

Theses of Doctoral (PhD) Dissertation

**EFFECT OF CROP MANAGEMENT FACTORS ON
YIELD OF MAIZE (*Zea mays* L.) HYBRIDS**

by

Bramdeo Karamchand

Supervisor

Dr. Tamás Rátonyi

Associate professor



UNIVERSITY OF DEBRECEN

Kálmán Kerpely Doctoral School of Crop Production and
Horticultural Sciences

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Introduction

Central to the challenges confronting agriculture in the 21st century is the sustainability of food production to meet the needs of a growing world population (Fróna et al., 2019). Constrained by declining arable land per capita and changing climatic conditions, alleviating the problem of food insecurity necessitates urgent improvement in agricultural efficiencies, which can increase land productivity and sustain yield, under both favorable and unfavorable agroecological conditions (Pepó & Csajbók, 2013).

The urge to increase food production in many countries has resulted in an intensification of farming practices that utilize high levels of inputs that have negatively impacted the environment, resulting in degradation of soil and groundwater quality (Liliane & Charles, 2020). Harmonization of the agronomic inputs and agroecological conditions with the needs of the specific genotype is fundamental for mitigating the disadvantages associated with intensive farming.

Cereals are among the most essential food crops for human survival and are relied upon to the greatest extent for global food security. Maize (*Zea mays* L.) is among the primary and most extensively cultivated cereals. It is a staple food for many around the world and a superb feed and cheap energy source for livestock (Nagy, 2006). Maize is cultivated on approximately

25% of arable land in Hungary and is considered one of the most important agricultural export products in Hungary (Fertő & Szerb, 2017). It contributes to research, investment, land use, gross value added, employment and export earnings. Mean sowing area over the last decade (2009-2019) varied between 0.96 and 1.20 M ha (25%), whereas yield fluctuation has been substantial (115%), ranging from 4.0 to 8.6 t ha⁻¹ (KSH, 2020). Challenged by the dynamics of the weather conditions and the need for protection of the environment, reducing fluctuation and achieving high and stable yield is no easy feat. It requires innovation and continuous evaluation of crop production technologies to identify the most appropriate levels of agrotechnical inputs and best practices that can be implemented to optimize and sustain the yield of a particular genotype under a given set of agroecological conditions. Hence, research provides the medium to facilitate evaluation and determination of sustainability of crop production technologies and effect of climate change on yield.

Established in 1989 and pioneered by Professor Dr. János Nagy, this long-term experiment provides the medium for investigating the effect of tillage practices, fertilization, planting densities, forecrop and irrigation on yield of maize hybrids under varying climatic conditions.

Research objective

The objective is to evaluate the effect of various levels of agronomic management factors (tillage, fertilization, plant densities, forecrop, irrigation) on grain yield and nutritional content (starch, protein, oil) of maize hybrids and determine the best treatment combination under the prevailing condition of the 2018-2020 crop years.

Materials and methods

The research was conducted at the Látókép Research Station (latitude 47°33' longitude 21°27'). The soil type was calcareous chernozem, with a pH_{KCl} of 6.26 and organic matter content of 2.4 – 1.9 % in 0-60 cm range. Available water is approximately 50% of field capacity, and the minimum field capacity (WC_{min}) is 275 mm in the 0-100 cm. Nitrate (NO_3) and nitrite (NO_2) level average at 6.6 mg kg^{-1} ; AL soluble P_2O_5 & K_2O average at 136 and 189 mg kg^{-1} soil respectively.

Weather station on site facilitated recording of meteorological data (rainfall & temperature) which were then used to compute monthly total and average during the growing season (fig.1).

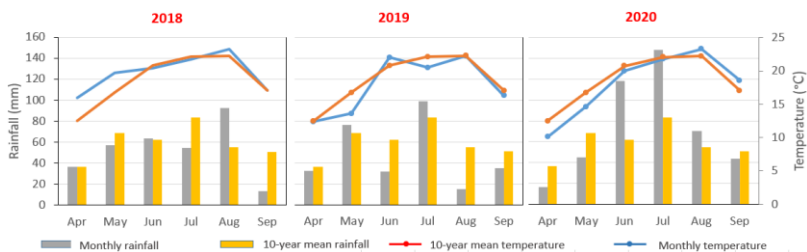


Figure 1. Growing season rainfall & temperature (Debrecen, 2018-2020)

and 60,000 plants ha⁻¹ at a row spacing of 76 cm and rotated with winter wheat forecrop on 20% of each block in succeeding year. The experiment was repeated with the same levels of agrotechnical inputs during the examined period 2018-2020.

Data collection

Soil moisture content, infiltration rate and penetration resistance in tillage practices were measured with a soil penetrometer (Penetronik) and infiltrometer. In season growth measurements, SPAD-reading (V_8), plant height (V_T), leaf area index and stem diameter (V_T), were measured during the growing season and grain yield for each plot was ascertained at time of harvest. Grain nutritional content (starch, protein and oil) was determined using a FOSS InfratechTM 1241 analyzer.

Statistical evaluation method

Analysis of variance (ANOVA) and test between subjects' effects was carried out on treatment combinations to determine their effect on maize yield. Experimental data were analysed with Microsoft Excel, SPSS 26.0 and Genstat 18th edition programs. The effect size and comparison of variables were performed with the ANOVA test and the Least Significant Difference (LSD) set at 5%.

RESULTS

Effect of tillage treatments on soil physical properties

Tillage practices impacted to varying extent on soil physical properties. Soil moisture content was significantly higher in ST and exceeded MT and RT by 27% and 18%, respectively.

