EFFECT OF INCREASING PLANT POPULATION DENSITY ON THE YIELD PARAMETERS AND PROFITABILITY OF SWEETCORN

P. KRIZSÁN[1], B. NAGYPÁL[2], Z. FUTÓ[3]

Hungarian University of Agriculture and Life Sciences, Institute of Environmental Sciences
Department of Irrigation and Land Improvement[1,3]
ZKI Research Institute of Vegetable Production Ltd.[2]
Corresponding author: Krizsan.Patrik@uni-mate.hu[1]

Abstract. *In the case of sweet corn grown for the canning industry, the most important aspect for the producers is to produce the raw material that best meets the canning industry's expectations, in addition to the highest yield possible in this form. The purpose of this experiment is to investigate the highest possible number of plants that does not yet have a negative effect in terms of the size of the cobs and the quantity of shelled grains. Currently, the most commonly used number of sweet corn plants by farmers producing for the canning industry is 65 thousand plants/hectare, which can certainly meet the expectations of the canning industry. Therefore, in our research, we examined the highest possible number of plants for a newly marketed sweet corn hybrid, which does not yet have a negative effect on the harvested cob yield, the size of the cobs, and the quantity of shelled grains, but increasing the number of plants is still profitable. In the experiment, we examined the same sweet corn hybrid in a total of 6 different populations in 4 repetitions in Szarvas, in 2023. The populations applied were as follows: 56; 58; 62.5; 65; 71 and 75 thousand plants/hectare. During the experiment, we examined the weight of the harvested cob yield and shelled grains, as well as the length of the cobs. In addition, the experiment also extended to the profitability of the populations. The experiment pointed out that increasing the number of plants per hectare of the examined sweet corn hybrid is worthwhile in terms of increasing the quantity of cob yield and shelled grain yield. However, above 65 thousand plants per hectare, the length of the cobs showed a minimally decreasing tendency, but even so, it still met the needs of the processing industry.*

Keywords: *sweetcorn, plant population, cob yield, shelled grain yield, canning industry*

INTRODUCTION

Sweet corn (Zea mays L. conv. Saccharata Koern.) is a subspecies of corn. It differs from common corn in that it has a recessive gene on its fourth chromosome, which prevents the sugars produced from being converted into starch (Lente, 2009).

In the 20th century, the cultivation and breeding of sweet corn underwent significant development. In the United States, particularly in the states of Iowa and Illinois, the cultivation of sweet corn reached industrial scales. The development of new hybrid varieties, which provided higher yields and better disease resistance, contributed to the increasing popularity of sweet corn worldwide (https 7).

Today, the global cultivation area of sweet corn exceeds 500,000 hectares. The largest area is cultivated in the United States, where the production standards are also the highest (Lente, 2009). A significant portion of American production is consumed fresh, but large quantities are also exported in canned and frozen forms (https 5).

In Hungary, sweet corn appeared at the beginning of the 1900s, but it has been cultivated on a significant scale only since the 1970s, when the demand for sweet corn from the canning industry increased significantly (Lente, 2009).

In Hungary, modern cultivation practices developed by the mid-to-late 80s. The major breakthrough occurred in the mid-90s. Although the yield fluctuated slightly, the cultivated area continued to grow steadily. The driving force behind this growth was the canning and freezing industry (Orosz, 2009).

Today, sweet corn has become the most widely cultivated vegetable in Hungary (https 1). The rapid increase in its cultivation area was primarily due to the fact that its cultivation, from planting to harvesting, can be well mechanized without significant risk of quality deterioration (Hodossi and Kovács, 1996).

Hungary's climatic, topographical, and soil conditions are also suitable for the cultivation of sweet corn, which further favors its spread (https 1). On average, it is cultivated on about 37,000 hectares annually in the country (https 1, 2), and the annual yield reaches 500,000 to 600,000 tons (https 6). This makes Hungary the largest sweet corn producer in the European Union, surpassing France (https 6). Among the domestic growing regions, Hajdú-Bihar County stands out with its 14,000 hectares of cultivated area, but significant cultivation also takes place in Szabolcs-Szatmár-Bereg, Bács-Kiskun, Békés, Csongrád, and Jász-Nagykun-Szolnok counties (https 7).

95% of Hungarian sweet corn products are sold abroad, mainly in Germany, the United Kingdom, France, and Poland. However, the demand for processed sweet corn products is also continuously increasing in Asian markets (https 6).

It has been experimentally proven that sweet corn and fodder corn require different agricultural techniques (Daróczi, 1995).

Sweet corn can be cultivated in monoculture for 3-4 years. Good preceding crops include cereals and leguminous plants (Hodossi et al., 2004).

