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Evaluation of silage and grain yield of different maize (*Zea mays* L.) genotypes in organic and conventional conditions

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Abstract

The intensification of agriculture is closely linked to high emissions of greenhouse gases. To address the challenges, the European Commission published the European Green Deal in 2019. The aim of our study was to compare the yield of maize genotypes bred in Martonvásár in three different cropping environments (organic, irrigated conventional, and non-irrigated conventional). The silage and grain yields of different maize hybrids and parental lines were evaluated in a three-replicate small plot experiments. The green mass yield of the organic area was 19 and 15% lower compared to the irrigated conventional and non-irrigated conventional treatments. The dry matter yield of the maize hybrids was 12.9 t ha^{-1} in the organic area, 15.7 t ha^{-1} in the irrigated, and 15.8 t ha^{-1} in the non-irrigated environment. Hybrids had significantly better grain yield in the conventional systems (irrigated: 10.0 t ha^{-1} and non-irrigated: 9.8 t ha^{-1}) than in the organic environment (7.6 t ha^{-1}). The difference in yield results was not as considerable for the parental lines as for the hybrids. In addition, our results indicated high presence of heterosis for yields. The heterosis of the grain yields was two times higher than for silage yields. Heterosis was highest at the non-irrigated conventional area.

Keywords: conventional agriculture, grain yield, maize genotypes, organic farming, silage yield.

Introduction

Maize (*Zea mays* L.) has become one of the most important crops for mankind. It is widely cultivated nearly all over the world due to its excellent adaptive properties and the determined breeding effort. The primary use is feed in most countries. It is an excellent source of energy due to its valuable nutritional properties. It is also increasingly important as a direct human food, especially in developing and food-insecure countries, where up to 80 - 90% of the crop is used for human consumption. In addition, its industrial uses are extensive (Pepó and Sárvári 2011, Otegui *et al*. 2021). The area under maize cultivation was 205.9 million hectares in 2021, with a total grain production of 1 210.2 million tons (FAO 2023). Maize is the largest arable crop in Hungary. For several decades, its area has been around 1 million hectares. It accounts for about 27% of the harvested area of the main arable land (KSH 2023a). The average yield is determined by several factors in a given year. It may depend on the variety chosen, the agro-technology used, the pathological and the pest factors present, and to a large extent on the meteorological conditions.

However, the world's population has grown rapidly in recent decades. While there were 2.5 billion people living on our planet in 1950, today that number has

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Abbreviations: DDMY - digestible dry matter yield per hectare; DIGOM - digestible organic matter content; DMY - dry matter yield per hectare; GMY - green mass yield per hectare, GY - grain yield; NIRS - near infrared reflectance spectrophotometer; WCR - western corn rootworm.
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risen to 8 billion (KSH 2023b). As a result, global demand for agricultural products is rising. However, the intensification of agriculture is closely linked to high emissions of greenhouse gases (van Beek *et al*. 2010). This drastic change has an impact on the Earth's climate. Extreme climatic conditions, such as drought or heat stress, can lead to crop failure, threatening people's food security, and farmers' livelihoods (Vogel *et al*. 2019). Climate adaptability of maize is predicted to decrease in sub-Saharan Africa and Latin America regions, while expanding in northern Europe. The relative change in climate suitability for future maize production has been estimated for the current leading countries. Production is expected to increase by 8% in the USA and 4% in China, but decline by 5% in Brazil, 2% in Argentina and 11% in Mexico by 2050 (Ramirez-Cabral *et al*. 2017).

Keeping up with these climate changes in agriculture, while protecting the planet, has become a major issue in recent years. To address these challenges, the European Commission published the European Green Deal in 2019 (EU Jog 2021). The main goal of the program is to achieve net zero greenhouse gas emissions by 2050, making us the world's first climate-neutral continent. The agreement promises fresh air, clean water, healthy soil, biodiversity, healthy and affordable food among other things. In order to achieve all of this, multi-step regulations covering different sectors are necessary (European Commission 2021a). Criteria in agriculture are also defined: increase the share of organically farmed land to 25%, reduce the use of fertilisers and pesticides (European Commission 2021b).

