average for all the years, being highest (at 6.4%) in 1994 (with its high precipitation totals and low sum of spring temperatures). Losses of

Table 4. Field emergence and plant density in dependence on experimental factors and trial years

Factors and levels		Field emergence (%)			Plant density ('000 plants ha^{-1})								
					after emergence			BBCH 14–18			at harvest		
		1992	1993	1994	1992	1993	1994	1992	1993	1994	1992	1993	1994
Sowing date	14.4	79.0**	64.0**	75.0*	211.1**	172.5**	198.0**	118.5	100.0**	121.2*	106.1*	91.1*	102.4*
	28.4	66.0	47.0	80.0	175.3	123.0	214.3	118.1	83.7	115.9	101.9	84.0	97.8
Plant density	controlled	72.0*	55.0	77.0	267.3**	204.0**	285.2**	119.4	96.2*	118.1	104.8	90.0*	100.4
	not controlled	73.0	56.0	78.0	119.1	91.6	127.1	117.2	87.5	119.0	103.2	85.1	99.8
Rate of N (kg ha^{-1})	130	72.0	56.0	77.0	191.7	145.0	204.2	115.9*	91.8	118.3	101.5*	86.6	99.7
	80	73.0	55.0	78.0	194.7	150.5	208.1	120.7	91.9	118.8	106.5	88.5	100.5
Timing of N fertilization	BS. BBCH 12	72.0	55.0	77.0	191.8	145.3	205.3	117.3	91.7	117.5	102.9	87.0	98.8
	BBCH 12 and 16	73.0	56.0	78.0	194.6	150.2	207.0	119.3	92.0	119.6	105.1	88.1	101.4
Division of N rate	60 + 40%	73.0	56.0	78.0	193.7	150.1	208.3	118.9	92.1	119.1	104.5	88.8	100.1
	100%	72.0	55.0	77.0	192.7	145.4	204.0	117.7	91.6	118.0	103.5	86.3	100.1

**, * – significant mean differences at the level $\alpha = 0.01$ and 0.05, respectively

Table 5. The share of plants of assumed spacing intervals in the row at harvest in dependence on experimental factors and trial years (%)

Spacing interval (cm)	Sowing date						Rate of N (kg ha^{-1})					
	1992		1993		1994		1992		1993		1994	
	14.4	28.4	14.4	28.4	14.4	28.4	130	80	130	80	130	80
< 7	4.2	4.9	8.3	2.4	1.2	1.7	4.3	4.8	5.3	5.6	1.7	1.3
≥ 7 < 14	41.8	40.3	30.4	21.0	22.1	26.2	38.4	43.6	26.3	25.6	25.2	23.3
≥ 14 < 21	24.1	20.9	33.0	43.1	47.7	45.8	24.4	20.8	38.7	36.9	46.0	47.4
≥ 21 < 28	17.5	18.4	6.7	7.4	5.8	6.8	19.3	16.6	7.0	7.1	6.5	6.2
≥ 28 < 35	3.5	3.6	11.0	15.8	13.1	13.7	4.0	3.1	11.2	15.4	13.2	13.6
≥ 35 < 42	5.1	6.0	2.4	2.0	1.5	1.1	5.0	5.9	2.1	2.4	1.4	1.2
≥ 42 < 50	0.8	1.9	4.1	4.4	5.7	3.0	1.0	1.7	5.0	3.5	3.9	4.6
≥ 50	2.9	4.0	4.0	3.9	2.9	1.6	3.5	3.4	4.4	3.5	2.1	2.4
Spacing: average	18.0	19.2	19.1	21.1	20.4	18.8	18.8	18.4	20.3	19.8	19.3	19.8
min.	2	1	1	2	1	2	1	2	1	1	1	2
max.	99	126	87	131	90	79	113	126	131	83	90	86
Standard deviation	11.27	13.54	13.41	13.52	11.71	9.86	12.58	12.26	14.68	12.24	10.64	10.96
Variation coefficient (%)	63	70	70	64	57	52	67	67	72	62	55	55