According to studies, the optimal planting period for sweet corn in Hungary is from May 1-30 for the main crop and from June 1-20 for the second crop (Lente, 2009). In Hungary, the common row spacing is 70-76 cm, and the plant spacing varies between 13-16 cm, which corresponds to 60-80 thousand plants per hectare (Orosz, 2009).

Based on a five-year experiment, it was found that increasing the plant density of sweet corn reduced the number of marketable cobs per plant and the average cob weight, but in contrast, the harvested yield per hectare increased (Vittum, 1961).

Sweet corn requires irrigation. Under irrigated conditions, the average yield can be increased by 25-31% (Szórádi, 1989; Daróczi, 1995).

One of the key points for successful sweet corn cultivation is effective weed control to ensure the uninterrupted growth of the plant population. This is most successfully achieved through pre-emergence treatment. If post-emergence treatment is also necessary, care must be taken with the proper dosage of herbicides, as they can cause scorching on the plants, which can slow their growth (Hadi, 1999). Like all corn, the most dangerous viral disease for sweet corn is the Maize dwarf mosaic virus (MDMV), which can be most effectively controlled by cultivating resistant hybrids, eliminating virus vectors (aphids), and using agricultural techniques (Michele, 2003). One of the most dangerous insect pests for sweet corn is the cotton bollworm, specifically its larvae, which can cause significant damage to the cobs awaiting harvest, thereby reducing their marketability. The key to successful control is the proper timing of interventions based on observations from insect traps. In the field, chemical control with pyrethroid-based products is most effective, using a high-clearance tractor (Vasas and Zöldi, 2005).

There can be differences in the agricultural techniques for normal and super-sweet hybrids. Super-sweet varieties poorly tolerate late planting, which can result in a decrease in their yield (Kovács, 1996). Additionally, super-sweet corn should be planted shallower (at a depth of 2-4 cm), and it is recommended to provide germination irrigation after planting (Nigicser, 1993, 1994). The optimal plant density can also vary between different hybrids. For super-sweet hybrids, the optimal plant density is 60-63 thousand per hectare, while for normal sweet corn, 65 thousand per hectare is recommended (Lente, 2009).

Sweet corn can be processed in many ways, but most products are canned or frozen. Fresh market sweet corn is most commonly cooked on the cob and consumed this way (Marshall and Tracy, 2003).

The canning industry's requirements for sweet corn include high sugar content, uniform kernel size and color, as well as the length and thickness of the cobs. The kernels must be healthy and free from pests and diseases (Orosz, 2009). Currently, the most commonly used plant density for sweet corn by farmers producing for the canning industry is 65 thousand plants per hectare, which reliably meets these expectations.

Excessive plant density can be detrimental to meeting the canning industry's requirements. If the plants are too close to each other, competition arises for light, water, and nutrients, which can reduce yield and cob size. Additionally, in overly dense stands, air circulation decreases, increasing the risk of diseases (https 4).

The choice of variety also plays an important role in meeting the expectations of the canning industry. Sweet corn varieties are classified according to their growing period, kernel color, sugar content, and cultivation purpose. Based on the growing period, we distinguish between: very early (below 800℃), early (800-870℃), mid-early (870-930℃), mid-season (930-960℃), and late (requiring a heat sum above 960℃) varieties (Orosz, 2009). The kernel color can be: yellow (dark yellow, light yellow), white, or bicolor (Pereczes, 1999). Based on their sugar content, sweet corn varieties can be classified into three main groups: normal sweet; sugar-enhanced; super sweet. Super sweet, also known as dessert-type varieties, do not form water-soluble polysaccharides in their kernels, which gives them a crunchy texture, unlike the other two types. Among the three types, they have the highest sugar content and the lowest starch content. They are also the most favorable in terms of ripening, as they retain their quality for a longer period, allowing for an extended optimal harvest time, and they maintain this quality even after harvesting and processing (Kovács, 2000).

The cultivation purpose is crucial in variety selection, which can be for processing industry or fresh market purposes (Orosz, 2009). The processing industry prefers super sweet varieties. A fundamental requirement is suitability for mechanical harvesting (low cob height and weak stalk strength are disadvantages) and kernel yield. Other advantageous variety traits include: a high number of kernel rows (around 18-20 is optimal), uniform cob size, relatively small round kernels, good kernel color (dark yellow is generally favorable), good taste, and thin, soft pericarp. Partial variety traits include husk coverage of the cobs, as varieties with open cob tips are more prone to damage (Temesvári and Borbély, 2005). In Hungary, commonly used hybrids belong to the Dessert series, such as R68, R70, R73, or R78, which meet the above-mentioned requirements (https 3).

