Relationships among yield, it's quality and yield components in winter wheat *(Triticum aestivum* L.) cultivars affected by seeding rates

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Beziehungen zwischen Ertrag, Ertragsqualität und Ertragskomponenten bei Winterweizensorten *(Triticum aestivum* L.) in Abhängigkeit von der Saatstärke

1. Introduction

Grain yield of cereals is a product of three yield components: the number of ears per unit area, the number of kernels per ear and individual kernel weight. The genotype-by-environment interaction likely dictates which component becomes the major determinant, for no single yield component always accounts for the variations observed in yield (DARWINKEL, 1983). Ontogenetically, ear number is the first yield component to be fixed, and, thus, assumes particular importance. Intensive productive tillering and higher number of kernels per ear compensate for grain yield at low seeding rates (BAVEC and BAVEC, 1995). Although kernel number per ear and kernel weight can somewhat compensate for deficient ear population, they cannot adequately make up for yield. Ear number is thus often positively correlated with grain yield. Increasing the number of plants per m^2 has generally been found to lead to fewer shoots per plant, lower kernel number per ear and lower weight of individual kernels (DARWINKEL, 1978).

When one component is changed, the other components sometimes compensate, resulting in a minimum grain yield change. The direction and magnitude of such compensation is often unknown, and results of studies of relationships between grain yield and yield components have been inconclusive and often contradictory. As seeding rates were increased from 167 to 670 seeds m^{-2}, yield declined in an average of 8 %. Decrease in yield was linear, increasing seeding rate caused quadratic decrease in kernels per ear and kernels weight, and linear increase in ears per m^2 (BEUERLEIN and LAFEVER, 1989). In general, increasing seeding rate increased number of ears per m^2 (ANDERSEN and OLSEN, 1992; VARGA et al., 2000) and decreased number of kernels per ear (ANDERSEN and OLSEN, 1992; MAZUREK

Zusammenfassung

Beziehungen zwischen Ertrag, Ertragskomponenten sowie Winterweizenqualität und Optimierung der Saatstärke (350, 500, 650 und 800 Körner m^{-2}) von 12 Winterweizensorten wurden durch sieben Jahre bei hoher Stickstoffdüngung in Feldversuchen in Nordost-Slowenien untersucht. Die Ertragskomponenten haben den Einfluss der Saatstärke auf den Ertrag von Winterweizen (8,19, 8,33, 8,40, und 8,26 t per ha) bei optimaler Saatzeit und -bedingungen kompensiert. Die Steigerung der Saatstärke erhöhte die Ährenzahl von 621, 677, 711 auf 760 Ähren m^{-2}. Die Ährenzahl war mit dem Ertrag von allen Ertragskomponenten am engsten korreliert (r = 0,597***), obwohl der Ertrag nur bis 650 Körner m^{-2} anstieg. In dieser Variante wurde im Durchschnitt bei 711 Ähren m^{-2} ein Ertrag von 8,40 t ha^{-1} erzielt. Negative Korrelationskoeffizienten bestanden zwischen der Ährenzahl und dem Korngewicht/Ähre (r = -0,398***) und zwischen der Ährenzahl und dem Tausendkorngewicht (r = -0,468***). Die Erhöhung der Saatstärke von 350 auf 800 Körner m^{-2} verminderte die Korngewichte/Ähre von 1,46 auf 1,28 g, die Kornzahl/Ähre von 34 auf 30 Körner und reduzierte das Tausendkorngewicht von 45,41 bis 42,99 g. Die Winterweizenqualität blieb nahezu unbeeinflusst, darauf deuten Proteingehalte zwischen 13,20 bis 13,06% und Sedimentationswerte zwischen 45 bis 43 ml hin.

Schlagworte: Winterweizensorten, Ertrag, Ertragskomponenten, Saatstärke.

