Grain yield and yield components of winter wheat grown in two management systems

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Ertrag und Ertragskomponenten verschiedener Winterweizen in zwei Bearbeitungssystemen

1. Introduction

Winter wheat is the most important cereal crop in Croatia. The 10-year average (1988–1997) yield of 4.17 t ha^{-1} (CROATIAN STATISTICS SERVICE, 1998) is low compared with yield levels in many western European countries. Inputs to achieve this yield level are relatively modest, since optimum sowing rates, herbicides, fungicides, insecticides, and sufficient nitrogen fertilisation rates are not regularly applied. The level of wheat grain yield may result from various ratios of yield components since the wheat plant has an ability to compensate growth and to adjust these components in response to variable growing conditions. Hence, winter wheat management should include management practices based on the cultivar and environmental potentials.

In most cases, high management inputs were beneficial to yield increase (PUCARIĆ and JUKIĆ, 1989; GUY et al., 1995). However, KHAN and SPILDE (1992) reported that intensive cereal management applied as a complete package under marginal production conditions in northern U.S. environment were not a viable option due to hot, dry environmental conditions at the critical growth stages of wheat. Moreover, the response to high management inputs is known to be environment and/or cultivar dependent (BEUERLEIN et al., 1989). HARMS et al. (1989) found that management systems (high vs. low input) did not differ for grain yields across three environments but management × cultivar and environment × management × cultivar interactions were highly significant.

Reduced sowing rates may result in more tillers and ears per plant, spikelets per plant, and grains per ear (COIC,

Zusammenfassung

Mit dreigliedriger Fruchtfolge (Winterweizen-Mais-Sojabohne) wurden zweijährige Versuche auf Alluvialböden im Nordwesten Kroatiens durchgeführt. Untersuchungsziel war die Beurteilung des Einflusses intensiver (IBS) und extensiver (EBS) Bearbeitungssysteme, auf Ertrag und Ertragskomponenten 8 regionaler Winterweizensorten bei zwei unterschiedlichen Saatdichten (440 und 770 keimfähige Körner/m^2). Das IBS umfasste: Pflügen (Tiefe bis zu 30–32 cm), Düngung (insgesamt 194 kg/ha N, 130 kg/ha P und 130 kg/ha K), sowie intensive Unkraut-, Krankheits- und Schädlingsbekämpfung; das EBS Pflügen (Tiefe 20–22 cm), Düngung (insgesamt 59 kg/ha N, 104 kg/ha P, 104 kg/ha K) und extensive Unkrautbekämpfung (mit 2,4 D). Der Kornertrag war bei IBS um 37,5 % höher, obwohl die Ährenzahl/m^2 im Vergleich zu EBS lediglich um 10,6 % gestiegen ist. So hat sich die Kornproduktion pro Ähre als eine wichtige Ertragskomponente erwiesen. Dichtere Saat erhöht die Ährenzahl und den Kornertrag in beiden Bearbeitungssystemen und hat sich eine Voraussetzung zur Erreichung der Höchsterträge im IBS gezeigt. In zwei verschiedenen Vegetationsperioden haben einige Sorten nur bei IBS unterschiedlich auf Kornertrag, Ährenzahl/m^2 sowie auf Hektolitergewicht reagiert, was darauf hindeutet, dass die Reaktion der Sorten vom Einfluss der Umweltverhältnisse abhängig sein kann. Vegetationsperiode und Sorte haben sowohl auf das 1000-Korn- als auch auf das Hektolitergewicht in beiden Bearbeitungssystemen einen bedeutenden Einfluss ausgeübt. Das Tausendkorngewicht war bei IBS sowie bei grösserer Pflanzendichte in beiden Bearbeitungssystemen niedriger. Das Hektolitergewicht wich auf beiden Ebenen nicht signifikant voneinander ab, zeigte jedoch bei einer dichteren Aussaat im IBS eine steigende Tendenz.

Schlagworte: Triticum aestivum, Sorten, Düngung, Saatdichten, Hektolitergewicht.