MATERIAL AND METHODS

In the experiment, the Zeaton F1 sweet corn hybrid was examined. The Zeaton F1 super sweet sweet corn stands out with its excellent taste and outstanding climatic stress tolerance. The plant has large cobs, which are well protected by good husk coverage. This type is mid-season, maturing in 76-78 days, and is less prone to lodging. The plant can reach a height of 210 cm, with cobs positioned at 80 cm. A cob weighs over 420 grams, with a length of 220-230 mm and a diameter of approximately 52 mm. The cobs are blunt-shaped, have 16-18 rows of kernels, and the kernel yield exceeds 40%. The kernels are elongated, with a depth of more than 11 mm, and are golden yellow in color. The husk leaves are deep green. This sweet corn is an ideal choice for both the processing industry and the fresh market. Additional characteristics of Zeaton F1 include resistance to certain diseases. This variety is resistant to maize dwarf mosaic virus (MDMV), corn rust (Ps), and northern leaf blight (Et) (https 8).

The experiment was set up in Szarvas on the School Field of the Department of Irrigation and Land Improvement of the Institute of Environmental Sciences of the Hungarian University of Agricultural and Life Sciences.

The experiment was conducted on chernozem meadow soil. Based on the soil test results (*Table 1*), it can be determined that the soil's physical texture is clay loam, its pH is slightly acidic, the cultivated layer does not contain $CaCO_3$, its nitrogen supply is medium based on humus content, its phosphorus supply is high, and its potassium supply is high. The soil is well supplied with magnesium, very well supplied with zinc, and adequately supplied with copper and manganese.

Table 1

Soil test results

pH (KCl)	**K_A**	**Total water-soluble salinity (%)**	**CaCO3 (%)**	**Humus (%)**	**AL-P2O5 ($mgkg^{-1}$)**	**AL-K2O ($mgkg^{-1}$)**	**Mg (KCl) ($mgkg^{-1}$)**	**Na (AL) ($mgkg^{-1}$)**	**EDTA-Zn ($mgkg^{-1}$)**	**EDTA-Cu ($mgkg^{-1}$)**	**EDTA-Mn ($mgkg^{-1}$)**	**S ($mgkg^{-1}$)**	**(NO2+NO3)-N (KCl) ($mgkg^{-1}$)**
6,71	49	0.05	0	2.48	235	668	462	41.8	2.53	5.03	336	8.49	5.47

In the experiment, the Zeaton hybrid was examined in 6 different plant populations (56, 58, 62.5, 65, 71 and 75 thousand plants/ha). The experiment took place in an area of approx. 2000 m^2. The 6 different treatments mentioned above were tested in 4 repetitions. Each plot was 6 rows wide and 15m long, and the used row spacing was 75 cm.

The entire experimental area was uniformly treated with base and starter fertilization, seedbed preparation, sowing, and weed control. As a base fertilizer, the area received Genezis NPK 8-15-15 complex fertilizer at a dose of 300 kg/ha. As a starter fertilizer, Genezis Pétisó was applied at a dose of 100 kg/ha. Seedbed preparation was carried out on June 12 using a combinator. The experiment was sown on June 13 with an Accord Optima 6-row seeder. After sowing, the experiment received a germination irrigation of 20 mm to promote rapid and uniform germination. After germination, thinning of the sweet corn was not necessary.

Due to the drought conditions, the experiment required multiple irrigations during the growing season, which were carried out using a reel irrigation system equipped with an irrigation boom. Throughout the entire growing season, in addition to the germination irrigation, a total of 260 mm of irrigation water was applied to the area in several smaller doses.

Weed control in the experiment was only needed once, which was done post-emergence with Laudis at a dose of 2 l/ha.

The collection and processing of yield samples from all treatments were uniformly carried out on the same day, September 12. The yield sample collection was done by harvesting and measuring all corn cobs (husked) from 1 linear meter in each of the 4 repetitions for every population. During the kernel yield examination, all kernels were cut from 3 cobs in each of the 4 repetitions for every population using a knife. We then separately measured the weight of the cob and the kernels, and obtained the results as a percentage. At the end of the examinations, the results obtained from the 4 repetitions were averaged.