Summary

The relationships among grain yield, it's quality and yield components of 12 spread winter wheat cultivars in Slovenia affected by seeding rates were observed in field experiments sown in mid October and fertilised with high nitrogen rates for a period of seven years. In spite of grain yield differences among cultivars, interactions between seeding rates x cultivars were significant in two years. Yield components such as number of ears (621, 677, 711 and 760 ears per m^2 formed at 350, 550, 650 and 800 seeds per m^2, respectively) compensated for the effect of different seeding rates on grain yield (8,19, 8,33, 8,40 and 8,26 t per ha, respectively), except in one year. Numbers of ears m^{-2} expressed firm correlation with grain yield (r = 0,597***). Negative correlation was found between number of ears per m^2 and kernel weight in ear (r = -0,398***), and between number of ears per m^2 and 1000-kernel weight (r = -0,468***). Increased seeding rate from 350 to 800 seeds per m^2 decreased kernel weight per ear (from 1,46 to 1,28 g), number of kernels per ear (from 34 to 30 g) and 1000-kernel weight (from 45,41 to 42,99 g); similar trends were found also in grain quality, i.e. grain protein content decreased from 13,20 to 13,06 % and sedimentation value from 45 to 43 ml, respectively. The results of this study suggest that less than 500 to 650 winter wheat seeds per m^2 can be recommended under optimal sowing date.

Key words: winter wheat, sowing density, yield components, quality.

and PODOLSKA, 1994) and 1000-kernel weight (BODSON, 1986; WOLLRING, 1990; ELLEN, 1990; VARGA et al., 2000).

Optimum seeding rates reported with different genotypes range from 220 seeds per m^2 in the south of Germany (DENNERT and FISCHBECK, 1991), 300 seeds per m^2 in Belgium (BODSON, 1986), 350 seeds per m^2 in Sweden (ANDERSEN and OLSEN, 1992) or 400 in England (LOCK, 1993) to 600–750 seeds per m^2 for some cultivars in Poland (MAZUREK and PODOLSKA, 1995). In intensive and extensive production system of 15 modern cultivars grown at 440 and 770 seeds per m^2 higher seeding rate maximized grain yields in both production systems in Croatia (VARGA et al., 2001). The lower seeding rate (250, 400 and 550 seeds per m^2) resulted in optimal relationship among yield components and increased grain yield in Czech republic (FLASAROVA, 1994).

Therefore, the objective of this study was to investigate the grain yield performance and associated relationships with yield components and grain quality of different winter wheat cultivars affected with different seeding rates, and to optimise seeding rate for humid continental climate in Slovenia.

2. Materials and methods

2.1 Crop husbandry and growing conditions

Experiments were conducted in the Podravje area (northeast of Slovenia) for seven years in two periods: 1987/88 to 1989/90 and 1993/94 to 1996/97. The experimental design was a randomised complete block with treatments arranged as split plot design (Latin rectangle) with four replications, using 12 bread making quality winter wheat cultivars (Table 1) spread in Slovenia and four seeding rates (350, 500, 650 and 800 germinated seeds per m^2). Investigated cultivars differed in chlorophyll content in the leaves, grain yield and percentage of crude protein in the kernels (BAVEC and BAVEC, 2001). The dimension of each subplot was 5 x 2 m.

Table 1: Data on investigated winter wheat cultivars
Tabelle 1: Einige Daten über untersuchte Winterweizensorten

Cultivar	Year of release in Slovenia	Country of origin	Years of evaluation
Marija	1988	Croatia	1988–1990, 1994–1997
Žitarka	1985	Croatia	1988–1990
Demetra	1995	Croatia	1996–1997
Julius	1995	Austria	1994–1995
GK Pinka	1995	Hungary	1994–1996
Soissons	1995	France	1996–1997
Justus	1995	Austria	1996–1997
Mihelca	1995	Croatia	1996–1997
Olga	1996	Croatia	1994–1997
Profit	1995	Germany	1997
Lonja	1980	Croatia	1988–1990
Zelengora	1982	Yugoslavia	1988–1990

Certified seed was planted with an eight-row Wintersteiger plot seed drill with 12-cm row spacing. The size of plots was 10 m^2 at sowing and 8 m^2 at harvesting. Seeding took place in mid to late October (optimal for this area) each year with exception in 1993 (November 2). Yield was harvested with Wintersteiger harvester in the mid of July each year.