In total, more than 76.4 million hectares were under organic farming worldwide in 2021. However, if we look at the proportion of organic land as a percentage of the total, only 1.6% of the world's total land was under organic production. The organic agricultural area reached 17.8 million hectares in Europe in 2021, of which 15.6 million hectares were in the European Union. This means that 9.6% of the agricultural land used in European Union was in organic farming, which is still far from the aimed 25% (Willer *et al*. 2023). In Hungary, the total agricultural area was 5.0 million hectares, of which 293 thousand hectares were converted into organic farming in 2021 (KSH 2022a,b). The area of organic arable land was 91 thousand hectares, of which more than a third was cultivated with cereals (KSH 2022b). However, despite the slowly increasing trend, we are still behind the European idea. In order to achieve dynamic development, the Hungarian National Action Plan for the Development of Organic Farming, approved by the Ministry of Agriculture, was published in 2022. One of its main priorities is to increase the current organic area ratio of almost 6 to 10% by 2027 (Drexler *et al*. 2022, Gov. HU 2022).

The benefits of organic farming are widely debated. On the one hand, some promote it as a solution to sustainable food security challenges. According to these views, organic agriculture is a production system that maintains the health of the ecosystem and people. It is based on the processes and cycles of biodiversity adapted to local conditions. External inputs are substantially reduced in organic agriculture due to the prohibition of synthetic fertilisers, pesticides, and additives. Organic farming is considered an environmentally friendly alternative to conventional agriculture (Reganold and Wachter 2016, Meng *et al*. 2017). Further and very important advantage is the significantly better quality of products; organic maize varieties are healthier and contain less residues (Revilla *et al*. 2008). On the other hand, others criticise it for being underdeveloped. Traditional agriculture uses a diverse set of technologies and the best available knowledge, with the ultimate aim of providing an abundant food supply at the lowest cost (Trewavas 2001, Connor 2008). Several studies have confirmed that organic farming yields are on average 20% lower than conventional farming (de Ponti *et al*. 2012, Kniss *et al*. 2016, Reganold and Wachter 2016). Presumably, the reason of this decrease in yields is the lack of fertilisers (especially nitrogen) and pesticides. Therefore, the better these are lifted or controlled in traditional agriculture the larger the gap between organic and conventional yield might be. Furthermore, the yield difference depends on the location and the type of crop grown. Regions with more intensive, higher yielding production systems (*e.g*., Western Europe), regions with humid tropical climates and crops that are more susceptible to pathogens and pests are expected to have higher yield losses in organic areas (de Ponti *et al*. 2012).

The purpose of plant breeding is to produce new varieties with good adaptability to biotic and abiotic stresses. Not only testing but breeding new varieties in the target environment is recommended (Revilla *et al*. 2008, 2015; Oliveira *et al*. 2011). In order to utilize the potential of modern genotypes, knowing their agronomic needs is essential. Sustainable maize production requires genotypes which produce high yields with good quality even without irrigation or use of chemicals. Though, the majority of modern hybrids are designed for intensive cropping systems. Some of them perform well in a less intensive environment, but they can only be identified based on field experiments. The aim of our study was to compare the yield of silage and grain maize hybrids and their parental lines bred in Martonvásár in three different cropping environments.

Materials and methods

The field experiment was carried out at the Centre for Agricultural Research in Martonvásár in 2021. Part of the field has been certified as suitable for organic agriculture since 2007, on which no chemicals are allowed. The rest of the experimental area was under conventional agriculture, with fertiliser, herbicide, and insecticide application. The soil type was endocalcic chernozem and good nutrient supplies. In the autumn, 400 kg ha^{-1} of complex fertiliser (NPK 15-15-15) was applied to the conventional site. Manure is applied to the organic land once every four years (last time was 2018). In the year of the experiment, 450 kg ha^{-1} fertiliser (N 27%) and 12 kg ha^{-1} soil disinfectant (15 g kg^{-1} tefluthrin) were applied before sowing.

The disinfectant was used against western corn rootworm (WCR, *Diabrotica virgifera virgifera*), which could have been present due to the long term monoculture. In the organic area only soil and seedbed preparation were done with a compactor. The forecrop was wheat at the organic location and maize at the conventional locations. Sowing was carried out on the same day with a density of 70 000 plants ha^{-1} and rows distance of 76 cm. 0.4 l ha^{-1} herbicide (240 g l^{-1} isoxaflutole) was applied in May and June and 0.3 l ha^{-1} insecticide (50 g l^{-1} lambda-cyhalothrin) was done twice in July against WCR and European corn borer (*Ostrinia nubilalis*) on the conventional area. Meanwhile in the organic area, only mechanical weed control was used by cultivator and hand hoe.

Total of 7 single cross maize hybrids and their 7 parental lines were tested (Table 1) using different cropping systems in a small plot field experiment with 3 replications and randomised block design. The 3 agricultural systems:
1) organic without irrigation, referred to as "organic"
2) conventional with irrigation, referred to as "irrigated"
3) conventional without irrigation, referred to as "non-irrigated".