The highest infiltration rate was recorded in RT inter rows (4.55 cm hr⁻¹), followed by MT (3.59 cm hr⁻¹) and ST (3.01 cm hr⁻¹). Rates of infiltration decrease with time, and after 40 minutes, differences in infiltration rates among tillage treatments were not statistically significant ($P > 0.05$).

Penetration resistance in ST inter-row was significantly higher than MT and RT. Mean penetration resistance in ST inter-rows in the 10-30 cm range was 1.2 MPa, which was 85% higher than MT (0.65 MPa) and 41% above RT (0.85 MPa) treatments. Similar results were reported by Bramdeo & Rátonyi (2020), Lin et al. (2016), Wang et al. (2015) and Jabro et al. (2010), who found soil penetration resistance in conventional tillage (MT) and deep tillage was significantly lower than reduced tillage.

Effect of tillage treatments on maize yield

Maize yield in ripper tillage (RT) was significantly higher ($P < 0.05$) than moldboard (MT) and strip tillage (ST) (fig.3b). The consistency in the order of performance of the tillage systems (RT > MT > ST) was the same in each of the three

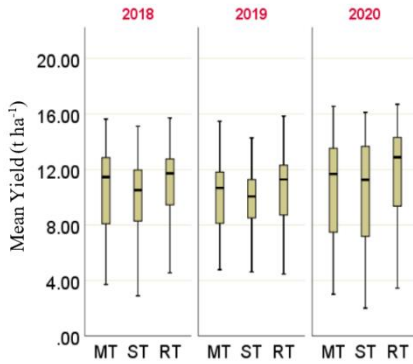


Figure 3a. Boxplot of yield x tillage treatments x year (Debrecen, 2018-2020)

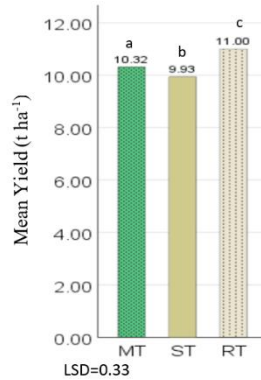


Figure 3b. Mean yield of tillage treatments (Debrecen, 2018-2020)

examined years (fig. 3a). RT also produced the tallest plants (229 cm), with the highest 1000 kernel weight (378 g) and grain yield (11.00 t ha⁻¹), followed by moldboard (MT); plant height (222 cm); 1000 kernel weight (374 g); grain yield, (10.32 t ha⁻¹). Strip tillage yield (9.93 t ha⁻¹), plant height (202 cm), 1000 kernel weight (348 g) were the lowest. Similar results were reported by Anjum et al. (2019) and Wasaya et al. (2017).

Tillage x forecrop interaction had a significant ($P < 0.05$) influence on grain yield of maize hybrids. Winter wheat forecrop enhanced the performance of tillage treatments by 30-40% (3.01-3.61 t ha⁻¹). Yield in RT was significantly higher (10-14%) than

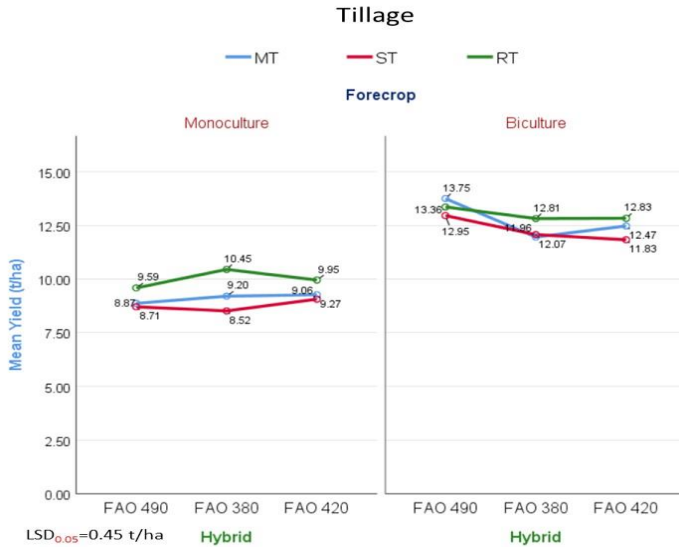


Figure 4. Hybrids x tillage x forecrop interaction ($t\ ha^{-1}$)

MT and ST in monoculture cropping system (fig. 4), whereas in biculture cropping system, the deep-tillage effect was reduced (2% - 6%). AL-Kaisi et al. (2006) reported similar results in corn-soybean rotation, which showed deep ripping yield was highest, followed by MT, ST and non-till. Bramdeo & Rátonyi (2020) reported yield of RT in monoculture was significantly higher than MT and posited that the higher yield of ripper tillage over moldboard tillage in monoculture demonstrated its suitability for soil with lower nutritional status (monoculture), poorer structure (lower organic matter content), and higher bulk density, as compared to biculture.

Tillage x irrigation x forecrop x fertilization interaction was significant ($P < 0.05$). Tillage treatments in monoculture plots were adversely affected by irrigation (fig.5). The control (N0)