Common agriculture practice was used – fertilisation for high yields according to soil analysis (before sowing 40 kg N per ha, 160 kg P_2O_5 and K_2O per ha including 46 kg N per ha in urea form for decomposition of maize incorporated rests and in spring 120 kg N per ha in two top-dressings), herbicides (chlortoluron or chlortoluron + triasulfuron and fluroksipir or tribenuron-metil) one or two times, fungicides (propiconazol) twice and insecticides (alfametrin or cihalotrin) used once.

2.2 Climatic circumstances

Rainfall over 40 years at the experimental sites averaged 1045 mm during 12 months (lower rainfall 221 mm and 98 mm were noted in 1989/90 and 1996/97, respectively) and 180 mm from October to November, 166 mm from January to February, 142 mm from March to April and 218 mm from May to June (from October to June 705 mm), where during these periods optimal rainfall averages for winter wheat amount to 50-200 mm, 20-60 mm, 50-200 mm, respectively and 15-90 mm from earing to ripening (AZZI, 1952). In our experiment, a shortage of water was noted in 1989/1990 and 1995/1996 only from sowing to emergence (5,0 and 2,1 mm, respectively), but there was in previous month more than 130 mm rainfall.

Long term (1951-1990) averages for temperature were 9,6° C, with 58 days of temperatures above 25° C, and an average July temperature of 19,3° C. In experimental years averages for temperature varied from 1987/88 to 1996/97 between 9,5 to 10,6° C, in October 8,6 to 11,1° C, in January –1,9 to 3,8° C, in April 8,4 to 11,4, in May 14,5 to 16,4 and in July from 19,2 to 22,4° C.

2.3 Data collection

Yield components were determined from plants collected in the middle of each plot (0,5 m^2) few days before harvesting. After counting number of ears, 40 ears were taken out randomly for further measurements (number of kernels per ear, ear weight). After harvesting samples were taken out of each plot for analysing 1000-kernel weight (4 x 100 kernels) (ISTA, 1993) and test weight (2 x ¼ l grains) (UL SFRJ 15/88), protein content after Kjeldahl (BREMMNER, 1960) and sedimentation value after Zeleny (VAJIĆ, 1962) were analysed to determine four replications average. Grain yield was calculated on 14 % moisture in the kernels.

2.4 Statistical analyses

For experimental years separately, an analysis of variance (ANOVA) for grain yield was conducted using SPSSX 7,5, where the significance of factor effects was determined at $P \leq 0.05$ (*) and 0.01 (**), respectively. For analysis of yield components (kernel number and kernel weight per ear) GOMEZ and GOMEZ (1984) model was used, which includes sampling error too. The LSD test was used to determine significant differences (at $P \leq 0.05$) between treatments (data not shown). Pearson's correlation coefficients between grain yield and yield components, grain yield and it's quality, were calculated using means across cultivars and seeding rates in experimental years (n = 176) at P ≤ 0,05 (*), 0,01 (**) and 0,001 (***). Regression lines of grain yield and yield components were calculated across treatments for all years.

3. Results

3.1 Yield and yield components performance

Analysed experimental years separately, increased seeding rates just in 1994 significantly affected grain yield, and interaction between cultivar and seeding rate was significant twice (1994 and 1996), but cultivars differed each year, except in1995 (Table 2). In average, increased seeding rate from 350, 550, 650 and 800 seeds per m^2 did not significantly change grain yield (8,19, 8,33, 8,40, 8,26 and 8,21 t per ha). According to year effect, grain yield varied from 6,91 t ha^{-1} (1996) to 9,43 t per ha (1997), and among cultivars with lower yield from 7,01 to 7,82 (Demetra, Julius and Pinka) to higher yield 8,80 t per ha (Soissons).

Increased seeding rate increased number of ears per m^2 significantly in all years although this did not result in the increase of yield. Number of ear per m^2 increased from 630 to 677, 711 and 760 ears per m^2 on average for all cultivars and years at different seeding rates (350, 500, 650 and 800 grains per m^2). In 1995 and 1996 the number of ears was lower (538 and 548, respectively) in comparison with 1990 and 1988 when averages amounted 827 and 818 ears per m^2.