Summary

Field studies in a winter wheat-maize-soybean crop rotation were conducted in northwestern Croatia in 1996 and 1997 to determine the effect of intensive (IMS) and extensive (EMS) management systems on the grain yield and yield components of 8 regional winter wheat cultivars grown at two sowing rates (440 and 770 seeds m^{-2}). IMS consisted of ploughing at 30–32 cm, fertilisation with 194 kg N ha^{-1}, 130 kg P ha^{-1}, 130 kg K ha^{-1}, and intensive crop protection (herbicide, fungicide, and insecticide applications). EMS involved ploughing at 20–22 cm, fertilisation with 59 kg N ha^{-1}, 104 kg P ha^{-1} and 104 kg K ha^{-1}, and herbicide application. Average grain yield was 37.5 % higher in IMS than in EMS, although ear number per square meter increased only by 10.6 %, indicating the importance of grain production per ear as a yield component. Higher sowing rate increased ear number per square meter and grain yield in both management systems, and was shown to be a necessary practice for achieving the maximum grain yield in IMS. In the two growing seasons, some cultivars responded differently for grain yield, ear number per square meter, and test weight only in IMS, indicating that responses of cultivars to management inputs can depend on environmental influences. Test weight and 1000-kernel weight were highly affected by growing season and cultivar in both management systems. 1000-kernel weight was lower in IMS, and at higher sowing rate in both management systems. Test weight was not significantly affected by the management system, but it demonstrated a trend to increase at higher sowing rate in IMS.

Key words: Triticum aestivum, cultivar, fertilisation, sowing rate, test weight.

1958; GOTLIN and PUCARIĆ, 1966) but in many cases they reduce grain yield per hectare (VARGA, 1980, PUCARIĆ and JUKIĆ, 1989). However, because of the mutual compensation occurring among the yield components of wheat, high yields may result from a relatively wide range of sowing rates (DARWINKEL, 1980; BAVEC, 1999). SHAH et al. (1994) achieved a grain yield increase at higher sowing rates only for the late sown crop, while ROTH et al. (1984) reported that yield responses to sowing rates were highly affected by the environment.

Increasing levels of N fertiliser usually improve grain yield (HEBERT, 1969; BAVEC, 1999). Generalised responses of the wheat crop to increased N rates are a higher tiller density, higher ear density, more grains per ear, and a reduced 1000-kernel weight (BRUCKNER and MOREY, 1988; BAVEC, 1999). However, decreased grain yields from excessive N fertilisation have also been reported due to lodging (VARGA, 1980), increased water stress due to excessive vegetative growth (FREDERICK and CAMBERATO, 1995), and a higher incidence of foliar diseases (PUCARIĆ and JUKIĆ, 1989). Application of foliar fungicides to winter wheat leads to a wide range of response (ROTH and MARSHALL, 1987), but in most cases have been shown to be beneficial (PUCARIĆ and JUKIĆ, 1989), particularly when cultivars were susceptible to disease and yields were high (GUY et al., 1989).

The objective of this study was to determine the effect of intensive (IMS) and extensive (EMS) management systems on the grain yield and yield components of 8 regional winter wheat cultivars.

2. Materials and methods

Field studies in a winter wheat – maize – soybean crop rotation were conducted in northwestern Croatia at the Faculty of Agriculture Zagreb experimental field during the 1995-1996 and 1996-1997 growing seasons on a loamy sand soil (fluvisol). The two years study will be referred to by the year of the spring growing season (1996 and 1997). Eight winter wheat cultivars were grown at low (440 seeds m^{-2}) and high (770 seeds m^{-2}) sowing rates under intensive (IMS) and extensive (EMS) management systems. The experimental design of each management system consisted of five replications with two factors arranged as a strip-plot design with winter wheat cultivars as the vertical factor and sowing rate as the horizontal factor.

IMS involved ploughing at 30–32 cm, fertilisation with a total of 194 kg N ha^{-1} including three topdressing applications (54, 27, and 27 kg ha^{-1} at growth stages (GS) 22, 24, and 31, respectively)(according to ZADOKS et al., 1974), 130 kg P ha^{-1}, 130 kg K ha^{-1}, and intensive crop protection. Herbicides amidosulfuron (25 g a.i. ha^{-1}) and bromoxynil (0.225 l a.i. ha^{-1}) were applied at GS 24 to control weeds, while fungicide tebuconazol (0.25 l a.i. ha^{-1}) and insecticide lambda cihalotrin (0.005 l a.i. ha^{-1}) were tank mixed and applied at GS 60. EMS consisted of ploughing at 20–22 cm, fertilisation with a total of 59 kg N ha^{-1} including one topdressing application with 27 kg ha^{-1} at GS 24, 104 kg P ha^{-1}, 104 kg K ha^{-1}, less effective herbicide, and no fungicide and insecticide applications.