plants during the period from canopy closure through to the end of the growing season were smallest in 1993, with its favourable rainfall distribution (at 2.8%). In 1992 and 1994 (with their low June and July rainfall totals), the losses were of 12.0 and 16.1%, respectively. Final plant density was high, and on average for each year of investigation it reached 104 000, 87 500 and 100 100 plants ha^{-1}, while mean spacing between plants in a row was 18.6, 20.1 and 19.6 cm, respectively. There was major irregularity to the distribution of plants in rows by the end of the growing season (Fig. 2). Variation in plant distributions within a row is presented against the background of the sowing date and rate of N application (Table 5). In accordance with ISO 7256/1 methodology (Anonymous, 1992) plants growing properly are those between which the real spacing falls within the interval 0.5 to 1.5 times the length of the theoretical interval (length of sowing seeds). The share of properly-growing plants (assuming plant spacing of 7–21 cm) was modified to a greater degree by year of study than other studied factors. The contribution of plants of spacings between 7 and 21 cm was greatest in 1994 and amounted to 70.9%, while the smallest came in 1992 – at 63.5%. The coefficient of variation for plant distances in a row was the lowest in 1994 (55%), attesting to greater evenness of distribution that year as compared with 1992 and 1993, in which it was 66.5% and 67%, respectively. Plant distributions in a row evaluated at harvest time were more strongly modified by sowing date than by dose of N.

There was found to be only a minor share of plants with spacing of more than 50 cm (equating to gaps) in the investigation conducted with high final plant density, this was ranging from 2.2% in 1994 to 3.9% in 1993. In

