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ECONOMIC EFFICIENCY OF SWEET CORN GROWING WITH NUTRITION OPTIMIZATION

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ABSTRACT. The efficiency of sweet corn production for grain has been studied; economic advantages of cultivation in comparison with other crops have been highlighted. The article presents the results of research on issues of improving the economic efficiency of technology elements for growing sweet corn of the variety Moreland F1 under conditions of Precarpathians of Ukraine. Taking into account the production strategy, have been outlined cost-effective resource-saving and intensive technologies which provide the stable yielding capacity of early-ripening hybrid of sweet corn under conditions of Precarpathians at the level of 4.99–6.65 t ha^{-1} accordingly with the profit of 370–500 € ha^{-1} and grain production profitability 112–135%. It is established that under the conditions of application of mineral fertilizers at the dose of $N_{135}P_{90}K_{125}$ + N_{60} + N_{30} in two stages the grain yield of corn increases compared to the absolute control (by 2.26 t ha^{-1}, or 30.3%) with increasing costs per 1 ha of sown area 68.23 €, or 26.4%). In proportion to the increase in yield, the amount of profit, which is 192.42 € ha^{-1}, also increased significantly.

Introduction

It has long been known that the constant cultivation of food grain is one of the main ways for the development of the agricultural sector of Ukraine. Nowadays, corn occupies one of the first places among grain crops (Zynchenko, 2013; Hadzalo *et al.*, 2016; Hryhoriv *et al.*, 2020a; Hryhoriv *et al.*, 2021a).

Every year, Ukraine's role in the world corn market becomes more important. Our country provides 3.5% of global corn cultivation. According to statistical data for 2015–2020, the average productivity of corn grain in our country was 6.6 t ha^{-1}. It should be noted that that year Ukraine has surpassed such world exporters as Brazil and China by yielding capacity (Pasternak, 2015).

It should be noted that in recent years Ukraine has taken one of the first places in the world in terms of economic parameters of agricultural complex, after having gained a deserved leading position of corn producer-exporter in the world market (Long *et al.*, 2018; Hryhoriv *et al.*, 2021b).

Everyone knows that the main purpose of developing components of varietal farming techniques of modern intensive corn hybrids is the opportunity to increase crop productivity. It is no secret that establishing the

feasibility of any agricultural complex techniques only on the dynamics of the harvest is not enough, as the cost of its production is missed. Proceeding from this assumption, it is necessary to determine not only agrotechnical but also the economic expediency of growing the crop (Garkavy *et al.*, 2003; Vlashuk, 2017; Hryhoriv *et al.*, 2021b).

Currently, during the intensification of production, economic evaluation of technologies for growing crops under conditions of market relations is very important. It should be noted that in recent years, prices for, fertilizers, plant protection products, and energy resources have risen significantly. It has an impact on rising costs of corn production and, consequently, declining sales revenues (Vozhehova *et al.*, 2018). That is why, when developing technologies for corn growing, to prevent inefficient use of production resources it is necessary to take into account the strategy of production, its goals and the resource potential of agricultural enterprises, which stipulate their focus on intensification or resource-saving. Thus, intensive technology models are aimed primarily at ensuring maximum profits with sufficient cost recovery, and resource-saving technologies aim to achieve the highest recovery from the profits (Kaminskyi *et al.*, 2017; Hryhoriv *et al.*, 2020).

Taking into account the type and specialization of agricultural enterprises, it is necessary to develop and implement cultivation technologies that will guarantee the possibility of forming homogeneous grain consignment as it is important for large producers. In addition, the resource provision level of enterprises has a significant impact on the efficiency of grain production. Thus, at the low level of resource provision, the profitability of corn grain production does not reach 50%, and enterprises with a high level of resource provision can have much higher profitability – more than 74% (Lü *et al.*, 2019; Kaminskyi *et al.*, 2020; Dhakal *et al.*, 2020).