Monthly temperature (Fig. 1) and precipitation (Fig. 2) data were recorded by the meteorological station located next to the field experiment. It was evaluated and compared to the 20 years mean (2001 - 2020). Overall the mean temperature for 2021 was lower (10.7°C) than the average of the last 20 years (11.1°C). However, July, which is one of the most important months for the maize because of the flowering time, was 1.6°C hotter with 22.0 mm more rain. Overall the year precipitation was almost 83 mm below the 20-year average. In addition, the total rainfall during the growing season (April to September) was 305 mm against the 20-year average of 321 mm. There was extremely low rainfall in June. Additionally to the rainfall, 30 mm of excess water was applied twice with sprinklers to the irrigated area in July.

During the growing season data were collected about the hybrids and parental lines. Grain harvesting and yield (GY) measurement of maize genotypes was done with combine harvester on the same day for the 3 cultivations. To estimate the silage yield, 3 competitive plants per plot were cut and chopped, fresh mass was measured. The chemical compositions of the samples were measured at the harvesting day by near infrared reflectance spectrophotometer (NIRS) using the *INGOT* calibration software. The obtained plot data were used to calculate the green mass yield per hectare (GMY), the dry matter yield per hectare (DMY), and the digestible dry matter yield per hectare (DDMY) of maize genotypes:

$$GMY\ [t\ ha^{-1}] = (IM\ [kg] \times N_p) / 1000$$

$$DMY\ [t\ ha^{-1}] = (GMY\ [t\ ha^{-1}] \times DM\ [\%]) / 100$$

$$DDMY\ [t\ ha^{-1}] = (DMY\ [t\ ha^{-1}] \times DIGOM\ [\%]) / 100$$

where IM = individual mass; N_p = plant number per hectare; DM = dry matter; DIGOM = digestible organic matter content. Data were analyzed by two-way *ANOVA*.

Table 1. Total of 7 single cross maize hybrids and their 7 parental lines were tested in Martonvásár 2021. The hybrids belonged to different maturity groups: very early (FAO 200 - 299), early (FAO 300 - 399), medium (FAO 400 - 499), and late (FAO 500 - 599). Grain and silage hybrids were examined in the experiment as well.

Hybrids	Parental lines	FAO number	Grain/Silage
F1	P1 × P3	460	S
F2	P4 × P3	500	S
F3	P6 × P4	550	S
F4	P5 × P1	420	S
F5	P2 × P6	360	G
F6	P1 × P7	270	G
F7	P4 × P7	505	G

Results and discussion

The analyzed yield data showed significant differences between organic and conventional agriculture. The average GMY of the hybrids in the organic area was 32.9 t ha^{-1}. The average yields in the conventional locations were significantly higher: 40.4 t ha^{-1} in the irrigated environment and 38.5 t ha^{-1} in the non-irrigated one (Table 2). Consequently, the silage yield of the organic area was 19 and 15% lower compared to the fertilized treatments. The average GMY of the parental lines in the organic area was 21.9 t ha^{-1}, which was approximately 12% lower than in the irrigated field. There was no significant difference between the organic and conventional areas in the case of parental lines.

The DMY of the maize hybrids was 12.9 t ha^{-1} in the organic area, 15.7 t ha^{-1} at the irrigated location and 15.8 t ha^{-1} in the non-irrigated environment (Table 2). According to our results there was a significant difference between the average yields of the organic and conventional treatments, but not between the irrigated and non-irrigated areas. Significant yield gaps in case of the inbred lines were not obtained. The average DMY of the organic area was 89% of the irrigated production and around 92% of the non-irrigated conventional system.

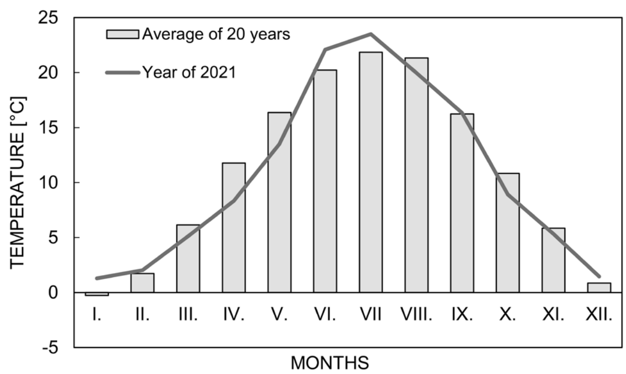

Fig. 1. Monthly temperature [°C] for the year and location of the field experiment. The collected data was compared to the average of previous 20 years (2001 - 2020) for the same exact area.

