Maize hybrid performance as affected by production systems in Croatia

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Leistung von Maishybriden und ihre Beeinflussung durch Produktionssysteme in Kroatien

1. Introduction

Maize is the most important arable crop in Croatia. However, the national average grain yield of 5.37 t ha^{-1} (DRŽAVNI ZAVOD ZA STATISTIKU, 2001) for the last decade (1990–2000) is low compared with the yield potentials of currently grown hybrids. This is largely due to the suboptimal plant populations, low rates of chemical fertilizers, particularly nitrogen, and lack of effective weed control.

Improved grain yield due to more intensive maize management practices has been found by many authors (GOTLIN et al., 1969; PUCARIĆ, 1971; CARLONE and RUSSELL, 1987). Tillage systems may affect maize yield responses (GRIFFITH et al., 1973), but LIEBHARD (1996) found no improvement in grain yield by increasing ploughing depth more than 17 cm in his long term research in upper Austria. Nitrogen application is an important input for maize production. Larger grain yields due to increasing levels of N fertilizers were found by GOTLIN et al. (1969), BUNDY and CARTER (1988), and PUCARIĆ and VARGA (1996). In early studies, MOOERS (1933) reported that maize varieties produced optimum grain yields at unique plant density and soil fertility levels. LANG et al. (1956) evaluated nine single-cross hybrids at three N levels and also observed that indi-

Zusammenfassung

Die Anwendung intensiver Produktionssysteme könnte die Maiserträge in Kroatien substantiell steigern, weil der nationale Durchschnittsertrag von 5,37 t ha^{-1} angesichts der Umwelt- und Hybridpotentiale vergleichsweise gering ausfällt. Zwischen 1996 und 1999 wurden Feldversuche durchgeführt, um die Reaktion von 12 mehrortigen Maishybriden auf intensive und extensive Produktionssysteme festzustellen. Die Hybriden gehörten zu den Reifeklassen FAO300–FAO500, wovon jede vier Hybriden umfasste.

Das intensive Produktionssystem umfasste Pflügen zwischen 30 cm und 32 cm; Düngung mit 213 kg ha^{-1} N, 130 kg ha^{-1} P_2O_5 sowie 130 kg ha^{-1} K_2O; 60.000–65.000 Pflanzen ha^{-1}, intensiveren Herbizideinsatz. Das extensivere Produktionssystem umfasste Pflügen zwischen 20 cm und 22 cm; Düngung mit 105 kg ha^{-1} N, 104 kg ha^{-1} P_2O_5 sowie 104 kg ha^{-1} K_2O; 37.000–38.000 Pflanzen ha^{-1} und geringerer Herbizidgebrauch. Die Kornerträge stiegen beim intensiveren Produktionssystem signifikant und lagen im Mittel bei 11.419 kg ha^{-1} gegenüber 8.214 kg ha^{-1} beim extensiven Produktionssystem. Dieser Unterschied war in erster Linie auf eine Zunahme der Kornzahl pro m^2 (um 47,1 %) hervorgebracht durch 50,5 % mehr Kolben pro Hektar zurückzuführen, wohingegen im Mittel bei intensivem Produktionssystem das Korngewicht pro Kolben um 6,8 %, jenes pro Pflanze um 12,8 %, die Körnerzahl pro Kolben um 2,9 %, jene pro Pflanze um 9,3 % und das Tausendkorngewicht um 3,5% sanken. Hybride der späteren Reifeklassen tendierten bedingt durch höhere Tausendkorngewichte und durch höhere Körnerzahlen pro Pflanze im Durchschnitt zu um 7,7 % höheren Kornerträgen (vgl. die Zahlen FAO400 vs. FAO300 bzw. vgl. die Zahlen FAO500 vs. FAO400). Eine signifikante Produktionssystem × Hybrid Wechselwirkung war zu finden, weil manche Hybride stark auf intensive Produktionssysteme ansprachen, während andere dies nicht taten. Folglich scheint die Hybridauswahl eine wichtige Entscheidung für kroatische Landwirte zu sein, wenn sie von extensiven auf intensive Produktionssysteme bei Mais umsteigen.