Table 1: Average grain yield, ear number per square meter, 1000-kernel weight and test weight of 8 winter wheat cultivars in intensive (IMS) and extensive (EMS) management systems in 1996 and 1997

Tabelle 1: Durchschnittlicher Kornertrag, Ährenzahl per m^2, Tausendkorn- und Hektolitergewicht von 8 Winterweizensorten in intensiven (IMS) und extensiven (EMS) Bearbeitungssystemen, 1996 und 1997

	IMS		EMS		IMS	EMS
	1996	1997	1996	1997	Average	Average
Grain yield (kg ha^{-1})	6962	8375*	5799*	5378	7669*	5589
Ear number m^{-2}	607^{NS}	586^{NS}	567*	515	596*	541
1000-grain weight (g)	44.6*	41.8	45.1*	44.2	43.2	44.6*
Test weight (kg m^{-3})	815*	802	801	811*	808^{NS}	806^{NS}

Herbicide treatment (2,4 D; 1 l a.i. ha^{-1}) was applied at GS 24. In October of each year, 500 kg ha^{-1} of 8-26-26 (N-P-K) with 100 kg ha^{-1} of urea (46 %) in IMS, and 400 kg ha^{-1} of 8–26–26 (N-P-K) in EMS, were broadcast before ploughing. At sowing, plots consisted of 10 rows (11 cm between rows) and were 7.0 m long. Wheat was sown on 16 Oct. 1995 and 28 Oct. 1996. Granular nitrogen (ammonium nitrate, 27 %) was hand broadcast in each topdressing application.

Ear density was determined from a central 0.55 m^2 plot area just prior to harvest. Plots were combine harvested and total grain yields are expressed on a kg per hectare basis at a 130 g kg^{-1} moisture. Average 1000-kernel weight was determined by counting and weighing two 100-kernel samples taken from each plot at harvest. Test weight was determined from grain yield samples using a standard test weight scale.

Data within each management system were subjected to ANOVA using MSTAT-C (Michigan State University, 1990). Means separation was calculated with LSD test. The comparisons of grain yield, yield components, and test weight data across management systems were made by t-test analysis. Unless otherwise stated, significant differences are reported for the 0.05 level of significance.

3. Results and discussion

3.1 Weather data

Climatic conditions during the 1996 growing season greatly differed from 1997. The 1996 growing conditions were, in general, unfavourable for wheat production due to a period of drought during stem elongation and heading. In contrast, the 1997 growing season was characterised by excellent growing conditions throughout whole crop vegetation, with normal precipitation and air temperature slightly above normal during early spring growth.

3.2 Grain yield and yield components

The average grain yield across the two growing seasons was highly affected by the management system and it improved by 37.5 % in IMS (Table 1) despite the fact that pests severity was generally negligible during experimentation. However, ear number per square meter increased only by 10.6 %, indicating the importance of grain production per ear as a yield component. Higher grain yield in IMS was principally due to the increased number of grains per ear since 1000-kernel weight significantly decreased in IMS in both growing seasons. Furthermore, the low incidence of diseases in this experiment probably had no influence on 1000-kernel weight in EMS.

Growing season significantly altered grain yield in both management systems. In the stressed growing conditions of 1996, grain yield in IMS was by 16.9 % lower than in 1997, although ear number per square meter did not differ significantly for both growing seasons (Table 2). Conversely, grain yield in EMS was 7.8 % higher in 1996 than in 1997, primarily due to 10.1 % more ears per square meter. This significantly higher ear number per square meter in EMS in 1996 was partly caused by the so called "rotation effect" since the proceeding soybean crop was grown under IMS, in contrast to the 1997 growing season when wheat grown in EMS followed soybean also grown in EMS.

A significant interaction between sowing rate and growing season was found in EMS since grain yields did not differ significantly between sowing rates in the favourable 1997 growing conditions, though ear number per square meter increased by 56.6 % at high sowing rate (Table 3). In contrast, the absence of interaction between sowing rate and growing season for ear number per square meter in IMS indicated that management practices, particularly more intensive N fertilisation, were not sufficient to provide ear number per square meter required to achieve the maximum grain yield at low sowing rate.