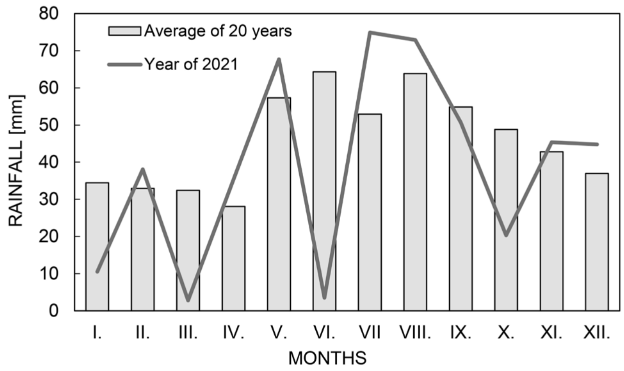

Fig. 2. Monthly rainfall [mm] for the year and location of the field experiment. The collected data was compared to the average of previous 20 years (2001 - 2020) for the same exact area.

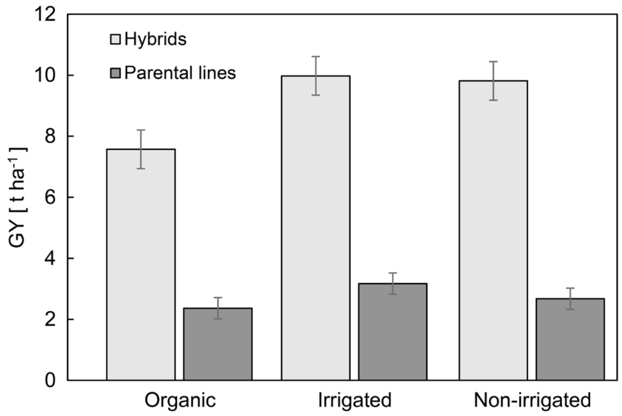

Fig. 3. GY [t ha^{-1}] of maize hybrids and their parental lines grown in three different cropping systems (organic, irrigated conventional, and non-irrigated conventional) in Martonvásár 2021. Significant differences were determined by two-way *ANOVA*. $LSD_{5\%}$ for the hybrids was 0.6 and $LSD_{5\%}$ for the parental lines was 0.3 (in both cases is significant difference at $P < 0.001$).

Calculating the DDMY proved to be a suitable method for evaluating silage hybrids because it gives a more precise prediction of the feeding value than DMY or DIGOM separately (Tóthné Zsubori *et al.* 2013). The average yield of the hybrids in the organic area was 7.5 t ha^{-1}, which was significantly lower than the conventional ones (irrigated: 9.7 t ha^{-1}; non-irrigated: 9.6 t ha^{-1}). Furthermore, there were no significant differences between the DDMY of inbred lines in the organic and conventional cultivations (Table 2).

The average GYs of the genotypes at 14% moisture content were measured as well. Hybrids had significantly better yield in the conventional systems (irrigated: 10.0 t ha^{-1} and non-irrigated: 9.8 t ha^{-1}) than in the organic environment (7.6 t ha^{-1}). According to our results the production of the modern genotypes was around 24% higher in the fertilized treatments (Fig. 3). Inbred lines produced the highest GY at the irrigated location (3.2 t ha^{-1}), while the non-irrigated (2.7 t ha^{-1}) and the organic location (2.4 t ha^{-1}) did not differ significantly.

Similarly as in previous studies (de Ponti *et al.* 2012, Kniss *et al.* 2016, Reganold and Wachter 2016), we established lower yields in the organic cropping system, than in the conventional agriculture. Based on our yield results, significantly lower yields were obtained in the organic area compared to the conventional treatments. Furthermore, the highest yields were in the irrigated area, but not significantly higher than in the non-irrigated area. These results suggest that the applied conventional farming (which mainly linked to the use of fertilizer) significantly increased the yield value, while the effect of irrigation had an additional positive contribution to the improved yield. In contrast, the GY of the inbred lines was significantly the highest in the irrigated conventional area and there was no significant difference between the non-irrigated conventional and organic treatments. Irrigation had a positive effect on the yield of the parental lines but the production system did not make a difference in the yield to a great extent. Kaplan *et al.* (2016) observed positive effect of increasing irrigation levels and fertilizer doses on the fresh mass of silage maize. Another study reported that the increasing irrigation influenced significantly the grain yield (Majid *et al.* 2017). In contrast, Masoero *et al.* (2013) found no effect of irrigation treatments on yield of maize hybrids and Lynch *et al.* (2013) established no effect of nitrogen fertilizer on DMY. In our experiment, no statistical difference between the yields of the conventional cultivations was measured in most cases. This may be due to the fact that the effect of irrigation

Table 2. Silage yield [t ha^{-1}] of maize hybrids and their parental lines grown in three different cropping systems (organic, irrigated conventional, and non-irrigated conventional) in Martonvásár 2021. Significant differences were determined by two-way *ANOVA*. The $LSD_{5\%}$ values are shown in the table, where ** indicates significant difference at $P < 0.01$, * indicates significant difference at $P < 0.05$ and ns means no significant difference.