Schlagworte: Mais, Hybrid, Produktionssysteme, Kornertrag, Ertragskomponenten, extensive Produktionssysteme, intensive Produktionssysteme.

Summary

The use of intensive production systems (IPS) may substantially increase maize (*Zea mays* L.) yields in Croatia because the national average of 5.37 t ha^{-1} is low compared with the environmental and hybrid potentials. Field experiments were conducted during 1996 through 1999 to evaluate the agronomic responses of 12 widely grown maize hybrids in both an IPS and an extensive production system (EPS). Hybrids belonged to three maturity groups (FAO 300–FAO 500), each consisting of four hybrids. The IPS involved ploughing at 30 to 32 cm; fertilization at 213, 130, and 130 kg ha^{-1} N, P_2O_5, and K_2O; 60–65 000 plants ha^{-1}; and more intensive use of herbicides. The EPS consisted of ploughing at 20 to 22 cm; fertilization at 105, 104, and 104 kg ha^{-1} N, P_2O_5, and K_2O; 37–38 000 plants ha^{-1}; and the use of fewer herbicides. Grain yields significantly increased in the IPS and averaged 11 419 kg ha^{-1} compared with 8 214 kg ha^{-1} for the EPS. This difference was primarily due to a 47.1 % increase in kernel number per square meter produced by 50.5 % more ears per hectare, while grain weight per ear and plant, kernel number per ear and plant, and 1000-kernel weight for the IPS decreased by an average of 6.8, 12.8, 2.9, 9.3, and 3.9 %, respectively. Longer-maturity groups tended to produce higher grain yields by an average of 7.7 % through heavier 1000-kernel weight (FAO 400 vs. FAO 300) or more kernels per plant (FAO 500 vs. FAO 400). A significant production system × hybrid interaction was found because some hybrids were highly responsive to the IPS while others were not. Thus, hybrid selection appears to be an important decision for Croatian farmers when changing from an EPS to an IPS for maize.

Keywords: Maize; Hybrid; Production system; Grain yield; Yield components, EPS, extensive production system; IPS, intensive production system.

vidual hybrids showed a different response to N levels. This work stimulated interest by BUNDY and CARTER (1988) who conducted a two-year research in Wisconsin to evaluate the N response characteristics of widely grown hybrids of similar maturity in the northern Corn Belt. Their findings indicated that maize yields are not likely to be improved by adjusting N application rates for individual maize hybrids. HATLITLIGIL et al. (1984) also found no differences among hybrids in grain yield responses to N fertilization. However, CARLONE and RUSSELL (1987) reported highly significant interactions between N-levels and maize cultivars. TSAI et al. (1984) in their research identified three hybrids that differed markedly in their response to N fertilization. MACKAY and BARBER (1986) showed that root growth of B73 × Mo17 was increased by N fertilization while applied N had no effect on root growth of Pioneer 3732, which may contribute to the N response differences observed between these two hybrids in their research.

Optimum plant populations for maize may vary with factors such as hybrid, soil fertility, moisture stress and yield goal (BENSON, 1990). Higher plant populations increased grain yields in research conducted by many authors (COLVILLE et al., 1964; GOTLIN et al., 1969; CARLONE and RUSSELL, 1987; BAVEC and BAVEC, 2002), although lower populations may produce the largest yields under dry conditions where moisture stress occurs (THOMISON and JORDAN, 1995; NORWOOD, 2001). Shorter-maturity hybrids appear to be more responsive to an increase in plant population compared to longer-maturity hybrids, as was shown in research conducted by LANG et al. (1956), COLVILLE et al. (1964), PUCARIĆ (1971), and NORWOOD (2001).

The objective of this study was to evaluate the agronomic responses of 12 widely grown maize hybrids in Croatia at two production input levels, namely intensive (IPS) and extensive production systems (EPS).