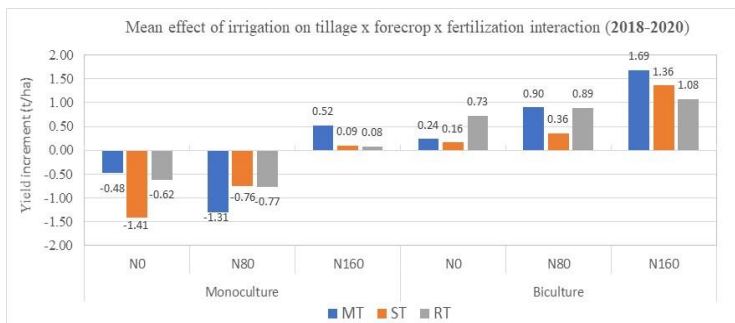


Figure 5. Mean effect of irrigation on yield increment of tillage x forecrop x fertilization interaction

plots of ST were mostly affected and could be attributed to the higher moisture level due to its conservative nature, compared to RT and MT. Moldboard was most responsive to irrigation and N160 treatments with the highest yield increment of 1.69 t ha^{-1} in biculture and 0.52 t ha^{-1} in monoculture (fig. 5). The result suggests that MT is more suitable for favorable crop-years (high rainfall) and intensive maize production than RT and ST. The positive effect of irrigation on fertilization x tillage interaction in biculture and the negative effect in N0 and N80 in monoculture is in harmony with research findings which showed biculture cropping system tends to augment soil fertility and simultaneous adjustment of both irrigation and fertilization is necessary for optimum results (Megyes et al., 2005; Csajbók et al., 2014).

Effect of forecrop (crop rotation) on maize yield

Biculture mean yield surplus (2018-2020) was 36.4% (3.38 t ha⁻¹). Yield gain strongly correlated with growing season rainfall

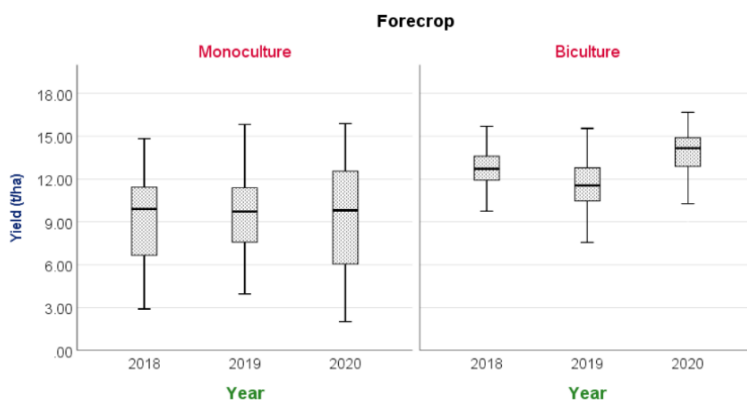


Figure 6. Yield x forecrop x year (t ha⁻¹)

and was highest in 2020, which recorded the highest growing season rainfall. Yield variation was also significantly lower in biculture (CV=14% vs. 32%) compared to monoculture (fig.6). The results demonstrated that winter wheat forecrop incorporated as part of the maize production system could enhance yield, improve yield stability and buffer for a reduction in dosages of applied fertilizer.

Effect of irrigation on yield

Yield gain from irrigation was marginal in 2018 & 2019, while in 2020, yield was adversely affected, resulting in significantly lower yields in irrigated treatments (fig. 7). The significant

decline in yield in 2020 was mainly in the control plots (N0) and could be explained by the disproportionate water to nutrient ratio.

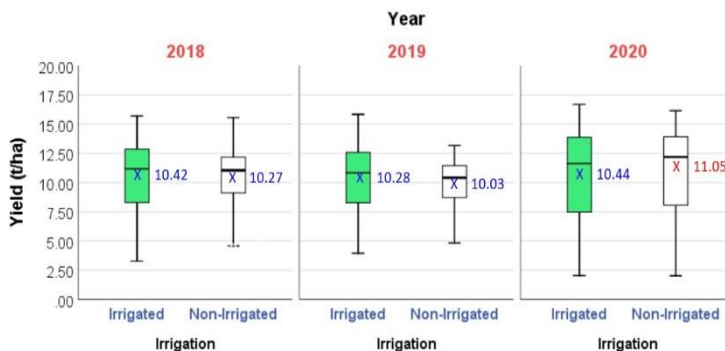


Figure 7: Irrigation vs. non-irrigated x year (t ha^{-1})

Effect of planting density on maize yield

Plant density x hybrid interaction was significant ($P < 0.05$). Differences in yield among the three hybrids were not significant at 60,000 planting density. However, at 80,000 plant ha^{-1} in both monoculture and biculture, yield differences between Armagnac (FAO 490) and the other two test hybrids were statistically significant (Table 1).

Table 1. Yield of hybrids at 60 and 80,000 plants ha^{-1} (Debrecen, 2018-2020)

Hybrid	Mean yield (t ha^{-1})			Yield difference (t ha^{-1})		
	60,000 Mono (a)	80,000 Mono (b)	80,000 Biculture (c)	(b) - (a)	(c) - (a)	(c) - (b)
Armagnac (FAO 490)	9.32 ^a	8.80 ^b	13.35 ^b	-0.52	4.03	4.55
Loupiac (FAO 380)	9.41 ^a	9.37 ^a	12.28 ^a	-0.04	2.87	2.91
Fornad (FAO 420)	9.49 ^a	9.36 ^a	12.38 ^a	-0.13	2.89	3.02
Mean	9.41	9.18	12.67	-0.23	3.26	3.49
LSD _{0.05} =0.43 Values with different letters in column differ significantly						

Armagnac (FAO 490) yield was significantly lower than Loupiac (FAO 380) and Fornad (FAO 420) at 80,000 plants ha⁻¹ (mono), whereas in 80,000 (biculture), yield was significantly higher. Increasing planting density from 60 to 80,000 plants ha⁻¹ in monoculture plots did not increase yield for any of the test hybrids and suggested that 80,000 plants ha⁻¹ had exceeded the threshold for optimum yield gain. Therefore, it can be concluded, that the optimum planting density for the test hybrids is between 60,000 to 80,000 plants ha⁻¹. The conclusion is in conformity with research findings which showed that increasing planting density, increased yield up to a maximum, beyond which yield decline with any further increase in plant population (Vad et al., 2007 ;Tokatlidis & Koutrubas, 2004). The significantly higher yield of the test hybrids at 80,000 plants ha⁻¹ in biculture buttressed the need to ensure that increasing plant population density is complemented with the requisite nutrient in order to realize the full yield potential of the hybrids. Individual plant productivity (IPP) for the test hybrids in monoculture decreased with increase in density (80,000 plants ha⁻¹). Armagnac IPP decline was highest (-29%), whereas, Loupiac and Fornad decline was almost on par. Since both yield and IPP of all the hybrids decreased at the higher density in monoculture it can be inferred that 80,000 plants ha⁻¹ exceeded the nutritional capacity of the soil. The result is corroborated by findings of Yan et al.