Yield [t ha^{-1}]		Organic	Irrigated	Non-irrigated	$LSD_{5\%}$
GMY	hybrids	32.9	40.4	38.5	5.1*
	parental lines	21.9	24.7	22.8	2.6ns
DMY	hybrids	12.9	15.7	15.8	2.1*
	parental lines	7.7	8.7	8.4	1.1ns
DDMY	hybrids	7.5	9.7	9.6	1.4**
	parental lines	4.6	5.3	5.0	0.7ns

Table 3. Heterosis [%] of the silage and grain yield results at three different cropping systems (organic, irrigated conventional, and non-irrigated conventional). Heterosis was calculated as the ratio of the yield of hybrids to the mean yield of their parental lines. Significant differences were determined by two-way *ANOVA*. The $LSD_{5\%}$ values are shown in the table, where * indicates significant difference at $P < 0.05$ and ns means no significant difference.

Heterosis [%]	Organic	Irrigated	Non-irrigated	$LSD_{5\%}$
GMY	163.9	174.7	178.6	30.7ns
DMY	179.6	188.5	194.9	35.3ns
DDMY	178.2	193.8	198.3	39.3ns
GY	330.1	326.1	383.7	46.7*

was not large due to the amount of rainfall recorded during the growing season and the soil of the experiment had excellent water holding capacity. The 67.7 mm of rain in May was favourable for emergence and early development. In addition, a total of 151.3 mm rainfall during the summer months was not significantly affected by the additional 60 mm of irrigation water applied.

Heterosis is an advantage of the hybrids over their parental lines in certain traits. Hybrids are more tolerant to different stress factors due to adaptive heterosis (Chairi *et al*. 2016). Therefore they are able to tolerate agrotechnological changes (such as different production systems) better. Heterosis was calculated as the ratio of the yield of hybrids to the mean yield of their parental lines. Our results indicated high presence of heterosis for silage and grain yields. In case of each yield values, heterosis was highest at the non-irrigated conventional area. In case of the silage yield evaluation, heterosis was lowest at the organic field, whereas for GY irrigated area had the lowest value (Table 3). However, significant difference between cropping systems could be detected only for GY. Furthermore, the heterosis of the GYs was approximately twice as high as for the silage yield.

It should be noted that all genetic test results are relevant to the examined population in the examined environment. According to Sang *et al*. (2022), heterosis models for maize are difficult to predict and they are not persistent with the tested genotypes and environment, therefore their use is limited. We can conclude that there is not much variation in the trend across hybrids. Although the effect of heterosis should have been greatest in the least favourable condition for the parental lines. Alternatively, the inbred lines should have declined more in organic area because they are less resistant to stress factors. However, the forecrop used in the organic area was wheat, whereas in the conventional area we have been using monoculture for years. We conclude that the organic area has a better soil structure and more available water. As a consequence, the plants were able to resist the stress factors better in the organic field than in the non-irrigated conventional one, resulting less heterosis effect.

Conclusions

The aim of our study was to compare the silage and grain yield of maize (*Zea mays* L.) hybrids and their parental lines bred in Martonvásár in three different cropping environments. Total of 7 single cross maize hybrids and their 7 parental lines were tested using different cropping systems in a small plot field experiment with 3 replications and randomised block design. We established significantly lower yield results in the organic cropping system, than in the conventional agriculture. In case of the parental lines, the yield loss was lower. Irrigation had a positive effect on the grain and silage yield, however, there was no significant difference between the irrigated and non-irrigated treatments in 2021 (except the grain yield of the inbred lines). This might be due to the fact that the effect of irrigation was not large due to the amount of rainfall recorded during the growing season and the water holding capacity of the soil. In addition, our results indicated high presence of heterosis for yields. The heterosis of the grain yield was considerably higher than for silage yield. Significant difference between the treatments could be detected only for grain yield. In all cases heterosis was highest at the non-irrigated conventional area.

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