It is known that achieving the high yielding capacity of corn is possible only with an increase in production intensity level (Kaminskyi, 2015). Fertilizer cost occupies the largest share in the structure of changeable costs at intensive technologies of corn cultivation, as this crop is characterized by a high need for nutrients and to form 1 tonne of grain with the appropriate amount of by-products producers have to use 24–32 kg of nitrogen, 10–14 kg of phosphorus and 25–35 kg of potassium (Shpaar *et al.*, 2012; Tanchyk *et al.*, 2021).

The direction of resource-saving in corn cultivation technology provides for not only reduction of agrochemical and pesticide load on the agrocenosis, but also obligatory compensation of their action by replacing them with the latest high-tech products which increase plant resistance to environmental stress, micro fertilizers, plant growth stimulants and so on.

In general, innovative resource-saving technologies of corn growing are aimed at reducing direct labour costs, material consumption of products and production processes. The application of such technologies in agricultural enterprises helped to reduce the cost of 1 tonne of product by 15.2–23.8% (Shpaar *et al.*, 2012; Honcharenko, 2017). Varietal resources are an independent element of resource-saving in modern crop production, and the use of hybrids of different ripeness groups with the integrated application provides regulation of yielding capacity level and the level of production costs in corn cultivation technologies (Dziubetskyi *et al.*, 2007; Pashchenko *et al.*, 2009; Tonkha *et al.*, 2021).

However, it should be remembered that the general economic effect of growing sweet corn is determined by market conditions, government policy concerning the development of the grain industry, and most important factors, resource efficiency of implemented cultivation technologies, level and quality of products (Holosov, 2004; Landré *et al.*, 2020; Kvitko *et al.*, 2021).

The aim of the research based on an economic evaluation is to establish the efficiency of corn cultivation technologies for grain depending on the level of fertilization and determine the most appropriate of them to realize the potential of crop productivity with maximum use of agro-climatic and industrial resources under the Precarpathians conditions.

Material and Methods

Field research was conducted based on the dendrological park "Druzhba named after Zinovii Pavlyk" at Vasyl Stefanyk Precarpathian National University in Ivano-Frankivsk region on sod-podzolic surface-gleyed soil from 2018 to 2020; GPS coordinates latitude 58°56'65', longitude – 34°41'55".

According to the results of the soil survey, the soils of the study area are of average humus – 2.63%. The sum of absorbed bases is in the range of 11–12 mg eq. per 100 g of soil, saturation degree of the bases – 85%, soil solution reaction – acidic (pH of salt solution 4.1–4.4, hydrolytic acidity is negligible).

Field and laboratory studies were conducted by generally accepted methods of research in agronomy (Lytvynov, 2011; Bondarenko, 2001).

General and special methods were used in the research: field – to study the relationship of the object with biotic and abiotic factors; quantitative and weight – to account for the grain harvest, which was carried out in sections, taking into account clogging and humidity; mathematical and statistical – to determine the reliability of the data; comparative-calculated – for the economic evaluation of corn cultivation technologies.

The economic efficiency of corn cultivation was calculated according to modern generally accepted methods, namely by technological maps. While determining production costs, we included sums of wages, costs of soil tillage, herbicides, seeds, depreciation, maintenance and inspection, the cost of fuel and lubricants, fertilizers, and seed storage costs. Calculations of the economic efficiency of sweet corn cultivation are given in the prices for 2021.

Obtained results of the research were processed by methods of mathematical statistics: disperse calculations of field research data with the help of computers and software programs MS Excel 2010 and Agrostat 2013. The results of the yield evaluation were generalized and statistically processed by the means of a multi-factor analysis of variance (ANOVA) at the probability level of 95% ($P < 0.05$). The differences between the variants of the trials were significant. We used the recommendations of domestic scientists through the conduction of mathematical data processing (Ushkarenko *et al*., 2014).