(2016), Sangoi (2001), and Sárvári (2005), who found with increasing plant density, the individual plant productivity is reduced, but the yield per unit area increases until the optimal number of plants density is reached.

Hybrids x planting density x fertilization interaction

Yield of Fornad(FAO 420) and Armagnac(FAO 490) at 80,000 plants ha⁻¹ (mono) in the control(N0) were significantly lower

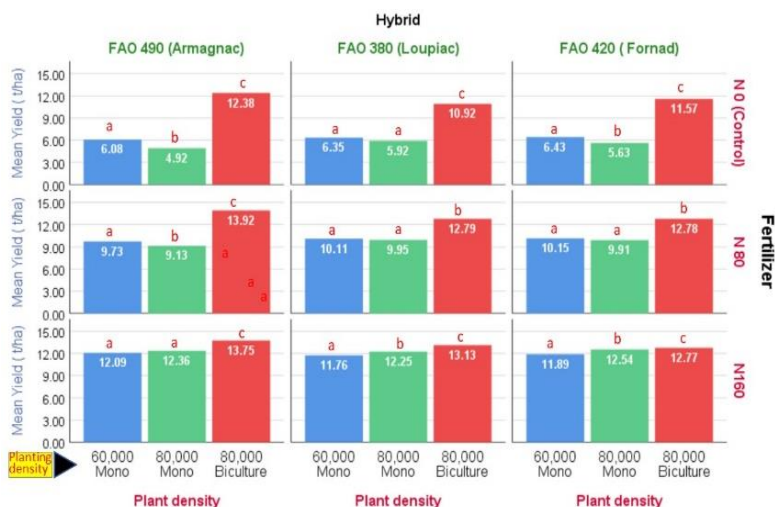


Figure 8. Hybrids x plant density x fertilization

than 60,000 plants ha⁻¹, whereas FAO 380 yield differences was not statistically significant (fig. 8). The result suggests that the higher FAO hybrids (later-maturing) were more sensitive to higher planting density, especially under low nutrient supply.

Effect of fertilization on yield

Fertilization accounted for the largest yield variance (39.9%) among the agrotechnological inputs and significantly influenced growth, yield parameters and nutritional content of maize. The lack of nitrogen in the control (N0), manifested in deficiency symptoms, shortest plant, smallest LAI, lowest SPAD reading, reduced number of leaves, lowest 1000-kernel weight and ultimately the lowest grain yield (table 2).

Table 2. Growth and yield parameters of fertilization treatments (Debrecen, 2018-2020)

	Mean yield (t ha ⁻¹)	SPAD Value	Plant height (cm)	No. of leaves per plant	Cob length (cm)	1000 kernel weight (g)	LAI
N0	7.80 ^a	34.77 ^a	159.7 ^a	11.5 ^a	18.3 ^a	232.2 ^a	2.5 ^a
N80	10.94 ^b	57.81 ^b	214.0 ^b	13.3 ^b	20.2 ^b	348.5 ^b	3.3 ^b
N160	12.50 ^c	60.87 ^b	235.7 ^c	13.8 ^c	21.5 ^c	365.1 ^c	3.7 ^c
		LSD _{0,05}	values with different letters in column differ significantly				

N160 treatment delivered the best results for growth and yield parameters and was significantly higher than N80, except for the SPAD value (V_8). Agronomic Nitrogen use efficiency (AE) was however, significantly lower with N160, compared to N80 (AE= 29% vs. 39%). In similar research, Šarčević-Todosijević et al. (2018), found nitrogen fertilization had a significant impact on maize yield and observed increasing the rate of applied nitrogen up to 120 kg ha⁻¹, increased plant height, total leaves, length of a cob, grain rows and the total grains per cob, after which all the measured parameters declined with higher rate (N180 kg ha⁻¹).

The highest yield gain from fertilization was obtained in 2020 (fig.9) and closely correlated with growing season rainfall.

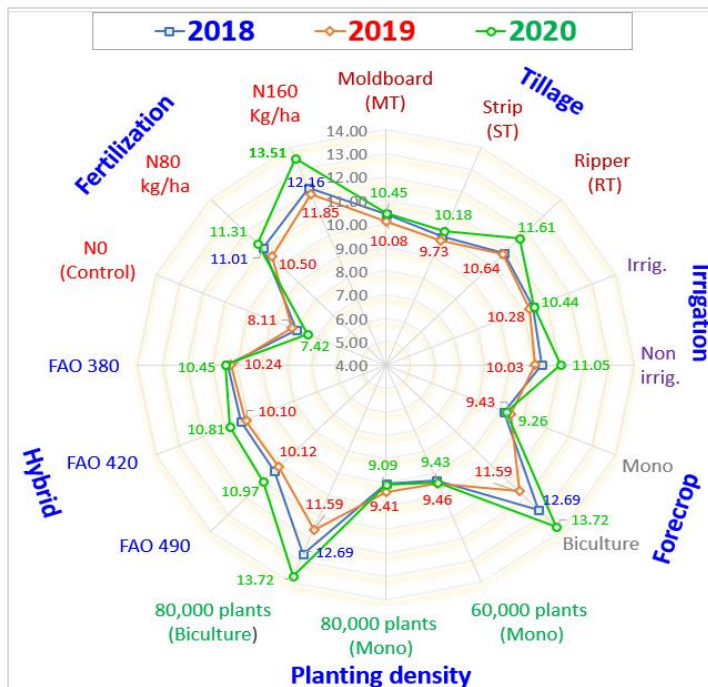


Figure 9. Effect of crop-year x treatments interaction on yield (t ha⁻¹) (Debrecen, 2018-2020)