Table 2: Combined analysis of variance for grain yield, ear number per square meter, 1000-kernel weight, and test weight in intensive (IMS) and extensive (EMS) management system

Tabelle 2: Ergebnisse der Varianzanalyse für die Kornertrag, Ährenzahl per m², Tausendkorn- und Hektolitergewicht bei intensivem (IMS) sowie extensivem (EMS) Bearbeitungssystem

Effect	Grain yield		Ear number m⁻²		1000-kernel weight		Test weight	
	IMS	EMS	IMS	EMS	IMS	EMS	IMS	EMS
Year (Y)	P ≤ 0.001	P ≤ 0.001	NS	P ≤ 0.001	P ≤ 0.001	P ≤ 0.001	P ≤ 0.001	P ≤ 0.001
Cultivar (C)	P ≤ 0.001	P ≤ 0.001	P ≤ 0.001	P ≤ 0.001	P ≤ 0.001	P ≤ 0.001	P ≤ 0.001	P ≤ 0.001
Y × C	P ≤ 0.001	NS	P ≤ 0.05	NS	P ≤ 0.001	P ≤ 0.001	P ≤ 0.001	NS
Sowing rate (SR)	P ≤ 0.001	P ≤ 0.001	P ≤ 0.001	P ≤ 0.001	P ≤ 0.05	P ≤ 0.01	P ≤ 0.001	NS
Y × SR	NS	P ≤ 0.01	NS	P ≤ 0.01	NS	NS	NS	NS
C × SR	NS	NS	NS	NS	P ≤ 0.05	NS	NS	NS
Y × C × SR	NS	NS	NS	NS	NS	NS	NS	NS

Table 3: Average grain yield and ear number per square meter of 8 winter wheat cultivars at two sowing rates in extensive management system in 1996 and 1997

Tabelle 3: Durchschnittlicher Kornertrag und Ährenzahl per m² von 8 Winterweizensorten in zwei Saatdichten bei extensivem Bearbeitungssystem, 1996 und 1997

Sowing rate	Grain yield (kg ha⁻¹)		Ear number m⁻²	
	1996	1997	1996	1997
440 seeds m⁻²	5561	5301	481	401
770 seeds m⁻²	6038	5445	652	629
LSD	162		28	

Comparing high sowing rate in IMS to low sowing rate in EMS, grain yield improved by 41.2 % by virtue of 45.8 % more ears per square meter (Table 4). VARGA (1980) and MLINAR (1983) also reported a similar relationship between grain yield and ear number per square meter. However, high sowing rate in IMS and EMS produced grain yields higher by only 3.5 % and 5.8 %, whereas ear number per square meter increased by 16.9 % and 45.1 %, respectively (Table 2). At low sowing rate, more intensive N fertilisation in IMS resulted in 24.6 % more ears, and a 35.8 % improved grain yield in comparison with EMS. Ear number per square meter at high sowing rate was practically the same in both management systems while grain yield increased by 35.8 % in IMS, once more demonstrating the compensation ability of yield components in a wheat crop.

Significant differences were found among cultivars for all traits in both management systems. Moreover, an interaction between cultivar and growing season occurred for all traits in IMS, since two cultivars responded differently for grain yield, one cultivar for 1000-kernel weight, and all the three previously mentioned ones for ear number per square meter, demonstrating the cultivar specific compensation ability among yield components with respect to growing conditions. However, two cultivars that outyielded other cultivars in IMS had also the highest grain yield in EMS (data not shown), suggesting cultivar superior performance at various management inputs under given experimental condition.

Growing season, cultivar, and their interaction highly affected 1000-kernel weight in both management systems. 1000-kernel weight was significantly higher in 1996 (average 44.6 g) than in 1997 when it achieved the expected average of 41.8 g (Table 1). Higher 1000-kernel weight in 1996 was due to the smaller number of grains per ear caused by prolonged drought during stem elongation and normal weather conditions during grain-filling period. In contrast, the 1997 growing conditions were consistently favourable and resulted in more grains per ear in both management systems, and subsequently a lower 1000-kernel weight. 1000-kernel weight decreased at high sowing rate in both management systems primarily due to the increased num-