The economic efficiency of sweet corn production was determined by using the standard methodology of calculation of the profitability level (Ushkarenko *et al*., 2014). Profitability level was calculated as the ratio of the obtained pure profit to the full expenditures required by a certain variant of cultivation technology.

The sowing was carried out according to the scheme of the experiment. Sugar maize hybrid Moreland F1 was used for sowing.

Research topics included the study of such factors as:

Factor A – nutrition background:

- without fertilizers;
- $N_{90}P_{90}K_{90}$;
- $N_{135}P_{90}K_{125}$+ N_{60}+ N_{30}.

Factor B – densification of plants, thousand ha^{-1}:

- 60;
- 70;
- 80.

The experiment was repeated four times. The total area of the experimental plot was 50 m^2, accounting area – of 10 m^2. Placement of repetitions was carried out by the continuous method, arrangement of variants – by the method of randomized split blocks.

The variant without fertilizers was the control. The following mineral fertilizers were used for the research: complex fertilizers in the form of nitrogen-phosphorus-potassium (16% of a.s.); ammonium nitrate (34.4% of a.s.). Fertilizers were introduced on the plots in spring under cultivation. Additional fertilization of sweet corn crops was carried out with nitrogen fertilizers according to the corresponding variants of the experimental scheme in the phase of 3–4 and 6–7 leaves.

During the experiments, meteorological observations of the following indicators were conducted: average air temperature, and precipitation amount. For studying meteorological indices, data were used from the weather station in Ivano-Frankivsk, Ukraine.

The weather conditions during the vegetation period of sweet corn growing during the research differed significantly from the average long-term data both in terms of temperature and precipitation indices (Figs. 1, 2).

General and special methods were used in the research:

- field – to study the interrelationship of the object with biotic and abiotic factors;
- quantitative and weight – to account for grain harvest which was carried out in every plot, taking into account littering and humidity;
- mathematical and statistical – to determine the reliability of the data;
- comparative-calculating – for the economic evaluation of corn cultivation technologies, which was carried out according to technological maps in the prices of July 2020.