RESULTS AND DISCUSSIONS

The results and data of the measurements and tests carried out during the experiment are presented in the form of tables and graphs. *Table 2* illustrates the results of cob yield and grain yield for the populations examined in the different experiments. The table shows that the lowest yield was achieved with the population of 56,000 plants per hectare, both in terms of cob yield (17.82 t/ha) and grain yield (11.08 t/ha). The highest yields were observed in the treatment with 75,000 plants per hectare. From this population, 23.55 t/ha of cob yield and 15.4 t/ha of grain yield were harvested. In addition, the table shows that with the increase in the number of plants per hectare, both cob yields and grain yields increased proportionally. Fortunately, this suggests that the increase in cob yield per hectare, parallel to the increase in plant density, is not due to a higher number of cobs, but rather to an increase in grain yield. This implies that the grains were able to fertilize properly even at higher plant densities. No decrease in yields was observed even in the higher populations. Only a minimal stagnation can be observed in the treatment with 75,000 plants per hectare, as the increase in cob yield between the populations of 71,000 and 75,000 plants per hectare was only 1.5%, while a 9% increase in yield was observed between the populations of 56,000 and 58,000 plants per hectare.

Table 2

Grain yield results

Grain yield results			
Treatment Plants/ha)	**Cob yield (t/ha)**	**Cob (t/ha)**	**Grain crop (t/ha)**
56,000	17.82	6.74	11.08
58,000	19.42	7.23	12.19
62,500	20.75	7.98	12.77
65,000	22.08	8.18	13.9
71,000	23.2	8.7	14.5
75,000	23.55	8.15	15.4

The per-plant cob and grain yield results are presented in *Table 3*. Based on these results, it can be concluded that the examined populations do not show significant differences in this regard. Overall, it can be stated that the highest per-plant cob and grain yields were both achieved by the population of 65,000 plants per hectare, with cob yield values of 339.69 g/plant and grain yield values of 213.85 g/plant. In addition, it can be observed that the cob yield results of the smallest and largest populations examined in the experiment show almost identical values, which are also the lowest per-plant cob yield results among all. The table clearly illustrates that above a plant density of 65,000 plants per hectare, the individual productivity of the plants decreased, which can be attributed to the competition among the plants.

Table 3

Per-plant yield results

Treatment	Cob yield per plant (g/plant)	Grain yield per plant (g/plant)
56,000	318,21	197,86
58,000	334,83	210,17
62,500	332	204,32
65,000	339,69	213,85
71,000	326,76	204,23
75,000	314	205,33

This same competition among plants can also be observed in the development of cob sizes (*Figure 1*) as a result of higher plant densities. The graph clearly shows that the largest cobs developed in the population of 65,000, with this value averaging 22.08 cm across the repetitions. In treatments with higher plant densities, a minimal but gradual decrease in the length of the corn cobs can be observed. At a plant density of 71,000 per hectare, the average cob length was 21.04 cm, while at 75,000 it was only 20.96 cm. It can also be noted that the smallest cobs developed at the highest plant density, but they still met the values expected by the processing industry.

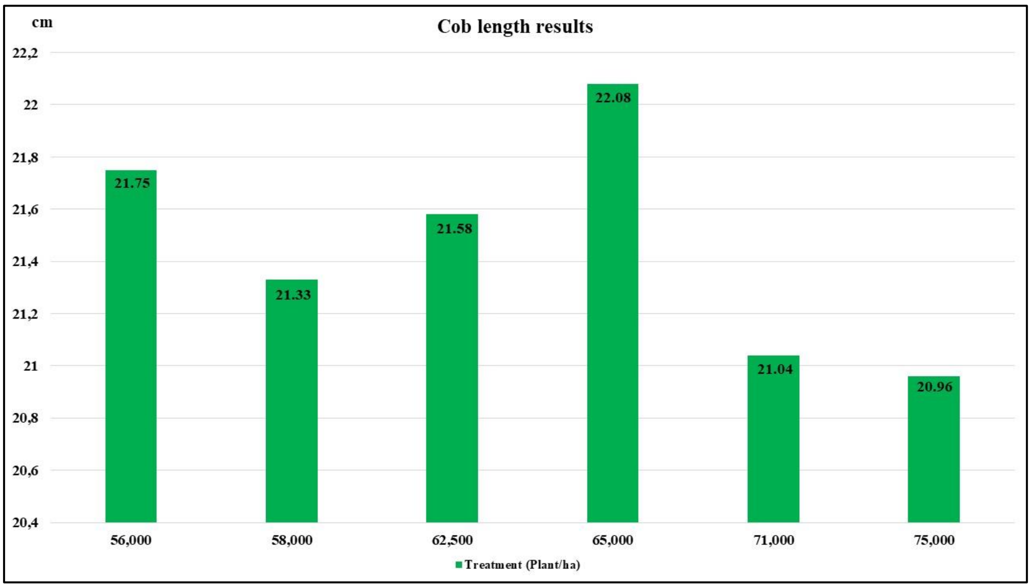

Fig. 1: Corn cob length results

Comparing the yield and cob length results, it can be concluded that despite achieving the highest yield in the 75,000 plants per hectare treatment, the smallest cobs were harvested here. Additionally, it can be stated that in populations of 65,000 and higher, the increase in yield is inversely proportional to the length of the corn cobs. The increase in yield despite the smaller cobs can be explained by the higher number of corn cobs per meter.