2. Materials and methods

Field experiments in a maize – soybean [*Glycine max* (L.) Merr.] – winter wheat (*Triticum aestivum* L.) crop rotation were conducted in northwestern Croatia at the Faculty of Agriculture Zagreb experimental field during 1996 through 1999 on a silt loam soil (Typic Udifluvents). Twelve maize hybrids were grown in both IPS and EPS. Previous crops (soybean and winter wheat) were also grown under these two production input levels. Hybrids were Pioneer 3563 (PR 3563), Pioneer 3475 (PR 3475), DeKalb 471 (DK 471), DeKalb 485 (DK 485), along with hybrids developed by the Bc Institute Zagreb (Podravec 36, Bc 3786, Bc 488B, Bc 5982) and the Agricultural Institute Osijek (OSSK 332, OSSK 382, OSSK 412, OSSK 552). Tested hybrids belonged to three maturity groups (FAO 300-FAO 500), each consisting of four hybrids.

A summary of production treatments is presented in Table 1. The IPS involved mouldboard ploughing at 30–32 cm; fertilization with 213 kg N ha^{-1} (40.5 kg N ha^{-1} applied with interrow cultivations at the growth stages V2 and V5) (RITCHIE et al., 1986), 130 kg P_2O_5 ha^{-1}, 130 kg K_2O ha^{-1}; and high input of weed control chemicals. The herbicides metolachlor {2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide} at the rate of 1.5 kg a.i. ha^{-1} and atrazine {6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3,5-triazine-2,4-diamine} at 1.0 kg a.i. ha^{-1} were applied preemergence. Herbicide 2,4-D ((2,4-dichlorophenoxy) acetic acid) at the rate of 1.0 kg a.i. ha^{-1} was applied at the growth stage V3 to control field bindweed (*Convolvulus arvensis* L.). Hybrids were planted at recommended rates to achieve a stand of 60-65 000 plants per hectare at harvest.

The EPS consisted of ploughing at 20-22 cm; fertilization with 105 kg N ha^{-1} (27 kg N ha^{-1} applied with interrow cultivation at the growth stage V5), 104 kg P_2O_5 ha^{-1}, and 104 kg K_2O ha^{-1}. Only atrazine at the rate of 1.0 kg a.i. ha^{-1} was applied as preemergence treatment. To control later emerged field bindweed, 2,4-D at the rate of 1.0 kg a.i. ha^{-1} was applied at the growth stage V3. Under the EPS treatment, hybrids were overplanted and thinned after emergence to obtain a stand of 37-38 000 plants per hectare at harvest.

In October of each year, 500 kg ha^{-1} N–P–K fertilizer (8:26:26) combined with 100 kg ha^{-1} of urea [$(NH_2)CO$] (46 % N) in the IPS or 400 kg ha^{-1} N–P–K fertilizer (8:26:26) in the EPS was broadcast before ploughing. Under the IPS treatment, an additional 100 kg ha^{-1} of urea was broadcast before seedbed preparation. At planting, plots consisted of 4 rows that were 70 cm apart and 5.6 m in length. Maize was planted on 18 Apr. 1996, 26 Apr. 1997, 29 Apr. 1998, and 1 May 1999 within the optimum planting date window for the region. Granular N [27 % ammonium nitrate (NH_4NO_3)] was applied in each interrow cultivation.

At maturity, plots were evaluated for final plant stand, barren plants and stalk lodging. Very few lodged plants occurred in our experiments, and therefore data are omitted from results. After physiological maturity, six ear bearing plants from the two central rows of each plot were randomly chosen and ears were hand harvested to determine plant and ear yield components. Harvested ears were counted and yield components were determined for each ear. The number of rows per ear was determined by counting rows in the middle section of ear. Kernel number per row was determined as an average of kernel number from two opposite rows which had kernels from the top to the bottom of the ear. Kernel number per ear was determined by counting all kernels after hand-shelling. A 1000-kernel weight was calculated as grain weight per ear/kernel number per ear × 1000. Grain samples were weighed and oven dried at 105 °C until constant weight to determine moisture content. Plant and ear yield components were adjusted to 14.0 % moisture. Ears per plant are given as an average ear number per ear bearing plant. Ears per hectare were calculated from average ear number per plant × ear bearing plants per hectare. Kernels per square meter were calculated as ear bearing plants per square meter × kernels per plant. The two central rows of plots were combine harvested. Yields were adjusted to include grain removed in hand-harvested ear samples. Grain yields are reported at 14.0 % moisture.