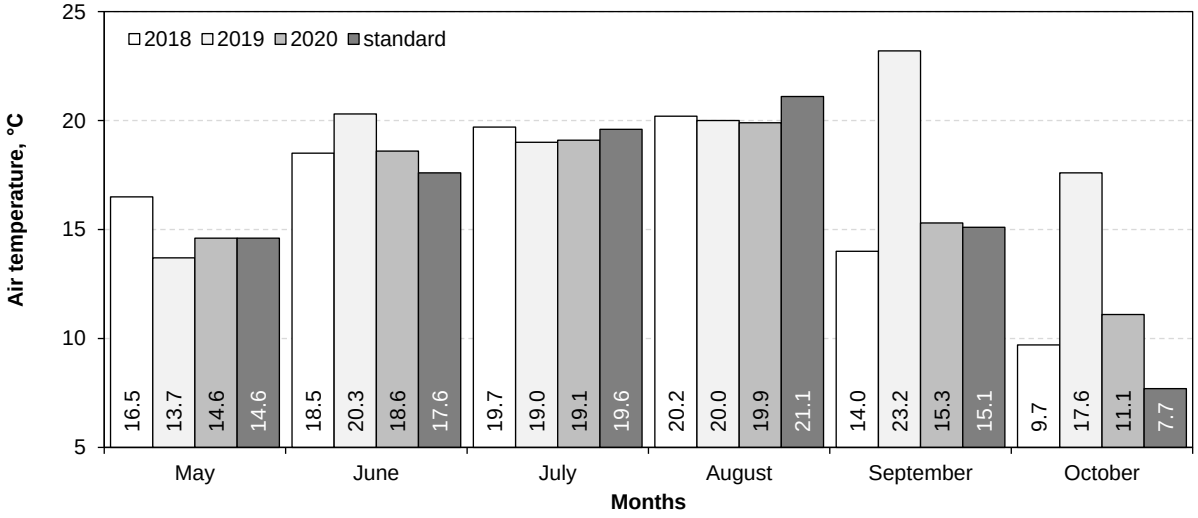

Figure 1. Air temperature (ºC) during vegetation period 2018–2020 of sweet corn

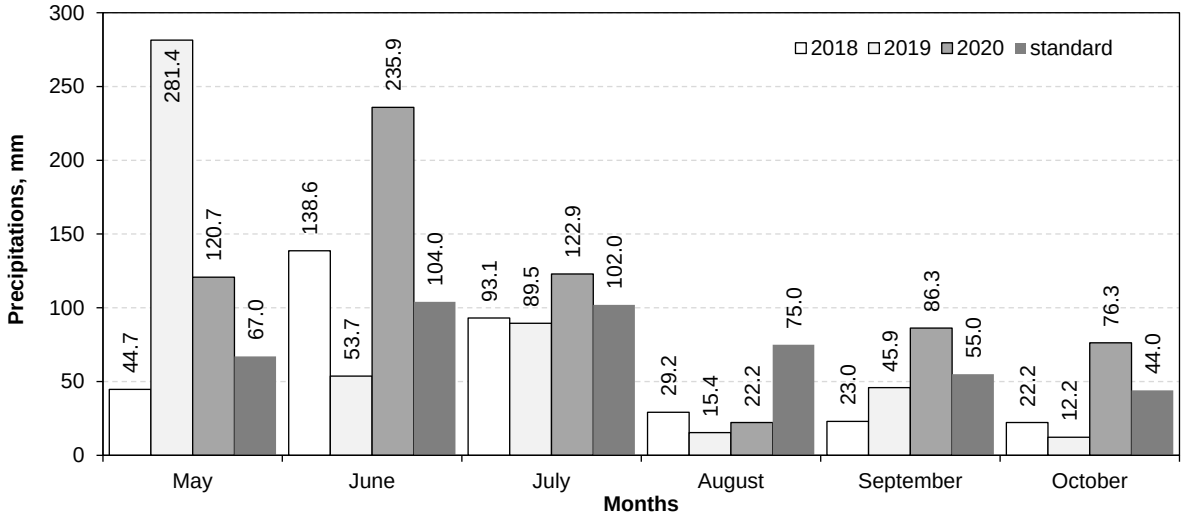

Figure 2. Precipitation amount (mm) during the vegetation period 2018-2020 of sweet corn

Results

The main index of the expediency for using a particular cultivation technology in agricultural production is its economic evaluation by the indices of production costs, the prime cost of one tonne of product, profit and profitability. Gradations of these indices depend on several factors, the most determining of which are the degree of technology intensity and the level of crop reaction to certain agro-technological measures and their combination in cultivation technology, which is manifested in changes in yielding capacity.

Productivity of early-ripening sweet corn, on average for 2018–2020, varied in a wide range – from 4.39 t ha^{-1} in the control variant with the agro-technical method and plant densification to 6.65 t ha^{-1} – with the application of $N_{135}P_{90}K_{125}$+ N_{60}+ N_{30} in two stages (Fig. 3).

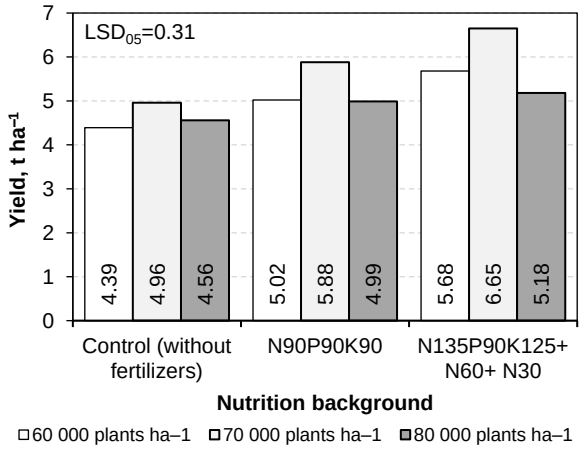

Figure 3. The yielding capacity of corn grain at a humidity of 14% depending on the density of plants and fertilizer doses average for 2018–2020, t ha^{-1}

It was have found that due to the intensive type of growth and high potential of individual productivity of plants, corn is characterized by a very low realization of potential productivity under undernutrition conditions close to the natural background of soil fertility. This is especially acute in case of insufficient moisture supply and on soils with low nutrient content, when already in the initial stages of plant development a weakened agrocenosis with minimal productivity is formed.