Table 4: Average grain yield, ear number per square meter, 1000-kernel weight and test weight of 8 winter wheat cultivars at two sowing rates in intensive and extensive management system

Tabelle 4: Durchschnittlicher Kornertrag, Ährenzahl per m², Tausendkorn- und Hektolitergewicht von 8 Winterweizensorten in zwei Saatdichten bei intensivem sowie extensivem Bearbeitungssystem

	Intensive management system		Extensive management system	
	440 seeds m²	770 seeds m²	440 seeds m²	770 seeds m²
Grain yield (kg ha⁻¹)	7536	7802 *	5431	5746*
Ear number m²	550	643*	441	641*
1000-grain weight (g)	43.4*	42.9	44.9*	44.3
Test weight (kg m³)	806	809*	806^{NS}	806^{NS}

ber of ears per square meter and grains per ear in EMS and IMS, respectively. However, the cultivar × sowing rate interaction was found in IMS since some cultivars failed to significantly decrease 1000-kernel weight at high sowing rate. Moreover, one cultivar consistently increased 1000-kernel weight at high sowing rate in both growing seasons in IMS. Interestingly, this cultivar had also the highest test weight of all cultivars at both sowing rates in each management system (data not shown).

Test weight is widely regarded as an indicator of milling quality of wheat though some authors (ALTAF ALI et al., 1969; GHADERI and EVERSON, 1971) have shown it to be an unreliable predictor. Despite small improvement in IMS, average test weight was not significantly affected by the management system in this experiment (Table 1). GUY et al. (1995) obtained similar results while KHAN and SPILDE (1992) reported about reduction in test weight under intensive management only in water stress environment during grain-filling. However, test weight was highly affected by growing season and cultivar in both management systems, and their interaction in IMS (Table 2). Test weight was higher in 1996 for all cultivars in both management systems except for one cultivar in IMS, which had a very high 1000-kernel weight. Significantly higher ear density in 1996 than in 1997 resulted in a lower 1000-kernel weight as well as the test weight for this cultivar.

Test weight did not differ between sowing rates in EMS but significantly increased at high sowing rate in IMS. Similar results were reported by PROTIĆ et al. (1988) and ROTH et al. (1984). Improved test weight values at high sowing rate in IMS, though 1000-kernel weight consistently decreased, showed that a higher 1000-kernel weight value *per se* is not a reliable indicator of higher test weight, as also reported by SCHULER et al. (1995).

Table 5: Simple correlation coefficients among average 1000-kernel weight and test weight of 8 winter wheat cultivars at two sowing rates in intensive and extensive management system in 1996 and 1997

Tabelle 5: Korrelationskoeffizienten zwischen durchschnittlichem Tausendkorn- und Hektolitergewicht von 8 Winterweizensorten in zwei Saatdichten bei intensivem sowie extensivem Bearbeitungssystem, 1996 und 1997

Sowing rate	Intensive management system		Extensive management system	
	1996	1997	1996	1997
440 seeds m^{-2}	- 0.56 *	0.26 NS	- 0.27 NS	- 0.11 NS
770 seeds m^{-2}	- 0.25 NS	0.10 NS	- 0.11 NS	- 0.14 NS
Average	- 0.40 *	0.18 NS	- 0.19 NS	- 0.13 NS

An overall correlation for all cultivars between 1000-kernel weight and test weight was negative at both sowing rates for two growing seasons in EMS, and in 1996 in IMS due to a very high 1000-kernel weight (Table 5). However, in the normal growing conditions of 1997, when 1000-kernel weight had the expected values in IMS, a small positive correlation was observed at both sowing rates.

4. Conclusions

Average grain yield was 37.5 % higher in IMS, though ear number per square meter increased only by 10.6 %, indicating the importance of grain production per ear as a yield component. High sowing rate increased ear number per square meter and grain yield in both management systems, and was shown to be a necessary practice to achieve the maximum grain yield in IMS. In two growing seasons some cultivars responded differently for grain yield, ear number per square meter and test weight only in IMS, demonstrating that cultivar specific responses to various management inputs can be environmentally dependent. Test weight and 1000-kernel weight were highly affected by growing season and cultivar in both management systems. 1000-kernel weight decreased in IMS, and at high sowing rate in both management systems. Test weight was not significantly affected by the management system, but demonstrated a trend to increase at high sowing rate in IMS.

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