The IPS and EPS were established on adjacent plots in the same field area. Twelve hybrids were arranged in a randomized complete block with five replications for each production system. All data were analyzed with analysis of variance using a mixed model procedure (SAS INSTITUTE, 1997). The hybrid effect was partitioned to test the maturity group responses. Mean separation was obtained using a LSD test at the 0.05 probability level when significant F-tests ($P < 0.05$) were observed.

3. Results and discussion

Average grain yield across four growing seasons and all production treatments was 9829 kg ha^{-1}, which is 89.9 % more than the national average. When averaged across all treatments, grain yields did not vary significantly across growing seasons (Table 2), although kernel number per ear and per square meter were affected by growing conditions. These results probably demonstrate some compensation ability among yield components in a maize crop. Weed competition was generally negligable in our experiments despite the fact that less herbicide was applied under the EPS treatment (Table 1). Moreover, no evidence of visual nutrient deficiencies or earlier plant senescence on the crop was observed in the EPS. However, the IPS treatment significantly increased grain yield by 39.0 % and averaged 11 419 kg ha^{-1} compared to 8214 kg ha^{-1} for the EPS (Table 3). Grain weight per plant in the IPS decreased by an average of 12.8 % because of the 9.3 and 3.9 % reduction in kernel number per plant and 1000-kernel weight, respectively. The IPS averaged 3616 kernels m^{-2} compared to 2458 kernels m^{-2} for the EPS; therefore, this larger grain yield was principally due to a 47.1 % increase in kernel number per

Table 1: Summary of agricultural practices and operations for maize cropping under intensive (IPS) and extensive (EPS) production systems
Tabelle 1: Übersicht über Bewirtschaftungsmaßnahmen und Arbeitsschritte bei der Maiskultur unter intensivem und extensivem Produktionssystem

	IPS	EPS
Fertilization, kg ha^{-1}		
N–P–K	500 (8:26:26)	400 (8:26:26)
Urea	200 (46 % N)	100 (46 % N)
Ploughing depth, cm	30–32	20–22
Plant population, plants ha^{-1}	60–65 000	37–38 000
Planting date	18 Apr. 1996, 26 Apr. 1997, 29 Apr. 1998, and 1 May 1999	
N dressing applied with interrow cultivation, kg N ha^{-1}	40.5 at V* 2	27 at V5 40.5 at V5
Herbicide	metolachlor (1.5 kg a.i. ha^{-1}) and atrazine (1.0 kg a.i. ha^{-1})	applied preemergence atrazine (1.0 kg a.i. ha^{-1}) applied preemergence
	2,4-D (1.0 kg a.i. ha^{-1}) at V3	2,4-D (1.0 kg a.i. ha^{-1}) at V3
Silking (R1)	7–15 July 1996, 14–23 July 1997, 12–20 July 1998, 10–20 July 1999	6–14 July 1996, 13–23 July 1997, 11–20 July 1998, 9–19 July 1999
Harvest date	10 Nov. 1995, 30 Oct.1997, 5 Nov. 1998, 29 Oct. 1999	

* V, growth stage.

Table 2: Analysis of variance for grain yield and yield components
Tabelle 2: Varianzanalyse für Kornerträge und Ertragskomponenten

Source of variation	df	Grain yield	Barren plants per hectare	Ears per plant	Ears per hectar	Grain weight per plant	Kernels per plant	Kernels per square meter	Rows per ear	Kernels per row	Kernels per ear	1000-kernel weight	Grain weight per ear
Growing season (Y)	3	NS	NS	NS	NS	NS	NS	*	NS	NS	*	NS	NS
Production system (PS)	1	**	**	NS	***	*	*	***	NS	NS	NS	NS	NS
Error a (Y × PS)	3	–	–	–	–	–	–	–	–	–	–	–	–
Hybrid (H)	11	***	*	***	***	***	***	***	***	***	***	***	***
Maturity group (F)	(2)	***	*	NS	**	***	***	***	***	***	***	***	***
Hybrid within maturity group (HF)	(9)	***	NS	***	***	***	***	***	***	***	***	***	***
PS × H	11	***	**	***	**	*	*	*	NS	*	NS	***	**
PS × F	(2)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PS × HF	(9)	***	**	***	**	*	*	*	NS	**	NS	***	***
Error b (pooled error term)	450	–	–	–	–	–	–	–	–	–	–	–	–