The effects of fertilization x crop-year interaction on maize yield have been widely reported and is often observed in long-term experiments (Orfanou et al., 2019; Buah et al., 2017, Pepó et al., 2007). Weather is known to regulate heat and water supply of the plant environment and therefore influences material transformation, nutrient uptake and ultimately crop growth and development. The strongest correlation between growing season

rainfall and fertilization treatment was observed at N160 level ($r=0.83$), followed by N80 ($r=0.75$), while the control (N0) showed moderate correlation ($r=0.46$).

Among the agrotechnological factors evaluated, fertilization had the largest impact on grain yield and the nutritional content of grains, particularly the protein and starch concentration. Yield variance for fertilization was 39.9%, followed by forecrop (26.5%), planting density (9.6%), hybrid (0.39%), tillage (3.4%) and irrigation (0.18%). Year effect accounted for 1.1% yield variance.

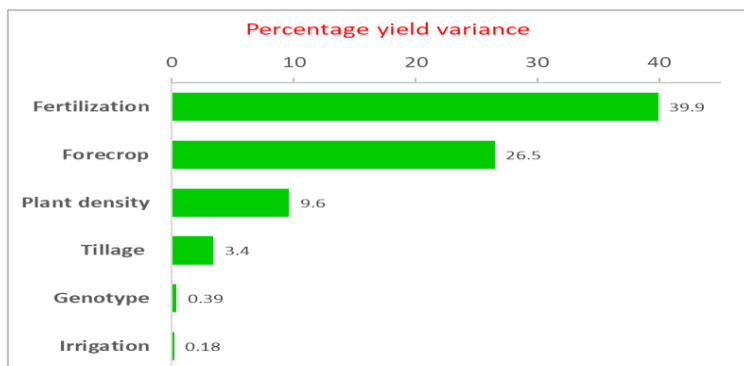


Figure 10. Percentage yield variance of agronomic factors

Hybrid yield performance and stability

Hybrids overall mean yield differences were not statistically significant. The hybrids, however, vary in their response to the same levels of agrotechnological input. Armagnac (FAO 490) yield was significantly higher with winter wheat forecrop

compared to Loupiac (FAO 380) and Fornad (FAO 420) , whereas at 80,000 plants ha⁻¹ in monoculture cropping system Armagnac (FAO 490) yield (8.80 t ha⁻¹) was significantly lower than both Loupiac (FAO 380) and Fornad (FAO 420) (fig. 11).

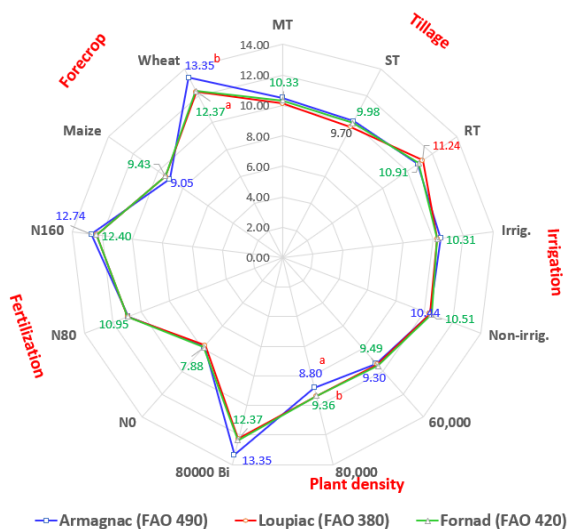


Figure 11. Radar chart of hybrids yield x treatments (Debrecen, 2018-2020)

Overall mean yield of Armagnac (FAO 490) was the highest, followed by Fornad (FAO 420), as indicated by their position on the axis (fig. 12). Yield of both hybrids were above average environmental condition (AEC), while Loupiac (FAO 380) yield was below. However, FAO 380 displayed the highest yield stability (CV=30%) , compared to FAO 490 (CV=43%) and FAO 420 (CV= 39%).

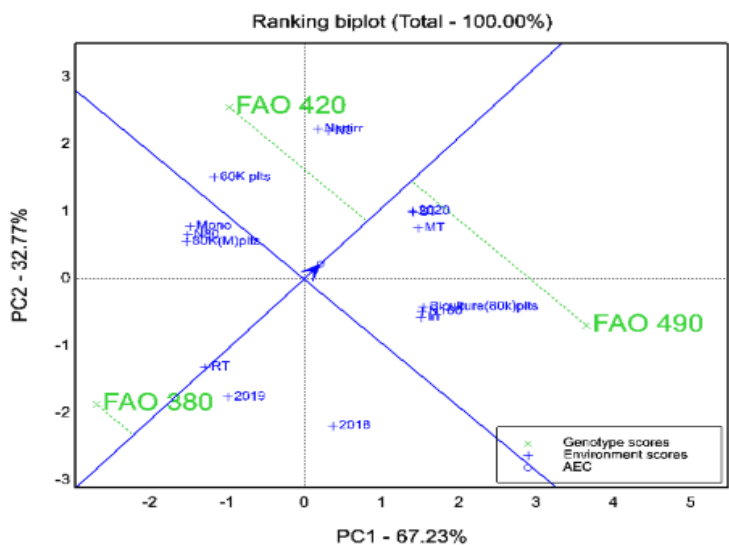


Figure 12. GGE ranking biplot of test hybrids

Effect of tillage practices on grain nutritional content

Tillage practices had no significant effect on grain nutritional content (protein, starch, oil). Although grain protein, starch and oil contents varied among tillage treatments, differences were not significant ($P > 0.05$). Protein content was highest in RT, whereas starch and oil content were highest in ST (table 5, Summary).