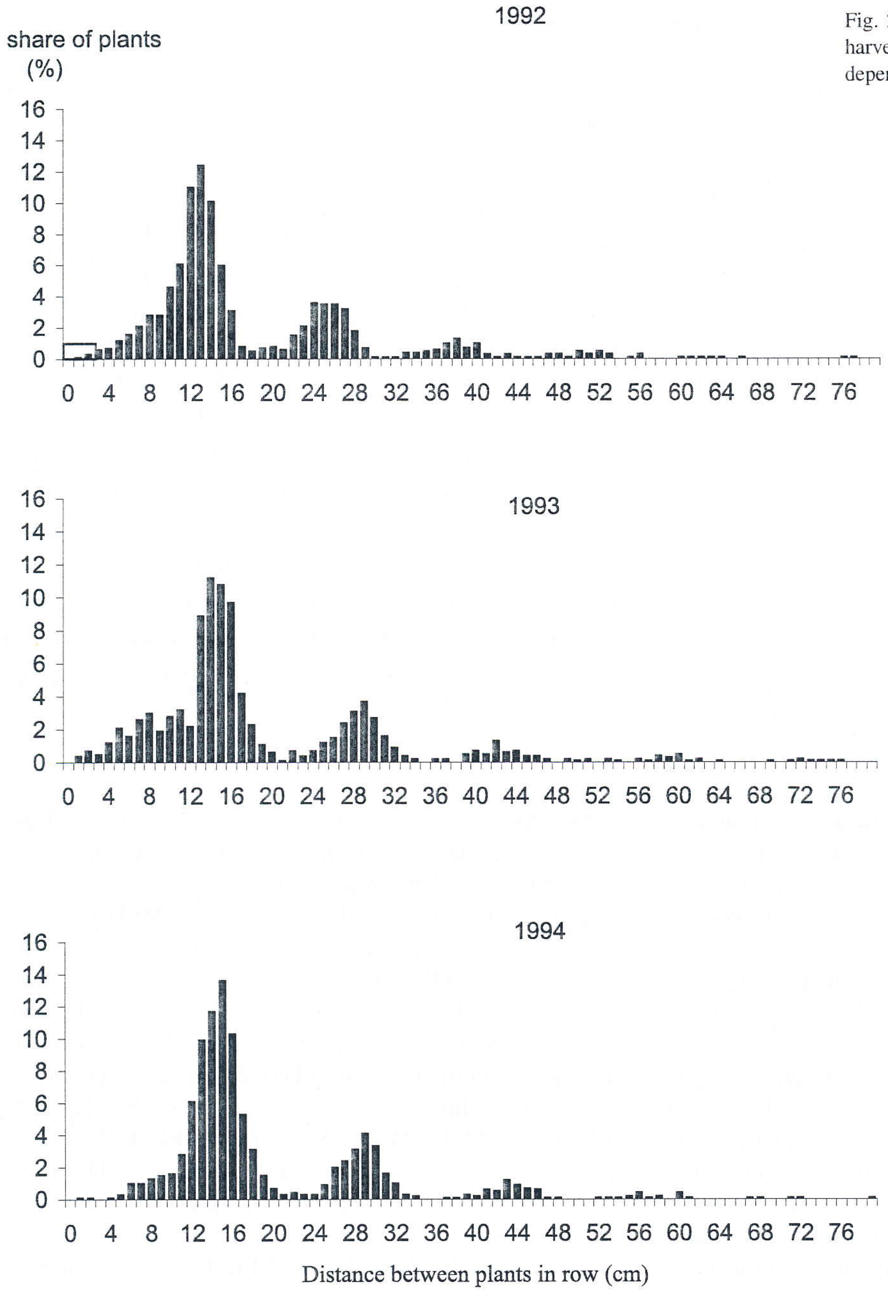

Fig. 2. The share of plants in the row (%) at harvest according to distances between them, depending on years

other Polish studies, the share of gaps was found to range from 4.4 to 8.3%, depending on the means of cultivation (Szymczak-Nowak et al., 2002). The smallest share was for treatments with traditional cultivation, with which the smallest mean distances between plants (of 25.6 cm) were also obtained. Cultivation involving sowing sugar beet in a mulch increased mean distance to 30.3 cm. However, the final plant density in the cited studies was lower by about 20 000 ha^{-1} as compared with present experiments.

A major role in sugar beet yielding is ascribed to the living area of plants. During presentation of the item an arrangement of plants in a row was assumed, 1 cm of row length being taken to equal 45 cm^2 of area. A sugar beet plant having a 20 cm length of living area side in fact occupies a ground surface of 900 cm^2. Table 6 presents the share of plants (%) of assumed intervals of varied life surface side, depending on sowing date and nitrogen rate. Taken as optimum for sugar beet is a living area equal to 950–1250 cm^2 (possible to obtain under even plant arrangement in row). This characterised a small part of the population – ranging from 14.4 to 26.9%, depending on a year of study and factors. Plants making use of a less-than-optimal living area dominated in the canopy. Those growing on too large a living area represented from 10 to 19.6% of the total. The range of recorded living areas – reflecting sowing and emergence parameters – was from 112.5 cm^2 to 3667.5 cm^2. Factors relating to the technology of production changed plant living area to only a small degree, and no directional effect was found.

In the investigation conducted, the habitat-related and agrotechnical conditions determining plant emergence and dieback were decisive where final plant density and

Table 6. The share of plants of assumed intervals of varied living area side in dependence on experimental factors and trial years (%)

Intervals of living area side (cm)	Sowing date						Rate of N (kg ha^{-1})					
	1992		1993		1994		1992		1993		1994	
	14.4	28.4	14.4	28.4	14.4	28.4	130	80	130	80	130	80
< 7	1.3	1.2	3.1	0.7	0.6	0.4	1.6	1.0	1.9	2.0	0.8	0.1
≥ 7 < 14	42.2	36.4	27.0	14.2	14.5	19.3	37.2	41.6	21.1	20.7	17.9	16.2
≥ 14 < 21	32.3	32.0	31.3	39.2	41.8	44.0	33.4	31.0	37.3	32.9	42.9	43.0
≥ 21 < 28	14.4	16.2	21.0	26.4	25.0	25.6	16.2	14.4	20.2	26.9	24.8	25.8
≥ 28 < 35	6.4	8.0	7.8	10.0	9.4	6.5	6.7	7.6	8.4	9.3	7.4	8.3
≥ 35 < 42	2.0	2.7	6.0	5.1	6.4	2.2	1.8	2.8	5.6	5.6	3.8	4.6
≥ 42 < 50	1.0	1.6	3.3	2.1	1.4	1.8	1.4	1.1	3.2	2.3	1.9	1.4
≥ 50	0.5	1.9	0.4	2.3	1.0	0.3	1.7	0.6	2.4	0.3	0.5	0.7
Living area side: average	17.8	19.2	19.1	21.2	20.4	18.8	18.8	18.2	20.3	19.9	19.3	19.8
min.	2.5	3.5	3.5	4.5	3.0	6.5	3.5	2.5	4.5	3.5	3	6.5
max.	69.5	75.5	56.5	81.5	58.5	57.5	75.5	75.0	81.5	52.0	57.5	58.5
Standard deviation	8.57	9.80	9.55	9.98	8.44	7.22	9.19	8.72	10.83	8.69	7.85	7.86
Variation coefficient (%)	45	51	50	47	41	38	49	48	53	44	41	40