*, **, ***, NS Significant at $P = 0.05$, 0.01, and 0.001 levels, and not significant, respectively.

square meter. Greater kernel number per square meter in the IPS was mainly due to more intensive fertilization rates and a 63.5 % higher plant population, which produced 50.5 % more ears per hectare. These results demonstrated that kernel number per plant and per square meter are yield components most responsive to changes in production inputs. TOLLENAAR (1992) found that 87 % of the variation in grain yield at two plant density extremes was due to the change in kernel number per plant.

Ear number per plant averaged 1.08 and 1.01 for the EPS and the IPS, respectively (Table 3) even though N fertilization was lower for the EPS treatment. Therefore, higher prolificacy in the EPS was primarily because of lower plant population, as also reported by PUCARIĆ (1971), TOLLENAAR et al. (1992), and THOMISON and JORDAN (1995). The EPS treatment had more ears per plant than the IPS in all growing seasons, except in 1997, when both production systems averaged 1.01 ears plants^{-1} (data not shown). RITCHIE et al. (1986) stated that potential ears are formed at V5 (five-leaf stage), while PRINE (1971) showed that a critical period for the abortion of secondary ears is during the silking period and few days following the silking period. In 1997, dryer than average silking and particularly post silking period (only 60.2 mm of precipitation fell in two months after silking; data not shown) probably inhibited the occurrence of secondary ears.

Higher plant population in the IPS consistently resulted in more barren plants per hectare which averaged 0.9 % in

Table 3: Average grain yield and yield components of 12 maize hybrids in intensive (IPS) and extensive (EPS) production systems, Zagreb, 1996–1999

Tabelle 3: Mittelwerte für Kornertrag und Ertragskomponenten von 12 Maishybriden bei intensivem und extensivem Produktionssystem in Zagreb 1996–1999

	IPS	EPS
Grain yield, kg ha^{-1}	11419**	8214
Barren plants per hectare, no.	561**	68
Ears per plant, no.	1.01	1.08 ^{NS}
Ears per hectare, no.	61 573**	40 920
Grain weight per plant, g	192	220*
Kernels per plant, no.	592	653*
Kernels per square meter, no.	3616**	2458
Rows per ear, no.	15.9^{NS}	15.7
Kernels per row, no.	37.5	39.0 ^{NS}
Kernels per ear, no.	588	606 ^{NS}
1000-kernel weight, g	324	337 ^{NS}
Grain weight per ear, g	190	204 ^{NS}

*, **, ^{NS} Significant at 0.05 and 0.01 probability level, and not significant, respectively, by F-test.

comparison to 0.2 % for the EPS, as also found by GOTLIN et al. (1969). When averaged across all treatments, row number per ear slightly (1.1 %) increased for the IPS, most probably due to a lower occurrence of secondary ears, which commonly have fewer rows compared to primary ears, as demonstrated in research conducted by PUCARIĆ (1971). In contrast to row number per ear, kernel number per row declined in the IPS by 3.8 % and averaged 37.5 compared to 39.0 kernels row^{-1} for the EPS (Table 3). The 1000-kernel weight also diminished similarly (3.9 %), which in turn, brought about lighter grain weight per ear under the IPS which averaged 190 g compared with 204 g for the EPS. The 1000-kernel weight decrease because of higher plant populations was found by GOTLIN et al. (1969), PUCARIĆ (1971), and COX (1996).