In 1988, 1989, 1990 and 1997 seeding rate significantly decreased number of kernels per ear, but interactions between cultivar and seeding rate were significant in 1988,

Table 2: Influence of seeding rate on the grain yield, it's quality and yield components of different winter wheat cultivars
Tabelle 2: Einfluss der Saatstärke auf Ertrag, Ertragskomponenten und Qualität von Winterweizensorten

	Grain yield kg per m^2	No. of ears per m^2	No. of kernels per ear	Kernels weight per ear (g)	1000-kernel weight (g)	Test weight (g)		
1988 Cultivar (C)	**	**	**	**	**	**		
S. rate (S)	n.s.	**	**	**	**	n.s.		
C X S	n.s.	**	n.s.	n.s.	*	**		
1989 Cultivar (C)	**	**	**	**	**	**		
S. rate (S)	n.s.	**	**	**	**	*		
C X S	n.s.	**	**	**	n.s.	n.s.		
1990 Cultivar (C)	**	**	**	**	**	**		
S. rate (S)	n.s.	**	**	**	n.s.	n.s.		
C X S	n.s.	n.s.	n.s.	n.s.	n.s.	**		
1994 Cultivar (C)	**	n.s.	**	**	**	n.s.		
S. rate (S)	*	**	n.s.	*	*	n.s.		
C X S	**	n.s.	*	**	n.s.	n.s.		
1995 Cultivar (C)	n.s.	**	n.s.	**	**	**		
S. rate (S)	n.s.	**	n.s.	n.s.	*	n.s.		
C X S	n.s.	n.s.	n.s.	n.s.	n.s.	**		
1996 Cultivar (C)	**	**	**	**	**	**		
S. rate (S)	n.s.	*	n.s.	n.s.	n.s.	n.s.		
C X S	*	n.s.	n.s.	n.s.	n.s.	n.s.		
1997 Cultivar (C)	**	**	**	**	**	**		
S. rate (S)	n.s.	**	*	n.s.	*	*		
C X S	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.		
Seeding rate (seeds per m^2)							Crude protein (%)	Sedimentation (ml)
350	8,19	621	34	1,46	45,41	76,1	13,20	45
500	8,33	677	32	1,39	44,20	75,9	13,10	44
650	8,40	711	31	1,32	43,67	76,1	13,01	43
800	8,26	760	30	1,28	42,99	75,6	13,06	43
Cultivars								
Lonja	8,26	851	33	1,18	35,62	74,77	13,33	27
Marija	8,64	714	35	1,38	40,16	75,61	12,45	38
Zelengora	8,02	723	31	1,43	40,53	75,93	13,78	40
Žitarka	8,67	766	33	1,33	40,99	78,27	14,25	52
Olga	8,44	616	33	1,39	43,36	76,30	12,82	42
Pinka	7,82	529	29	1,48	53,96	75,73	12,36	30
Julius	7,62	535	28	1,45	53,62	75,30	12,17	32
Soissons	8,80	793	30	1,23	39,50	76,45	12,77	55
Mihelca	8,08	664	25	1,23	48,10	74,75	13,31	59
Demetra	7,01	604	35	1,40	39,30	74,10	13,33	65
Justus	8,59	696	31	1,47	46,75	78,20	13,14	45
Profit	8,55	680	28	1,53	50,63	74,90	13,22	61
Years								
1988	8,82	818	39	1,66	42,56	75,6	12,74	31
1989	7,80	699	32	1,22	40,58	78,0	14,89	41
1990	8,86	8,27	31	1,10	36,95	75,2	13,21	45
1994	8,10	646	25	1,27	49,59	73,0	12,44	35
1995	8,14	538	32	1,49	51,75	78,2	11,91	31
1996	6,91	548	34	1,41	41,79	77,6	12,99	49
1997	8,29	770	30	1,36	44,07	74,0	13,09	44

1998 and 1994. Cultivars differed in kernels per ear (except one year) and can be divided in two groups, first group with more than 30 kernels per ear (Lonja, Marija, Zelengora, Žitarka, Olga, Soissons, Demetra and Justus) and second group from 25 to 30 kernels per ear (GK Pinka, Julius, Mihelca and Profit).

