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Yield of sweet corn and sunflower as affected by different cultivation methods and fertilisation schemes

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Abstract: If appropriately applied, tillage can positively affect the crop's yield by enhancing the soil's physical properties. Fertilisation also has beneficial effects on yield if applied at efficient rates by increasing available-to-uptake nutrients and improving soil's chemical properties. A field experiment was carried out in Debrecen, Hungary, to evaluate the individual and the interaction effects of these 2 factors on sunflower and sweet corn. The cultivation methods applied were ploughing (C1), direct drilling (C2) and deep loosening (C3). In addition, 3 fertilisation rates were applied to each cultivation system: F1 (control, no fertilisation); F2 (100:50:70) kg NPK/ha and F3 (150:100:120) kg NPK/ha in a randomised complete block design (RCBD) with 4 replicates. Our results showed that fertilisation did not affect the yield of sweet corn measurably. However, C1 resulted in the highest yield, whereas C2 and C3 resulted in relatively similar yields. In sunflowers, the yields of both C1 and C2 were higher than that of C3. No significant differences were recorded between C1 and C2. The yields of both F2 and F3 were higher than the yield of F1. The differences between F2 and F3 were insignificant. It could be concluded that the cultivation method is a determining factor in the yield of sweet corn. The effects of both fertilisation and cultivation treatments were more detectable in sunflowers. The differences between the two fertilisation rates (F2 and F3) were insignificant in both species, indicating that the extra fertilisation levels might be unnecessary.

Keywords: *Zea mays* L.; *Helianthus annuus* L.; nutrition; productivity; seed bed

Appropriate tillage application, along with proper fertilisation, massively affects soil structure, both physical and chemical properties of the soil and, consequently, the plant's yield potential. This is because the seedling emergence and establishment and, later, the plant's development and final yield are considerably affected by the physical properties of the seed bed prepared by tilling the soil (Xue et al. 2018). The misapplication of these practices can reduce soil productivity (Ultra et al. 2017), especially in areas with unfavourable climatic episodes like drought (Houshyar and Esmailpour 2020).

Through conventional tillage (plowing), the more-fertile soil from the top layers is buried into deeper layers, where the active root zone is (Nouraein et al. 2019). This practice, if frequently applied, can decrease

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pore volume and distribution and, consequently, water retention due to the compaction and erosion of the soil (Ordoñez-Morales et al. 2019). It can also restrict root elongation and development (Shamsabadi et al. 2017). Thus, proper conservational tillage applications should be taken into consideration for improving soil structure, texture and porosity to become loose with better physical properties for the plants (Paul et al. 2020). In addition to the benefits to the soil, conservational tillage practices result in saving energy and fuel as well (Lazcano et al. 2011). Conservation tillage can be performed in several methods that consist of no- to minimum tillage with work done on the upper soil layer without deep tillage (Raper 2005).

Sunflower is one of the most important crops, especially in the crop rotations that are cereal-based, because of its role as an energy crop (Barontini et al. 2015). In Hungary, sunflower is the third most cultivated crop after maize and wheat. The harvested area of sunflower increased from 502 000 hectares in 2010 to 655 000 hectares in 2021 (Hungarian Central Statistical Office 2022). Availability of nutrients is a major factor affecting the achene yield (Aryafar et al. 2023, Tovar Hernández et al. 2023). Sunflower generally has high demands for essential nutrients (Nuccio et al. 2018).

Sweet corn cultivation is getting more renowned in Hungary, with an increase in harvested area from 22 000 hectares in 2010 to 37 000 hectares in 2021 (Hungarian Central Statistical Office 2022). Not only the yield but also the quality of the ears (marketable ears), like the sweetness and flavour of the kernels, for example, is important when it comes to sweet corn production and marketing process. According to Alijani et al. (2021), available soil N, along with other soil quality traits, can massively influence kernels' quality. However, past research on sweet corn reported that the optimum N rate depends on several factors, including sowing dates and climatic conditions (Oktem et al. 2010). In Hungary, little is known about the nutrient requirements of sweet corn (e.g., Szalókiné Zima 2023), and more information needs to be published. Moreover, very few reports on the different cultivation methods and their probable influence on the vigour and yield of sunflower and sweet corn in Hungary are available (e.g., Vad et al. 2007). Whether there is an integrated effect of these cultivation methods or not when combined with different fertilisation levels in Hungary is not fully understood either. We hypothesised that cultivation and/or fertilisation, solely or combined, will affect the yield of both sweet corn and sunflower. Our experiment aimed to reveal the effects of different cultivation methods, alone or in combination with different fertilisation rates, on the final yield of a widely cultivated crop (sunflower) and a continuously expanding crop (sweet corn) in Debrecen, Hungary.