The FAO maturity groups of hybrids significantly differed in grain yields and all yield components (Table 2), except for ear number per plant, which averaged 1.05 (Table 4). Averaged across all treatments, longer-maturity groups showed a similar increase in grain yields compared to shorter-maturity groups, but these responses were achieved through different yield components. The FAO 400 group increased grain yield by an average of 7.9 % compared to the FAO 300 group even though it had fewer plants (3.0 %) and ears (3.5 %) per hectare. Moreover, kernel number per square meter was similar between these two maturity groups and averaged 2994 and 2979 kernels m^{-2} for the FAO 300 and the FAO 400 group, respectively. Consequently, larger grain yield for the FAO 400 group was primarily associated with a 8.6 % improvement in 1000-kernel weight, which averaged 342 g compared to 315 g for the FAO 300 group, while kernel number per ear and plant increased only by 2.7 and 2.1 %, respectively. In contrast, a 7.5 % yield increment for the FAO 500 group in comparison to the FAO 400 group was principally because of the 7.4 and 8.5 % increase in kernel number per ear and per plant, respectively, whereas 1000-kernel weight declined by an average of 2.0 %. TOLLENAAR et al. (2000) argued that greater yield potential of later-maturing hybrids is to be expressed as an increase in kernel number per plant since they considered that kernel weights greater than 330 mg kernel^{-1} are uncommon. However, six hybrids from longer-maturity groups (FAO 400–500) had average 1000-kernel weight heavier than 330 g in our research. The absence of production system × FAO group interaction for grain yield and all yield components (Table 2) indicated that maturity groups showed a similar response to various production input levels, though we expected that shorter-maturity hybrids will have greater benefits from increased plant populations in the IPS compared to longer-maturity hybrids, as reported by COLVILLE et al. (1964), PUCARIĆ (1971), and in recent years, by NORWOOD (2001).

Hybrids significantly differed among themselves in grain yield and all yield components (Table 2). When averaged across all treatments, the largest yielding were PR 3563 and PR 3475, two full-season hybrids from the FAO 500 maturity group (Table 5). Although PR 3563 had the smallest

Table 4: Grain yield and yield components of the three FAO maturity groups of hybrids averaged across all treatments, Zagreb, 1996–1999

Tabelle 4: Kornerträge und Ertragskomponenten von 3 FAO-Hybridreifeklassen gemittelt über alle Versuchsvarianten, Zagreb 1996–1999

	Maturity group		
	FAO 300	FAO 400	FAO 500
Grain yield, kg ha^{-1}	9095c*	9809b	10545a
Barren plants per hectare, no.	418a	300ab	225b
Ears per plant, no.	1.05a	1.05a	1.05a
Ears per hectare, no.	52117a	50315b	51307a
Grain weight per plant, g	188c	208b	222a
Kernels per plant, no.	605b	618b	668a
Kernels per square meter, no.	2994b	2979b	3249a
Rows per ear, no.	15.5b	16.0a	15.9a
Kernels per row, no.	37.5b	37.2b	40.0a
Kernels per ear, no.	579c	596b	637a
1000-kernel weight, g	315c	342a	335b
Grain weight per ear, g	180c	200b	211a

* Means within a row followed by the same letter are not significantly different.

plant population, it yielded 25.0 % more than the shorter-season hybrid Bc 3786, which in contrast, had the highest plant population on average. The greatest yield for PR 3563 was associated with the heaviest grain weight per plant (227 g), resulting from the largest kernel number per plant (691 kernels plant^{-1}) and per square meter (3613 kernels m^{-2}). This high kernel number per plant was principally due to the largest row number per ear, while some other hybrids had more kernels per row, and particularly, heavier 1000-kernel weight (Table 6). In contrast, Bc 3786 had the lightest grain weight per ear (175 g) and per plant (179 g), mainly because of the smallest 1000-kernel weight

Table 5: Grain yield, plant and ear number of maize hybrids in intensive (IPS) and extensive (EPS) production systems, Zagreb, 1996–1999
Tabelle 5: Kornertrag, Pflanzen- und Kolbenzahl von Maishybriden unter intensivem und extensivem Produktionssystem in Zagreb 1996–1999