Kernel weight per ear affected with increased seeding rate (350, 550, 650 and 800 seeds per m^2) significantly decreased in 1988, 1989, 1990 and 1994, and averages in all years from 1,46 g to 1,39, 1,32 to 1,28 g per ear, respectively. Significant differences were noted among cultivars in all years, and only twice with genotype x seeding rate interaction. In average, cultivars Marija, Olga, Zelengora, GK Pinka, Julius, Demetra, Justus, Žitarka, and Profit had over than 1,4 g per ear, and Lonja, Soissons and Mihelca had from 1,20 to 1,40 g per ear.

Increasing seeding rate from 350, 500, 659 to 800 seeds per m^2 significantly decreased 1000-kernel weight (except in 1990 and 1996) and averaged from 45,41 g, 44,20, 43,67 to 42,99 g, respectively. 1000-kernel weight varied among cultivars, and can be divided into 4 groups: below 40 g (Soissons, Demetra and Lonja), 40 to 45 g (Marija, Žitarka and Justus), 45 to 50 g (Zelengora, Olga and Mihelca) and over 50 g (GK Pinka, Julius and Profit).

3.2 Influences on grain quality

In average, seven cultivars (Lonja, Zelengora, Žitarka, Mihelca, Soissons, Justus and Profit) contained over 13 % protein. Grain protein content was rather similar with different seeding rates (Table 2).

By increasing seeding rate a trend of slightly decreasing sedimentation value from 45 to 44, 43 and 43 ml was noticed at 350, 500, 650 and 800 kernels per m^2, respectively. In year's average sedimentation value of investigated cultivars Zelengora, Žitarka, Olga, Soissons, Mihelca, Demetra, Justus and Profit was higher than 40 ml, Lonja less than 30 ml and others between 30 and 40 ml (Marija, GK Pinka and Julius).

Increasing sowing density significantly decreased test weight just in two years (1989 and 1997). Cultivars differed in test weight, except in 1994. Average test weight varied between 74 and 76 kg, but just Justus, Soissons, Olga and Žitarka had over 76 kg.

3.3 Correlation and regression analyses of grain yield, it's quality and yield components

However, between grain yield and number of ears exists a positive firm correlation r = 0,597*** (Table 3) and significant are also linear (y = 4,9924 + 0,0048x***), quadrate (y = 2,6104 + 0,0121x - 0,00005x^{2***}) and cubic regression (Figure 1), which explained highest influence on yield (38 %).

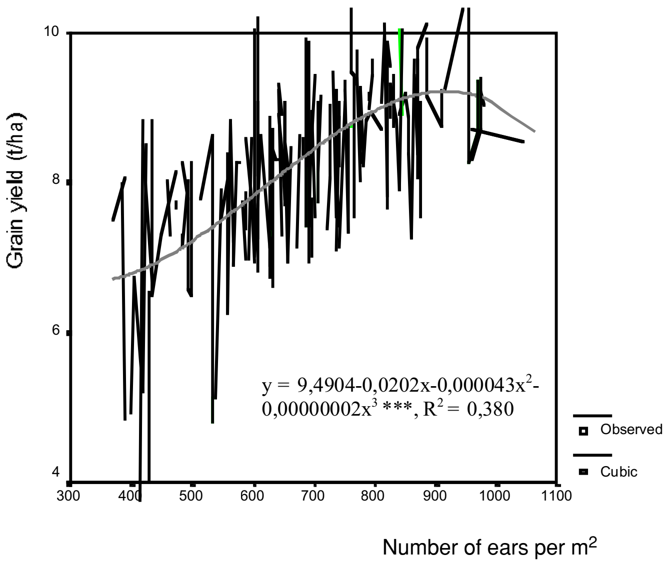

Figure 1: Grain yield dependence on number of ear per m^2
Abbildung 1: Die Ertragsabhängigkeit von der Ährenzahl pro m^2

Relationship between number of kernels per ear and kernel weight was clearly described by linear regression curve (Figure 2).