The result demonstrated that tillage practices have more influence on overall grain yield, rather than concentration of the grains' nutritional content. This observation is in harmony with report by Houx et al. (2016) and Lyon et al. (1998), who found tillage systems had no significant effect on grain nutritional

content and was not a dominant factor influencing composition of maize grain.

Fertilization effect on grain nutritional content

Among the agrotechnological factors, fertilization impact on grain nutritional was most significant ($P < 0.05$). At all levels of fertilization treatments, differences between starch and protein content (%) were significant ($P < 0.05$). Oil content was not significantly influenced by fertilization treatments, although the percent oil was highest in N160. Grain protein content positively correlated with fertilization, whereas, the starch content showed a negative correlation.

Protein content was the lowest in the control (N0) and increased significantly with N80 & N160. It is well established that Nitrogen is an essential component of amino acids which are the building blocks of protein; hence the positive correlation between N fertilization and grain protein content stands to reason. Similar findings were reported by Wasaya et al. (2018) and Simić et al. (2020).

Irrigation effect on grain nutritional content

Irrigation impacted negatively on protein content and positively on both starch and oil content; however differences were not statistically significant ($P > 0.05$). Similar observations were

made by Virág et al. (2020), who reported protein content of maize hybrids decreased with irrigation, while starch content increased, but differences were not statistically significant.

Effect of planting density on grain nutritional content

Planting density had no significant effect on grain nutritional content ($P>0.05$). Grain protein content was significantly higher at 80,000 plants ha⁻¹ (biculture), compared to 60 and 80,000 plants ha⁻¹ (mono), whereas starch content was significantly higher at 80,000 plants ha⁻¹(mono) (Table 3).

Table 3: Planting densities grain protein, oil and starch content

Planting density	Grain nutritional content (%)		
	Protein (%)	Starch (%)	Oil (%)
60,000 plts/ha (Mono)	9.06 ^a	73.01 ^a	4.60
80,000 plts/ha (Mono)	8.97 ^a	73.49 ^b	4.73
80,000 plts/ha (Biculture)	9.56 ^b	72.91 ^a	4.65
LSD _{0.05}	0.29	0.46	0.34
value with different letters in column differ significantly (LSD _{0.05})			

Effect of crop rotation on grain nutritional content

Crop rotation impact on grain nutritional quality was statistically significant ($P<0.05$). Forecrop correlated positively with grain protein content and was significant (table 5). The higher protein content with winter wheat forecrop could be attributed to the higher fertility of biculture soils and concurred with findings by Mahama (2018) and Negash et al. (2018), which showed protein

content of maize grains was significantly higher in biculture treatment plots compared to monoculture maize.

Grain nutritional content of the test hybrids were influenced mainly by fertilization levels and forecrop. Armagnac (FAO 490) protein content was significantly higher than Loupiac (FAO 380) and Fornad (FAO 420), while starch content was significantly higher in Loupiac (FAO 380). Oil content was highest in Fornad (FAO 420) but was not statistically significant ($P>0.05$).

Table 5. Summary, treatment effects on grain yield and protein, starch and oil (Debrecen, 2018-2020)

Effect of agrotechnological factors on grain yield and nutritional content of maize					
		Grain Yield (t ha ⁻¹)	Protein (%)	Starch (%)	Oil (%)
Tillage	MT	10.32 ^a	9.32	72.86	4.69
	ST	9.93 ^b	9.30	73.01	4.83
	RT	11.00 ^c	9.55	72.62	4.78
	LSD_{0.05}	0.33	0.36	0.41	0.30
Fertilization	N0	7.80 ^a	8.08 ^a	74.08 ^a	4.86
	N80	10.94 ^b	9.53 ^b	72.68 ^b	4.74
	N160	12.51 ^c	10.42 ^c	71.49 ^c	4.94
	LSD_{0.05}	0.26	0.34	0.40	0.31
Forecrop	Mono	9.29 ^a	9.04 ^a	73.32	4.84
	Biculture	12.67 ^b	9.55 ^b	72.98	4.85
	LSD_{0.05}	0.30	0.32	0.37	0.27
	60,000	9.40 ^a	9.06 ^a	73.01 ^a	4.60
Planting density	80,000 (mono)	9.18 ^a	8.97 ^a	73.49 ^b	4.73
	80,000 (biculture)	12.67 ^b	9.55 ^b	72.98 ^b	4.85
	LSD_{0.05}	0.43	0.29	0.46	0.34
	Irrigated	10.38	9.22	72.90	4.96
Irrigation	Non-irrigated	10.45	9.45	72.62	4.74
	LSD_{0.05}	0.28	0.30	0.35	0.25
	Armagnac (FAO 490)	10.49	9.58 ^b	72.51 ^a	4.63
	Loupiac (FAO 380)	10.35	9.28 ^a	73.80 ^b	4.79
Genotype (Hybrids)	Fornad (FAO 420)	10.41	9.21 ^a	72.29 ^a	4.94
	LSD_{0.05}	0.34	0.37	0.41	0.32

value with different letters in column differ significantly (LSD_{0.05})