MATERIAL AND METHODS

This experiment was conducted in 2019, 2020 and 2021 in the experimental station of the Faculty of Agricultural and Food Sciences and Environmental Management, University of Debrecen, Hungary (Látókép) (latitude 47°33'N, longitude 21°27'E). The soil type of the site is calcareous chernozem. Sweet corn (cv. Dessert R78) (April 11th, 20th and 27th in 2019, 2020 and 2021, respectively) and sunflower (cv. NK Neoma) were sown in (April 11th, 15th and 7th in 2019, 2020 and 2021, respectively) and harvested in (August 6th, 7th and 1st in 2019, 2020 and 2021, respectively) and (September 12th, 11th and 21st in 2019, 2020 and 2021, respectively). These genotypes

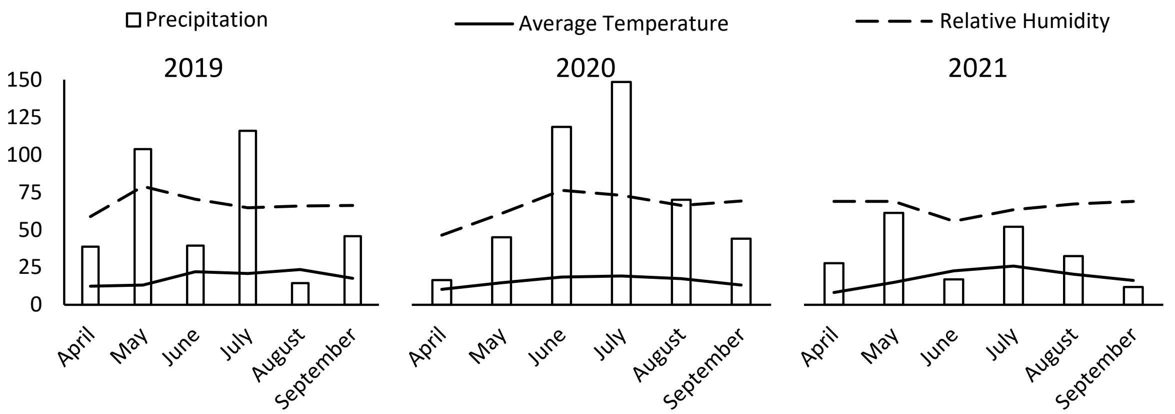

Figure 1. Precipitation amount, average temperature, and relative humidity during the experimental period of 2019, 2020 and 2021

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Table 1. Soil analysis of the experimental area at different depths (25 cm-layer depth), Látókép, Debrecen, Hungary

Soil layer depth (cm)	pH	$CaCO_3$	Organic matter	Total N	Available P	Available K	MgO	SO_4
		(%)			(ppm)			
0–25	6.46	0	2.76	0.150	133.4	239.8	332.4	9.25
25–50	6.36	0	2.16	0.120	48.0	173.6	405.4	9.13
50–75	6.58	0	1.52	0.086	40.4	123.0	366.6	10.80
75–100	7.27	10.25	0.90	0.083	39.8	93.6	249.0	7.95
100–125	7.36	12.75	0.59	0.078	31.6	78.0	286.6	22.98

were chosen based on their widely spread harvested area across the country. The meteorological data (i.e., precipitation amount, average temperature and relative humidity) during the experimental period each experimental year is shown in Figure 1.

Soil analysis was performed at different depths (25 cm-layer depth) before seeding. Soil analysis data are shown in Table 1.