Table 3: Correlation coefficients between grain yield and yield components of winter wheat cultivars at different seeding rates
Tabelle 3: Korrelationskoeffizienten zwischen Ertrag und Ertragskomponenten bei verschiedener Saatstärke von Winterweizensorten

Parameters	Number of ears	Number of kernels per ear	Kernel weight per ear	1000-kernel weight
Yield	0,597***	0,017	0,087	0,001
Number of ears		-0,111	-0,398***	-0,468***
Number of kernels per ear			0,570***	-0,382***
Kernel weight per ear				0,398***

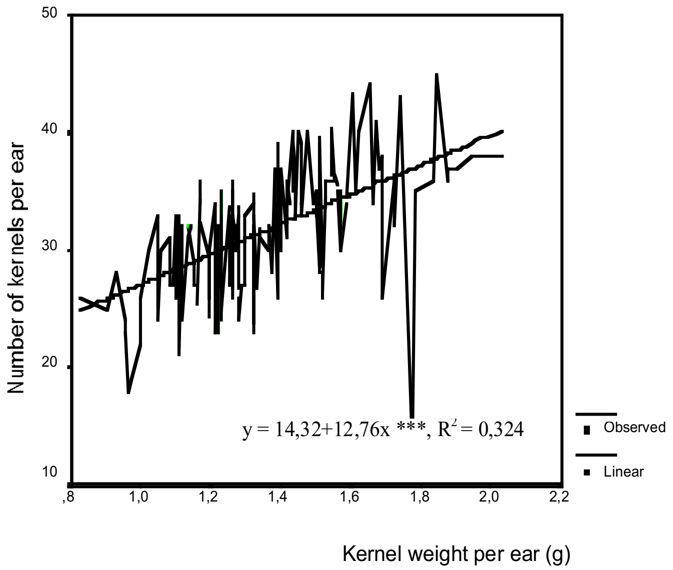

Figure 2: Relationship between kernel number per ear and kernel weight per ear

Abbildung 2: Die Beziehung zwischen der Kornzahl/Ähre und Korngewicht/Ähre

Negative correlations were between number of ears per m^2 and 1000-kernel weight (r = -0,468***) and between number of ears per m^2 and kernel weight per ear (r = -0,398***) (Table 3), where increased number of ears decreased kernel weight per ear (Figure 3) and 1000-kernel weight by linear regression curves (Figure 4). Similar trend was found with the effects of number of kernels per ear on 1000-kernel weight (Figure 5), but 1000-kernel weight increased with increased kernel weight per ear, where the effects were best explained (15 %) by linear curves.

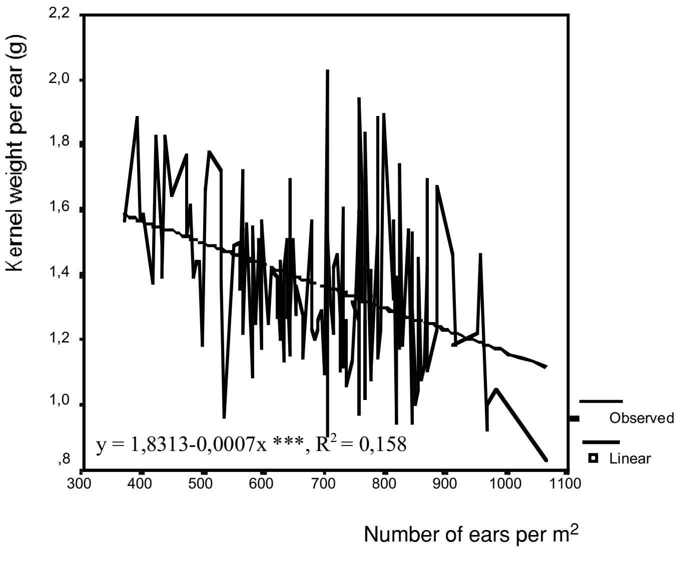

Figure 3: Changes in kernel weight per ear dependent on number of ears per m^2

Abbildung 3: Die Veränderungen des Korngewichtes/Ähre in Abhängigkeit von der Ährenzahl pro m^2