Summary charts of the impact of agronomic management factors on grain yield and nutritional content (starch, protein, oil)

Impact of agronomic management factors on grain yield (t ha⁻¹)

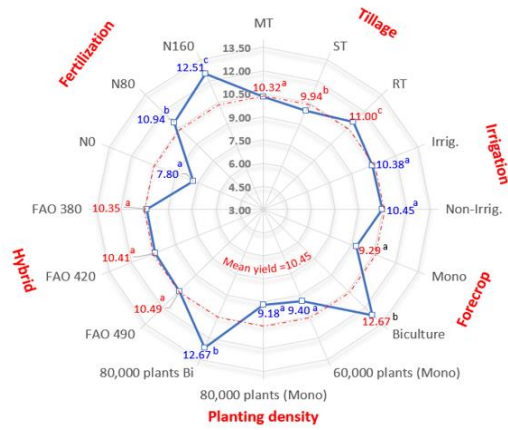


Figure 14. Impact of agronomic management factors on grain yield (t ha⁻¹)

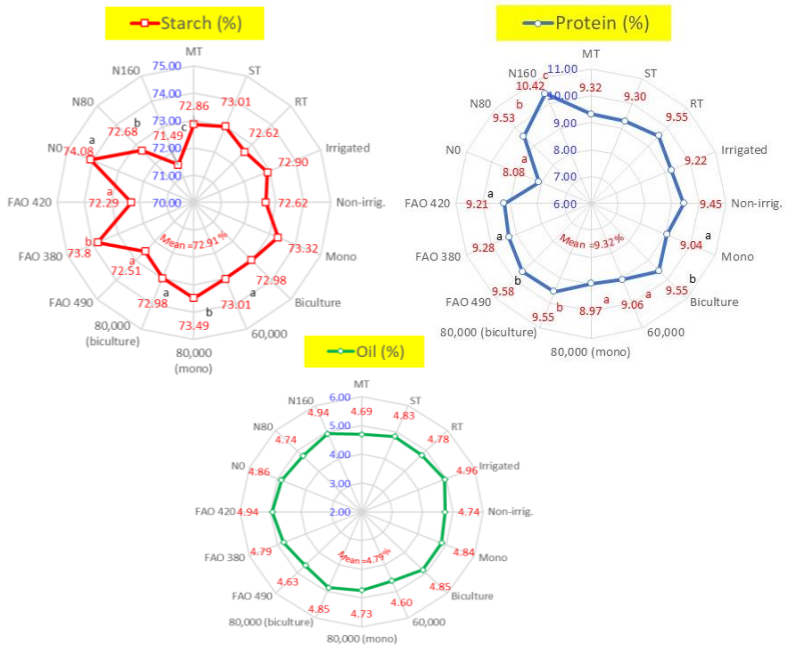


Figure 15. Impact of agronomic factors on grain starch, protein, and oil content (%) (Debrecen, 2018-2020)

NEW SCIENTIFIC RESULTS

- Mean yield of RT in monoculture was 10% (+0.89 t ha⁻¹) higher than MT, whereas in biculture there was no significant difference between the two tillage treatments (13.00 vs. 12.72 t ha⁻¹; P>0.05). The higher soil fertility of biculture, as indicated in the significantly higher yield in the control compared to monoculture (N0=11.62 t ha⁻¹ vs. N0=5.89 t ha⁻¹) compromised the potential of ripper tillage (RT) to increase root access to nutrient reserve in the lower soil profile (30-60 cm range). Thus, ripper tillage (RT) was found to be more suitable for monoculture cropping system, whereas moldboard tillage (MT) was more conducive for biculture cropping system.
- Ripper tillage (RT) fertilizer use efficiency (FUE) was 5.0-10.7% higher than Moldboard (MT) and Strip tillage (ST), whereas the Agronomic efficiency (AE) of both MT and ST was 9.6-11.5% higher than RT. The higher FUE of RT suggests it was better able to utilize soil residual nutrient (N), while the higher AE of MT and ST indicate better utilization from applied fertilizer, compared to RT. Ripper tillage can recover a minimum of 24 kg N from the deeper soil profile at the experimental site, since yield in the control(N0) of monoculture plot exceeded MT by 1.02, 0.95 & 1.29 t ha⁻¹ in 2018,2019,2020 respectively.

- Winter wheat forecrop significantly enhanced the yield of all hybrids (31-47%) in all tillage systems with yield increment being highest in Armagnac (FAO 490) (47%= 4.30 t ha⁻¹), followed by Fornad (FAO 420) and Loupiac (FAO 380) with 2.94 and 2.89 t ha⁻¹ respectively.
- Winter wheat forecrop significantly improved the yield performance of strip tillage (ST). Yield surplus of strip tillage (ST) x biculture, exceeded yield of Ripper (RT) and Moldboard tillage (MT) in monoculture by 23% (+2.28 t ha⁻¹) and 35% (+3.17 t ha⁻¹) respectively.
- Each hybrid has a unique environment in which it performs best:
 - Armagnac (FAO 490) yield was highest (13.75 t ha⁻¹) under biculture cropping system x N160 x 80,000 plants ha⁻¹ and surpassed Loupiac (FAO 380) and Fornad (FAO 420) by 5% (0.62 t ha⁻¹) and 8% (0.98 t ha⁻¹) respectively.
 - Loupiac (FAO 380) yield surpassed Armagnac (FAO 490) and FAO (FAO 420) by 18% (1.72 t ha⁻¹) and 13% (1.27 t ha⁻¹) respectively, in ripper tillage (RT) x N80 x biculture x 80,000 plants ha⁻¹.
 - Fornad (FAO 420) yield exceeded both Loupiac (FAO 380) and Armagnac (FAO 490) by 6% (0.47 t ha⁻¹) and 17% (1.24 t ha⁻¹) respectively, in the control (N0) x non-

irrigated x Ripper tillage x 60,000 plants ha⁻¹. Armagnac (490) was most sensitive to higher density (80,000 plants ha⁻¹) and lower nutrient status (N0) and recorded the lowest yield (4.92 t ha⁻¹), compared to Fornad (FAO 420) = 5.63 t ha⁻¹ and Loupiac (FAO 380) = 5.92 t ha⁻¹. This hybrid responds best to intensive management practices.