In addition, detailed characteristics (i.e., grain size, cation exchange capacity and bulk density) of the soil in the experimental site are shown in Table 2.

Each species was cultivated by 3 different cultivation methods: Ploughing (C1) (35 cm-deep inversions and burial using 3-head Rabe); direct-drilling (C2) (30 cm-cultivation using Köckerling quadro) and deep loosening (C3) (45 cm-soil loosening using Maschio Gaspardo loosener). For all three cultivation methods, discs (vaderstad carrier) were used to cut the fore crop residues, followed by either C1, C2 or C3 cultivation method, and then a combinator (vaderstad nza) was used to prepare the seed beds at 6 cm depth. In addition, 3 different fertilisation schemes were applied to each cultivation system: F1 (control treatment with no fertilisation); F2 (where the average fertilisation scheme of 100 kg N/ha (in the form of ammonium nitrate), 50 kg P/ha (in the form of triple superphosphate) and 70 kg K/ha (in the form of potassium chloride) and F3 (extra fertilisation scheme; i.e., of 150 kg N/ha, 100 kg P/ha and 120 kg K/ha) were applied. In March and September, N was added twice a year, whereas P and K were added once in September. All fertilisers were applied by hand, then immersing it into the soil at 10 cm depth using a disc cultivator. Plot size was 3 × 7 m, with 4 rows per plot and a width of 70 cm. The plant density was 72 thousand plant/ha for sweet corn and 60 thousand plant/ha for sunflower. The average yield per plot was calculated after harvesting the middle 2 rows of each plot. The experiment was arranged in a randomised complete block design (RCBD) with 4 replicates. GenStat software 20th edition (VSN International Ltd, Hertfordshire, UK) was used to conduct the analysis of variance (ANOVA) and the effect size (partial eta squared), followed by Tukey's PostHoc test to indicate the statistically significant treatments at 95% probability level (P < 0.05).

RESULTS AND DISCUSSION

The fertilisation treatments did not have an effect on the yield of sweet corn, whereas the cultivation treatments significantly affected this trait, where 12.8% of the changes in the yield could be explained by the different cultivation methods. The effects of both fertilisation and cultivation treatments were more detectable in sunflowers, where 39.1% and

Table 2. Grain size, cation exchange capacity and bulk density of the soil in the experimental site of Látókép, Debrecen, Hungary

Soil layer depth (cm)	Grain size (%)					Cation exchange capacity (mg/100 g)				Bulk density (g/cm^3)
	sand		silt		clay					
	> 0.25	0.25–0.05	0.05–0.01	0.01–0.002	< 0.002	Na^+	K^+	Mg^{2+}	Ca^{2+}	
	(mm)									
0–50	1.04	4.12	50.26	38.21	6.37	1.17	3.48	3.42	9.27	1.41
51–100	6.45	8.23	48.63	34.11	2.58	1.33	2.17	4.17	14.03	1.28
100–150	8.33	11.24	45.24	33.38	1.81	0.99	0.71	4.98	16.31	1.26

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18.3% of yield differences among treatments are explained by the different fertilisation and cultivation treatments, respectively. However, the interaction effect of both traits (fertilisation × cultivation) was insignificant in both species (Table 3).