In our studies, the yielding capacity of corn in the variants without fertilizers, regardless of plant density, did not exceed 4.39 t ha^{-1}, which was stipulated by the insufficient amount of precipitation during vegetation and long-term removal of biogenic elements by crops with crop rotations for growing without fertilizers on sod-podzolic soil with the very low level of nutrient supply.

At the same time, the application of mineral fertilizers provided high yield increases – at the level of 0.63–2.26 t ha^{-1}, and a combination of different plant densities and doses of mineral fertilizers helped to increase their use efficiency. Thus, significant yield increases (0.63–2.26 t ha^{-1} with LSD_{05} = 0.31) were obtained from intensification means at all variants of the experiment, except for the control (without fertilizers). This indicates a high degree of positive reaction of corn to increase of intensity level of cultivation technologies.

The results of the research showed that the highest yields during the studied years were obtained in 2019 and they varied from 4.77 t ha^{-1} (in the control version) to 7.05 t ha^{-1} (for the application of mineral fertilizers at a dose of $N_{30}P_{45}K_{45}$ + N_{60} + N_{30} It should be noted that this year the optimal growing conditions for sugar corn were formed, which resulted in high crop productivity.

Such high increases in yielding capacity are provided by a significant increase in resource capacity of production. This, in its turn, stipulated a significant increase in production costs. On average during 2018–2020, production costs of growing corn increased in proportion to saturation of technology with intensification means: from 298.9–327.7 € ha^{-1} – for resource-saving models with limited doses of mineral fertilizers and plant density, and to 327.7–371.2 € ha^{-1} – for intensive technologies and high-intensity model with application of increased doses of fertilizers (Table 1).

Table 1. Economic indices of sweet corn cultivation depend on the background of nutrition and densification of plants, the average for 2018–2020

Variant	Density of plants, plants ha^{-1}	Prime cost, € t^{-1}	Costs per, € ha^{-1}	Net profit, €	Profitability level, %
Control (without fertilizers)	60 000	68.03	298.72	291.36	56
	70 000	61.15	303.36	300.80	59
	80 000	66.91	305.15	295.17	53
$N_{90}P_{90}K_{90}$	60 000	64.29	322.78	410.34	127
	70 000	55.26	324.96	390.56	120
	80 000	65.70	327.81	367.23	112
$N_{135}P_{90}K_{125}+ N_{60}+ N_{30}$	60 000	64.45	366.08	495.23	135
	70 000	55.81	371.04	491.68	132
	80 000	71.68	371.33	473.47	127

The maximum economic efficiency of growing sweet corn is provided by an agro-technological complex with a nutrition background of $N_{135}P_{90}K_{125}+ N_{60}+ N_{30}$ and a plant density of 60 000 plants ha^{-1}. This is expressed in the highest index of profitability level – 135%. The lowest index of profitability level was in the variant without mineral fertilizers and plant density of 80 000 plants ha^{-1} and amounted to 53%. Analysis of economic efficiency concerning the production of commercial sweet corn cobs showed that cultivation of sweet corn is profitable even under unfavourable agricultural production conditions.