Hybrid	Maturity group	Plants per hectare		Grain yield		Barren plants per hectare		Ears per plant		Ears per hectare		Kernels per square meter	
		IPS	EPS	IPS	EPS	IPS	EPS	IPS	EPS	IPS	EPS	IPS	EPS
		no.		kg ha^{-1}				no.				no.	
OSSK 332	FAO 300	62 175	37 851	11 056	7900	250	188	1.03	1.22	63 523	45 776	3460	2431
OSSK 382		62 921	37 782	11 001	7934	742 125	1.00	1.04	62	179	39 223	3628	2428
Bc 3786		65 296	37 657	10 173	7207	801	0	1.00	1.05	64 494	39 535	3842	2383
Podravec 36		63 022	37 597	10 296	7493	1234	0	1.00	1.08	61 788	40 420	3452	2331
OSSK 412	FAO 400	60 501	37 657	10 349	7945	915	63	1.00	1.07	59 586	40 117	3364	2311
DK 471		61 093	37 657	11 913	8141	439	63	1.03	1.08	62 545	40 731	3422	2298
DK 485		60 404	37 657	12 403	8629	423	63	1.00	1.06	59 981	39 756	3583	2432
Bc 488B		59 330	37 719	11 114	7980	310	125	1.02	1.06	60 007	39 796	3782	2639
OSSK 552	FAO 500	60 611	37 719	12 135	8615	492	125	1.00	1.01	60 119	37 907	3725	2457
Bc 5982		60 558	37 719	12 135	8339	310	63	1.01	1.03	60 759	38 889	3721	2523
PR 3563		60 808	37 657	12 595	9125	122	0	1.02	1.16	61 678	43 611	4236	2990
PR 3475		62 903	37 719	11 856	9557	686	0	1.00	1.20	62 217	45 276	3705	2631
		LSD (0.05)*		484		394		0.060		2553		137	
		LSD (0.05)**		829		404		0.088		3110		152	

* LSD values for comparing means within production systems.
** LSD values for comparing means across production systems.

Table 6: Yield components per plant and per ear of maize hybrids in intensive (IPS) and extensive (EPS) production systems, Zagreb, 1996–1999
Tabelle 6: Ertragskomponenten pro Pflanze und pro Kolben in Maishybriden unter intensivem und extensivem Produktionssystem in Zagreb 1996–1999

Hybrid	Maturity group	Grain weight per plant		Kernel per plant		Rows per ear		Kernels per row		Kernels per ear		1000-kernel weight		Grainweight per ear	
		IPS	EPS	IPS	EPS	IPS	EPS	IPS	EPS	IPS	EPS	IPS	EPS	IPS	EPS
		g		no.								g			
OSSK 332	FAO 300	181	205	558	646	14.7	14.7	37.3	36.7	545	540	329	317	177	173
OSSK 382		180	205	584	645	16.7	16.5	35.2	37.7	584	619	322	325	180	198
Bc 3786		164	194	596	633	16.5	16.2	36.3	37.7	596	605	279	310	164	186
Podravec 36		168	205	560	620	14.6	14.3	38.9	40.6	560	583	301	334	168	194
OSSK 412	FAO 400	184	218	565	614	15.8	15.5	35.9	37.3	565	577	327	361	184	205
DK 471		196	212	566	611	16.1	16.3	34.3	35.1	548	566	356	355	190	197
DK 485		217	232	599	647	15.7	15.4	38.4	39.9	599	614	361	362	217	220
Bc 488B		189	213	641	702	17.1	16.6	36.9	40.0	631	665	301	312	186	203
OSSK 552	FAO 500	205	238	620	654	15.2	14.8	40.7	44.1	620	648	332	365	205	236
Bc 5982		204	223	617	670	16.1	16.5	37.8	39.4	613	651	335	332	202	217
PR 3563		212	241	698	794	17.2	16.9	40.0	41.4	687	694	306	308	209	211
PR 3475		199	250	595	698	15.6	15.3	38.4	38.0	595	588	341	363	199	211
LSD (0.05)*		11.6		29.7		NS§		1.40		NS		12.1		11.9	
LSD (0.05)**		23.1		38.2				1.66				23.5		18.2	

* LSD values for comparing means within production systems.
** LSD values for comparing means across production systems.
§ NS Not significant for hybrid × production system interaction at $P = 0.05$.

which averaged 295 g. Although DK 485 and OSSK 552 had heavier average grain weight per ear than PR 3563, they were significantly lower yielding because of smaller grain weight per plant due to fewer ears per plant (Table 5). The heaviest kernels were observed for DK 485 (Table 6), which had only 1.03 ears per plant on average. The lowest kernel number per ear and per plant was found for hybrid DK 471, but was relatively good yielding due to a high 1000-kernel weight which averaged 356 g.