* living area – an area of a rectangular shape taken as the product of the sum of two half distances from the neighbouring plants on the left and right side of plant under investigation and the width between rows, i.e. 45 cm

arrangement in the rows were concerned. Final plant density set against year and the levels of different factors was high, while the distribution of plants was characterised by considerable unevenness. The contribution of plants of optimum living area in the canopy was limited – as a result of the large number of plants growing in excessively crowded conditions, as well as the occurrence of gaps.

Despite far-reaching human intervention as regards technologies of production, it is very difficult to obtain an even distribution and development of plants within the sugar beet canopy. The phenomena present within that canopy are similar to those characteristic of the stands or swards of natural populations, i.e. plant death, differences in age, and mutual competitive interactions – all of which lead to considerable heterogeneity of the canopy. The consequence is major variability to the physical dimensions of plants in a canopy – something which determines the size and quality of the yield of sugar beet roots. With uneven distribution of the plants in rows, an increase in plant density – even to 120 000 ha^{-1} did not cause any reduction in root and sugar yield per unit area, while with an even distribution of plants, the optimum plant densities may be rather lower, as they are conditioned by soil moisture and fertility.

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Received for publication on February 6, 2006
Accepted for publication on May 3, 2006

WYSZYNSKI, Z. (Warsaw Agricultural University, Warsaw, Poland):

Variabilita počtu a uspořádání rostlin v zápoji cukrové řepy v environmentálních a agrotechnických podmínkách.

Scientia Agric. Bohem., *37*, 2006: 133–139.

Multifaktoriální pokus typu 2^7 byl uskutečněn u cukrové řepy odrůdy Kawejana v letech 1992–1994. Byla určena polní vzcházivost (FE) a počet rostlin ve fázích – po vzejití, BBCH 14–18 a při sběru. Dále bylo analyzováno uspořádání do řádku společně s životní plochou jednotlivých rostlin v zápoji. Polní vzcházivost (FE), která se pohybovala od 55,5 do 77,5 %, byla hlavně výsledkem počasí v daném roce. Při časném termínu byla polní vzcházivost v průměru 73 %, zatímco při pozdním termínu 64 %. Hustota rostlin při fázi 14–18 BBCH a při sběru byla určena podle polní vzcházivosti a přirozených ztrát během vegetační doby. Finální hustota rostlin u varianty s prvním výsevkem byla pro různé roky výzkumu 106 100, 91 100 a 102 400 rostlin/1 ha, zatímco v druhém termínu výsevu byla 101 900, 84 000 a 97 800 rostlin/ha. Ztráty rostlin mezi vzejitím a BBCH 14–18 byly v průměru 4,2 % z počátečního počtu, pak byl zaznamenán vzrůst 10,3 % až do sběru. Podíl rostlin s optimální životní plochou (950–1 250 cm^2) se pohyboval v rozmezí 14,4 až 26,9 % v závislosti na zkoumaném roce a úrovni experimentálních faktorů.

zápoj cukrové řepy; hustota rostlin; uspořádání rostlin; životní plocha rostlin

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