It should be noted that the application of mineral fertilizers in all variants of the experiment led to a reduction of prime cost, an increase in costs per 1 ha of crops and a significant increase in profits and level of production profitability. Whereas density increase of sweet corn plants from 60 to 70 000 plants ha^{-1} reduced the prime cost of commercial cobs of the crop, further densification of the crops led to the prime cost growth. Namely, densification of the crops to 80 000 plants ha^{-1} stipulated a decrease in profits and profitability level, while production costs per 1 ha remained almost at the same level as the variants where plant density was 70 000 plants ha^{-1}.

Discussion

There is little information on the economic consequences of different levels of fertilizer on the economic efficiency of growing sweet corn. The results of our study agree with the statement that the rationally scientifically sound application of nitrogen fertilizers on corn crops leads to a significant increase in the efficiency of growing crops from an economic point of view (Mulvaney *et al.*, 2006). We saw the above trend in our study: options with higher rates of mineral fertilizers were more cost-effective. However, some researchers note that there is no need to fertilize the crop, the best way is to apply the optimal dose of nitrogen and get the best result between yield and cost-effectiveness (Vanotti, Bundy, 1994). This statement is likely true.

However, it should not be forgotten that plant density is also an important factor in improving the economic efficiency of crops. It was determined that the influence of this element of agricultural technology differs in different genotypes of sweet corn. According to Yakunin's *et al.* (2011) research, some genotypes provided the best economic efficiency for 40 000 plants ha^{-1}, while others performed better for 50 000 plants ha^{-1}, depending on the length of the growing season. Note that the results of our study did not take into account the impact of the variety on economic efficiency. While the results of Eskandarnejad *et al.* (2013) indicate that, the best plant density for sweet corn in Iran is 90 000 plants ha^{-1} compared to 60 000 and 75 000 plants ha^{-1}. The Morris *et al.* (2000) study found that the yield of sweet corn increased with increasing plant density from 29 600 to 69 200 plants ha^{-1} in the study of varieties and hybrids.

However, there is a study that agrees with our results, namely that the yield of sweet corn increases to a certain number of ha^{-1} plants, and further thickening of crops harms productivity. It was found that the optimal plant density in the above study for the fresh market in sugar corn was considered 56 000 ha^{-1} plants (Landré *et al.*, 2020).

The optimal density of plants and the best options for fertilizers are the key to the efficient production of sweet corn and are highly dependent on the characteristics of the cultivated hybrid and environmental conditions. Thus, it is important to conduct research work for each area of cultivation, taking into account the range of varieties and hybrids, ecological, climatic, soil conditions and the level of agricultural development in the area.

Conclusion

It has been found that the economic efficiency of sweet corn growing technologies depends on the level of their intensity and is determined by the crop reaction to individual agricultural measures and their complex application in a single technological cycle. The results of the economic analysis of sweet corn agrotechnical showed that the best economic efficiency of crop production is ensured by applying mineral fertilizers standard $N_{135}P_{90}K_{125}$ + N_60 + N_{30}, and plant density 60 000 plants ha^{-1}. This agro-technical complex provided the maximum profitability of cultivation of 135%.

There have been outlined economically efficient resource-saving, intensive technologies and technologies providing the stable yielding capacity of early-ripening sweet corn hybrid variety Moreland F1 at the level of 4.99–6.65 t ha^{-1} by the profit of 367.36–495.36 € ha^{-1} with the profitability of grain production at the level of 112–135%.

Implementation of norming production costs for their optimization in changing soil-climatic and organizational-economic conditions is rather promising in the

direction of improving the technology of growing sweet corn with different intensities. Therefore, we recommend growing sugar corn for the needs of the market in the conditions of Precarpathia with the help of the above-mentioned technological operations, which will guarantee a high economic effect of crop production for farmers.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author contributions

YH – study conception and design, drafting of the manuscript;
VN – performed the literature data analysis and discussion of the results;
AB – analysis and interpretation of data and is the corresponding author;
ML – author of the idea, guided the research;
MK, IO – acquisition of data, drafting of the manuscript;
OS, VS, LK – critical revision and approval of the final manuscript.
All authors read and approved the final manuscript.

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