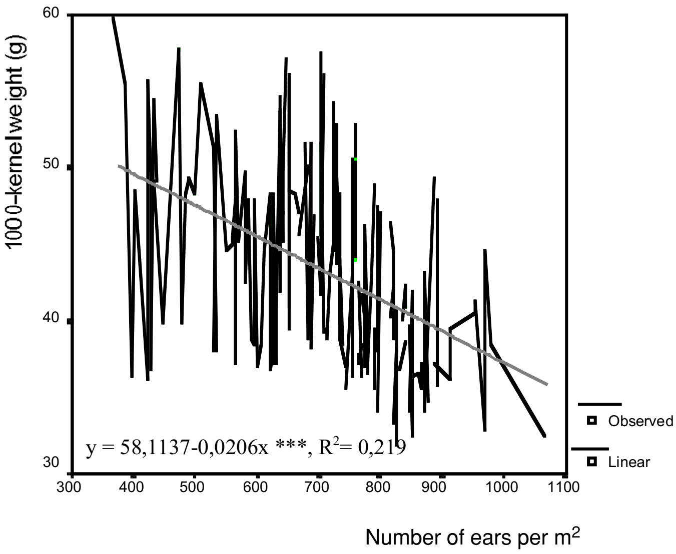

Figure 4: Changes in 1000-kernel weight dependent on number of ears per m^2

Abbildung 4: Die Veränderungen des Tausendkorngewichtes in Abhängigkeit von der Ährenzahl pro m^2

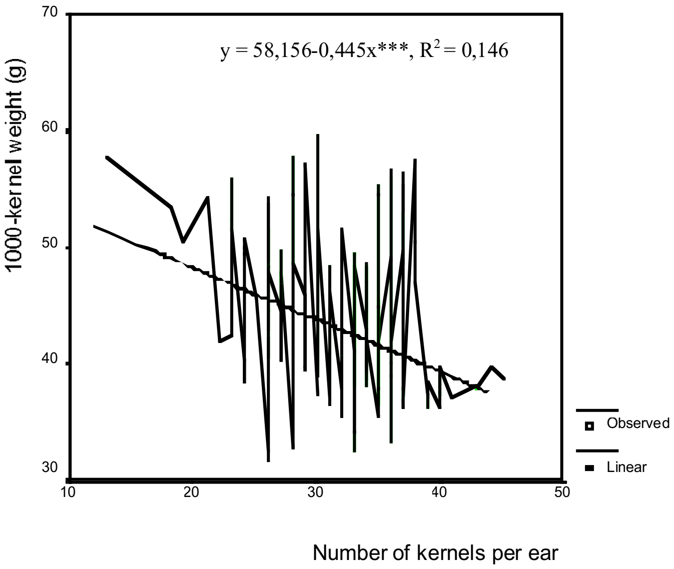

Figure 5: Changes in 1000-kernel weight dependent on kernel number per ear

Abbildung 5: Die Veränderungen des Tausendkorngewichtes in Abhängigkeit von der Kornzahl/Ähre

Significant negative correlation was estimated between grain yield and protein content (r = -0,259**), such as grain yield and test weight (r = -0,170*). Significant positive correlation was noted between protein content and sedimentation value (r = 0,323***).

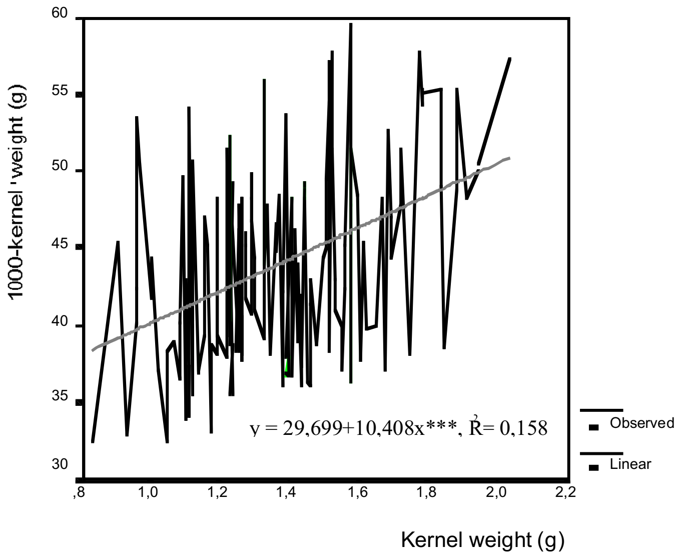

Figure 6: Changes in 1000-kernel weight dependent on kernel weight per ear

Abbildung 6: Die Veränderungen des Tausendkorngewichtes in Abhängigkeit vom Korngewicht/Ähre