The statistical analysis of the results described above revealed that the ear yield per hectare (t/ha) and the cob yield per hectare (t/ha) show a very strong positive correlation (0.973620), which means that if the ear yield increases, the cob yield also increases. The same can be said for the ear yield per hectare (t/ha) and the grain yield per hectare (t/ha), as they also show a very strong positive correlation (0.986452). The cob yield per plant (g/plant), grain yield per plant (g/plant), and cob length (cm) show a weaker correlation with the cob yield per hectare (t/ha) (0.222222), which means that they are less related to it. The analysis of variance revealed that different populations have a significant effect on yield and other measured variables.

In order to determine the profitability of different plant populations, we conducted a general cost calculation for all treatments, as illustrated in *Table 4*. In the table, we included an 'Expenditure' and a 'Revenue' side. On the 'Expenditure' side, we listed all the costs necessary for the production of sweet corn examined in the experiment, along with the quantities of input materials used in the experiment, based on 1 hectare of land. On the 'Revenue' side, we calculated with an average 2023 purchase price of €225 per ton for cob yield, which showed the revenue we would have achieved with the yield harvested from the different treatments, also based on 1 hectare of land. The profitability of the different treatments can be determined from the difference between the 'Revenue' and 'Expenditure' sides. The table shows that the different populations have varying production costs only in terms of seed price, partly due to the different quantities of seeds per hectare. On the other hand, each treatment in the experiment received the same agronomic practices, using the same quality and quantity of input materials, resulting in identical costs for each population. In the cost calculation, we used a value of €500 per 100,000 seeds.

Table 4

Cost calculation of treatments

Treatment			***56,000***	***58,000***	***62,500***	***65,000***	***71,000***	***75,000***
EXPENDITURE	Irrigation (€/ha)		250					
	Harvesting + Transport (€/ha)		125 + 375					
	Mechanical Works (€/ha)	Weed Control + Insecticide Treatment	23 + 23					
		Sowing	38					
		Seedbed Preparation with combinator	29					
		Incorporation of Base Fertilizer with a Disc Harrow (+ Roller)	35					
		Fertilizer Spreading	19					
		Primary Tillage with a Field Cultivator	88					
	Input Materials (€/ha)	Herbicide	90					
		Insecticide	90					
		Fertilizer (300kg NPK 8-15-15 / 100kg Pétisó)	313					
		Seed (price/ha €)*	266	276	297	309	337	356
		Total	**1 764**	**1 774**	**1 795**	**1 807**	**1 835**	**1 854**
REVENUE	Cob Yield (price/ha €)**		4 010	4 370	4 669	4 968	5 220	5 299
PROFIT (price/ha)			**2 246**	**2 596**	**2 874**	**3 161**	**3 385**	**3 445**

*Seed unit price: 500€ / 100,000 seeds
**Cob Yield Selling Price: 225 €/t

Based on the cost calculation, it can be determined that the lowest production cost (€1764) was for the smallest population, while the highest production cost (€1854) was for the largest population, which was due to the greater seed requirement. The revenues were similar, with the lowest gross revenue of €4010 resulting from the 56,000 plants/ha population due to the lower cob yield. Compared to this, the treatment with 75,000 plants/ha resulted in 32% higher gross revenue, making it the most profitable treatment due to the high yield. In terms of net revenue, this treatment could have achieved €3445 per hectare, but the 71,000 plants/ha population was not far behind, producing a net profit of €3385.

CONCLUSIONS

Our current experiment indicates that it is worthwhile to increase the recommended plant density of 62-65 thousand plants per hectare to as much as 75 thousand plants per hectare, as the increase in plant density does not have a negative impact on yield for the hybrid examined in the experiment. Based on all these factors, it can be stated that despite the higher costs associated with increased plant density, it is also worthwhile from a profitability standpoint to use a slightly higher plant density in the cultivation of sweet corn for the canning industry, as compared to the commonly used density of 65 thousand plants per hectare, an additional profit of up to €250 per hectare can be achieved.

Additionally, the increased plant density has not reduced the size of the cobs to a level that would be unacceptable for the canning industry, but it is worth noting that the individual productivity of the plants decreased above a density of 65 thousand plants per hectare.

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