In sweet corn, compared to C2 and C3, C1 resulted in a significantly higher yield, regardless of the fertilisation scheme (except for F2, where the yield in C1 was still higher than that of C2, but the difference was insignificant). Under all fertilisation schemes, C2 and C3 resulted in relatively similar yields, where the differences were statistically insignificant. Tillage significantly increased sweet corn yield when compared to the no-tillage treatment (Ginting et al. 2021). Significant yield reduction was reported in maize by Seddaiu et al. (2016) when the soil was not tilled compared to 40 cm-depth mould boarding treatments and 25 cm-depth chiselling. The reduction was justified by the non-favourable soil condition for the seeds, as the germination was constrained, and the plant density decreased by 50%. The authors concluded that 25 cm-depth chiselling is a better practice for sustaining stable grain yields as compared to the no-tillage method. The soil plowing at 30 cm-depth using disc plowing resulted in significantly higher sweet corn yield when compared to a traditional, shallow 12 cm-depth cultivation using a rotary cultivator (Shamsabadi et al. 2017). We found out that the C1 cultivation treatment, with deep soil inversion, resulted in the highest yield compared to traditional cultivation (C2) and loosening-only (C3) treatments. Alijani et al. (2021) reported that no-tillage treatment resulted in the lowest marketable yield of sweet corn as compared to both traditional (soil cultivation to a depth of 20–30 cm using moldboard plow) and reduced (soil cultivation to 15 cm depth using chisel plow) tillage treatments. The authors justified this reduction by the higher bulk density of the soil in the no-tillage treatment, which led to decreased root distribution and, thus, impaired nutrient uptake. The same authors reported that higher doses of N fertiliser (138 and 207 kg/ha) increased the yield compared to lower N rates (0 or 69 kg/ha), regardless of soil cultivation treatment, as a consequence of minimised N immobilisation. In our experiment, however, the different fertilisation treatments had different effects on the grain yield, depending on the cultivation treatment, although all the differences were minimal and insignificant, regardless of the cultivation method (C1, C2 and C3) (Figure 2A), probably because the 3 fertilisation levels used were insufficient to influence the yield. For example, KCl application at a rate of 150 kg/ha enhanced the vigour of sweet corn plants (determined by soil plant analysis development (SPAD) and leaf area index (LAI) and chlorophyll content), leading to better yield and yield components and better sucrose content (Pangaribuan and Sarno 2020). Thus, our findings will be considered for conducting separate experiments on the sole effect of different doses of the main macro-nutrients (N, P and K) on the yield of sweet corn, with a broader spectrum of the rates of each nutrient.

Better development and yield of sunflowers can be achieved by enhancing the tillage method used, which can lead to an optimised utilisation of the soil nutrients and a stable microbial colonisation (Wang et al. 2017). In our experiment, the yield in both treatments, where either a deep soil inversion at 35 cm deep (C1) or a direct drilling at 30 cm deep (C2), was significantly higher than that of the treatment where only a deep loosening (C3) was applied to the soil. No significant differences were recorded between C1 and C2, regardless of the fertilisation scheme. Sunflower yield was measurably better when moldboard plowing at a depth of 35 cm or a moderately deep tillage (25 cm) using a chisel plow was applied as compared to the surface (10 cm) tillage application using a disc harrower (Aboudrare et al. 2006). Using the same chisel plow method but at different depths (10, 20 and 30 cm) in sunflower resulted in significant grain yield differences in 2 different locations, where the treatment that received

Table 3. Analysis of variance (ANOVA) and the effect size (Partial Eta Squared) of the yield of 2 species (sweet corn and sunflower) under different fertilisation schemes and cultivation methods, averaged over 3 years (2019–2021)

ANOVA	Sweet corn			Sunflower		
Source	*F*	sig.	effect size (%)	*F*	sig.	effect size (%)
Fertilisation	0.200	0.819	0.3	27.888	0.000	39.1
Cultivation	9.885	0.000	12.8	9.742	0.000	18.3
Fertilisation × cultivation	0.459	0.766	1.3	0.965	0.431	4.2

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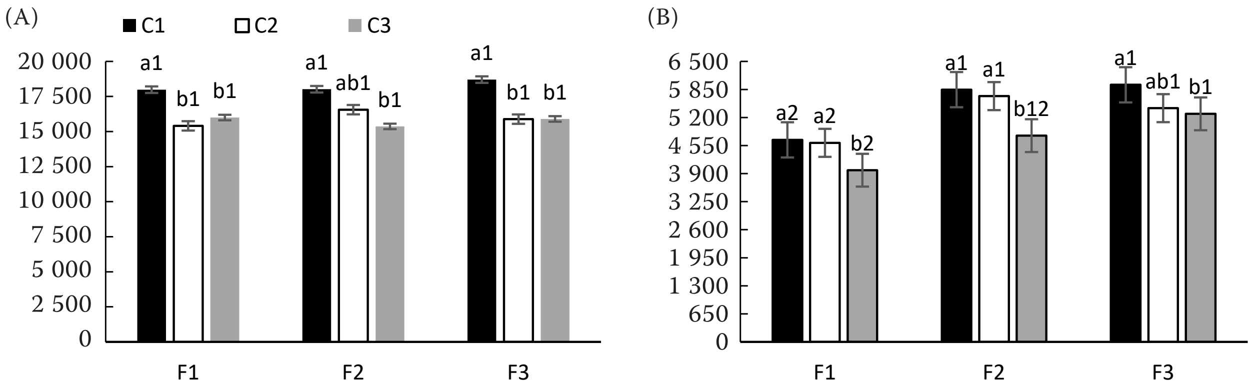