- Loupiac (FAO 380) showed the highest yield stability across all treatments with a CV of 30%, compared Fornad (FAO 420) and Armagnac (FAO 490) with 39 and 43% respectively.
- Higher levels of nutrient supply in favorable crop year had greater yield increasing effect. N160 yield surplus in 2020 which recorded the highest growing season rainfall (442 mm) was 1.66 and 1.35 t ha⁻¹ higher than 2019 (290 mm rainfall) and 2018 (318 mm rainfall), respectively.
- Agronomic nitrogen use efficiency (AE) was higher at 80,000 plants ha⁻¹ (N80=52%; N160=43%) in monoculture, compared to 60,000 plants ha⁻¹ (N80=46%; N160=35%). Biculture AE was significantly lower (N80=19%; N160=10%), compared to monoculture.
- The best treatment combination for favorable crop-year with above average precipitation (>300 mm) is: biculture cropping system x moldboard tillage x N160 fertilization

x Armagnac (FAO 490) x 80,000 plants ha⁻¹, while in monoculture cropping system in average crop-year (\approx 300 mm rainfall): ripper tillage x N80 x Fornad (FAO 420) x 60,000 plants ha⁻¹ will give optimum result.

PRACTICAL UTILIZATION OF RESULTS

- Soil infiltration rate, moisture and penetration resistance varied among tillage practices and provides an indication of the soil physical properties which can allow for the proper selection of tillage implements for removal of root restricting layers and conservation of moisture if necessary. Ripper tillage for example, becomes necessary if infiltration rate of the soil is below the average <10 mm hr⁻¹ and penetration resistance exceed 3.5 MPa at field capacity.
- Integrating a suitable crop rotation system such as winter wheat forecrop in maize production can reduce the dependency on synthetic fertilizer and minimize risks associated with pollution (N leaching). In this research for example, there was no significant difference in yield between N80 and N160 treatments in biculture (13.17 vs. 13.22 t ha⁻¹). Hence, winter wheat forecrop can eliminated the need for N160 treatment and deliver similar results

with N80, thereby reducing the volume of applied fertilizer (-80 kg N) in the environment.

- The significantly higher yield surplus of ripper tillage (+0.96 t ha⁻¹) over MT and ST in the control(N0) of monoculture plot can be buffer for a reduction of 24 kg N ha⁻¹, assuming 25 kg N per ton of grain. This can reduce operational costs by at least, 1,608 HUF per ha (24 kg N @ 67 HUF kg⁻¹) and minimize risk of N leaching. However, there is a need to ascertain the amount of available nutrients in the lower soil profile (30-60 cm).
- ST moisture was 27% higher than MT and 18% above RT in the 0-30 cm range. The higher moisture content of the soils in strip tillage, followed by ripper tillage, provides scope for both tillage systems to be substituted for conventional moldboard plowing during drought condition to aid in conservation of soil moisture and save on applied irrigation.
- The yield surplus of strip tillage (ST) in tandem with crop rotation (+3.52 t ha⁻¹) can significantly reduce costs of operation and improve production efficiency. The yield surplus of ST with crop rotation can generate revenue of 235,840 HUF (3.52 t @ 67,000 HUF t grain⁻¹) and offset 80 kg N ha⁻¹, since yield difference between N80 and N160

in ST x biculture was not significantly different (12.73 vs. 12.98 t ha⁻¹).

- Fertilizer use efficiency (NUE) can be used as a determining factor in matching planting density and fertilizer dosages, both from an economical as well as environmental standpoint. In this research for instance the low AE of 19 % with N80 and 10% with N160 in biculture, suggests that the planting density (80,000 plants ha⁻¹) was below the threshold for optimum yield or vice-versa the soil fertility was higher. Hence, the fertilizer dosage could be correspondingly reduced, or the plant population increased to achieve higher efficiency levels.
- Agrotechnological inputs can be tailored to suit prevailing agroecological conditions to facilitate more efficient utilization of resources and realization of optimal yield. Example, applying lower (N80) fertilizer dosages in crop-year, with lower levels of rainfall (<300 mm growing season rainfall), while higher dosages (N160) can be applied in favorable year (>400 mm growing season rainfall).

CONCLUSION

The results demonstrated that crop management factors do not act in isolation, they interact with each other, and their effect-size is modified by the prevailing weather condition of the crop-year.

Each genotype has a unique environment in which it performs best. Hence, choosing the appropriate level of agrotechnology based on agroecological conditions and the needs of the specific genotype can mitigate against adverse weather condition and allow for more efficient utilization of resources and the realization of optimal and sustainable yields.

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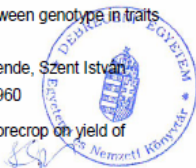
1. **Bramdeo, K., Rátónyi, T.:** Effect and interaction of crop management factors and crop year on the yield of maize (*Zea mays* L.).
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