A significant production system × hybrid interaction was found for grain yield and most yield components (Table 2), which demonstrated that hybrids responded differently under various production input levels, as also found by COLVILLE et al. (1964) and GOTLIN et al. (1969). The average yield increase with the IPS compared to the EPS treatment for DK 471 (a high response hybrid) and R 3475 (a low-response hybrid) was 3772 (46.3 %) and 2299 kg ha^{-1} (24.1 %), respectively (Table 5). Moreover, PR 3475, which had the largest grain yield (9557 kg ha^{-1}) under the EPS treatment, was significantly lower yielding than PR 3563 and DK 485 in the IPS even though it had slightly more plants per hectare. The largest yield for PR 3475 in the EPS was primarily associated with the heaviest grain weight per plant (250 g) because of a high prolificacy which averaged 1.20 ears per plant. Under the IPS treatment (Table 6), PR 3475 showed the greatest (20.4 %) decline in grain weight per plant because of the 14.8 and 6.1 % reduction in kernel number per plant and 1000-kernel weight, respectively. The smallest decrease in grain weight per plant in the IPS compared to the EPS had DK 485 (6.5 %), which in turn, brought about significantly larger grain yield from PR 3475, in contrast to the EPS treatment where PR 3475 yielded significantly more (Table 5). In addition to DK 471, above average grain yield increase to the IPS treatment also shown Bc 5982 (45.5 %), DK 485 (43.7 %), Bc 3786 (41.2 %), OSSK 552 (40.9 %), OSSK 332 (39.9 %), and Bc 488B (39.3 %). The three most prolific hybrids in the EPS had the largest decrease in kernel number per plant under the IPS, which averaged 14.8, 13.6, and 12.1 % for PR 3475, OSSK 332, and PR 3563, respectively (Table 6). Conversely, relatively small reduction in kernel number per plant under the IPS treatment was demonstrated by monoprolific hybrids OSSK 552 (5.2 %), DK 485 (7.4 %), and Bc 5982 (7.9 %). Consequently, these three hybrids had similar yields to the highest-yielding PR 3563 in the IPS even though they were significantly lower yielding under the EPS (Table 5). In their two-year research conducted in 11 environments in Ohio, THOMISON and JORDAN (1995) also reported that single-ear hybrids required higher populations than the prolific hybrids to achieve the greatest yields.

In contrast to row number per ear, hybrids tended to decrease kernel number per row and per ear under the IPS treatment (Table 6). The greatest reduction in kernel number per ear under the IPS was determined for monoprolific hybrids Bc 5982 (5.8 %), OSSK 382 (5.7 %), Bc 488B (4.8 %), and OSSK 552 (4.7 %). Only OSSK 332 and PR 3475 succeeded to slightly increase kernel number per row and per ear in the IPS, most likely due to a low occurrence of secondary ears even for these two most prolific hybrids. However, longer-maturity PR 3475 reduced 1000-kernel weight like most hybrids in the IPS, whereas shorter-maturity OSSK 332 showed an opposite pattern of response, demonstrating that hybrids may respond differently for yield components under various production input levels regardless of similar prolificacy.

4. Conclusions

Croatian farmers should be aware of reduced productivity potentials under the EPS. Hybrids significantly increased grain yields in the IPS by an average of 3205 kg ha^{-1} (39.0 %) because of an increase in kernel number per square meter primarily due to more intensive fertilization rates and higher plant populations, which produced more ears per hectare. Longer-maturity groups of hybrids tended to similarly improve grain yields compared to shorter-maturity groups by an average of 7.7 %, though these responses were achieved through different yield components. Although full-season PR 3563 demonstrated superior performance in both production systems, our study indicated that among the tested hybrids, there may be different responses to the IPS. Under the IPS treatment, DK 485, OSSK 552, and Bc 5982 yielded similarly to PR 3563, even though they had significantly lower yields in the EPS. In contrast, PR 3475 had the largest grain yield in the EPS, but was significantly lower yielding than PR 3563 and DK 485 under the IPS. Therefore, hybrid selection appears to be an important consideration when changing from an EPS to an IPS for maize.

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