Figure 2. Yield (kg/ha) of (A) sweet corn and (B) sunflower under different cultivation methods (C1 – ploughing; C2 – direct-drilling; C3 – deep loosening) and different fertilisation schemes (F1 – control treatment with no fertilisation; F2 – average fertilisation scheme of 100 N kg/ha, 50 kg P/ha and 70 kg K/ha; F3 – extra fertilisation scheme of 150 kg N/ha, 100 kg P/ha and 120 kg K/ha), averaged over 3 years (2019–2021). n = 4 ± standard deviation. For each species within certain fertilization treatment, different letters indicate significant differences among cultivation treatments at 0.05 level. For each species within certain cultivation treatment, different numbers indicate 198 significant differences among fertilization treatments at 0.05 level

a 30 cm-depth chisel plowing had a 20% yield increase, averaged over the 2 locations, as compared to the 10 cm-depth treatment (Muhsin et al. 2021). The authors associated this increase with the enhancement of the seed weight and the seed number per plant. Nouraein et al. (2019) reported that enhanced tillage application (applied through chisel plowing) was significantly correlated with better sunflower yield compared to the conventional tillage practice using the moldboard plowing method. The authors justified this enhancement by enhanced source/sink ratio resulting from a better tillage method and, thus, better soil physical conditions. They also reported that optimum nitrogen application resulted in the highest achene yield. The authors associated this outcome with the role of N in chlorophyll synthesis, which leads to better photosynthetic rate and, consequently, final assimilation. In our experiment, in all cultivation methods, the yields of both F2 and F3 were significantly higher than the yield of F1 (except for the insignificant differences between F1 and F2 in C3). Regardless of the cultivation scheme, the differences between F2 and F3 were insignificant (Figure 2B), indicating that the extra fertilisation levels in F3 treatment might be unnecessary, as they did not significantly enhance the yield of either the sweet corn or the sunflower plants. García-López et al. (2016) reported that compared to the control treatment (0 N) and the reduced N rate (75 N), the application of 150 kg N/ha (150 N) significantly increased the achene yield due to the increased number of seeds per head. Our results suggest that applying the recommended N, P and K fertiliser rates increased the yield significantly. In contrast, the further enhancements of the yield in both C1 and C3 treatments resulting from excessive rates of NPK were insignificant (the yield of the C2 treatment was even lower under excessive fertilisation). Bai et al. (2017) also reported increased sunflower seed yield when applying K fertiliser sufficiently. The application of K fertiliser (in the form of potassium sulfate (K_2SO_4)) at 150 kg/ha to sunflower plants increased the seed weight by 24%, and the application of 300% K further increased this trait by 9% as compared to the non-fertilised control (Zamani et al. 2020).

It could be concluded that cultivation methods influenced the yield of both sweet corn and sunflower, whereas fertilisation had a more announced influence on the yield of sunflower only. In sweet corn, ploughing resulted in the highest yield. The effects of both fertilisation and cultivation treatments were more detectable in sunflowers. Both ploughing and direct drilling resulted in higher yields than did deep loosening. In all cultivation methods, the yields of both the average and the extra fertilisation schemes were higher than the yield of the control (no-fertilisation) scheme. The differences between the average and the extra fertilisation schemes were insignificant, indicating that the extra fertilisation levels might be unnecessary. Further research should be conducted on the nutritional needs of both studied species, but more deeply on sunflower, to achieve better yield.

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