4. Discussion

In north-east of Slovenia yield components compensated for the influence of rising seeding rate (350, 500, 650 and 800 seeds per m^2) on yield of different winter wheat cultivars, which was similarly (8,19, 8,33, 8,40 and 8,26 t per ha) independent of seeding rate, because winter wheat grain yield is a result of three yield components (number of ears per unit area, number of kernels per ear and individual kernel weight). Changes of one yield component can be compensated by the others, which results in minimum change of grain yield (BEUERLEIN and LAFEVER, 1989). Just in one out of seven years of experimentation, seeding rate had significant influence on grain yield, when grain yield at seeding rate 350 grains per m^2 (7,32 t per ha) was significantly lower than yields of the other three seeding rates, among them grain yields were not significantly different. Also MARSHALL and OHM (1987) found just in one year of experiments in USA 7,1 % higher yield at seeding rate 538 seeds per m^2 in comparison to 377 seeds per m^2. At early sowing dates in west Croatia seeding rate higher than 550 seeds per m^2 decreased grain yields for 3 to 9 % (PUCARIĆ and JUKIĆ, 1990). In Bavarian conditions (Germany) at optimal sowing date between 9^{th} and 14^{th} of October higher yields gave lower seeding rate (220 and 400 seeds m^2) and yield components showed compensating effects (DENNERT and FISHBECK, 1991). Also in Sweden higher net yield (for 2 %) was achieved at lower seeding rates (350 and 450 seeds per m^2) in comparison to higher seeding rate (ANDERSEN and OLSEN, 1992).

In experimental conditions the trends of grain yields reached plateau at seeding rates 500 and 650 seeds per m^2 (8,33 and 8,40 t per ha^1) and decreased at 800 seeds per m^2 (8,26 t per ha) on the average for all years and cultivars. In England increased plant population increased grain yield to reach plateau (vs. 400 seeds per m^2) and then decreased (LOCK, 1993). Number of ears per unit increased (621, 677, 711 and 760 ears per m^2) with increasing seeding rate (350, 500, 650 and 800 seeds per m^2). Although correlation between grain yield and number of ears per unit was firm (r = 0,597***), grain yield increased only to 650 seeds per m^2, which formed 711 ears per m^2 in average. Negative correlation exists among number of ears and kernels weight per ear (r = -0,398***) and 1000-kernel weight (r = -0,398***). In some cases compensation of yield components is proved by presence of negative correlation among yield components. Similarly in Slovenia, AKANDA and MUNDT (1996) proved great direct influence on grain yield changed yield components. Increasing seeding rate increased number of ears of different winter wheat cultivars in Poland (MAZUREK and PODOLSKA, 1995) and in Sweden (ANDERSEN and OLSEN, 1992) where also early date of sowing increased (31 %) number of ears; the similar results are presented for Germany by WOLLRING (1990), for Ohio in USA by BEUERLEIN and LAFEVER (1989). In Austria more plants were left after the winter in the standard seeding rate (400 seeds per m^2) than in the low seeding rate ones (250 seeds per m^2) and the same regarded the number of ears. There was also a substantial influence of the years and soils (EDER, 1994).

Kernel weight per ear decreased from 1,46 g, 1,39 g, 1,32 g to 1,28 g by increasing seeding rate (350, 500, 650 and 800 seeds per m^2, respectively) on the average for all cultivars and years; in 1995, 1996 and 1997 the influence was not significant, but the similar trend was observed. Kernel weight per ear decreased with increasing seeding rate also in Swedish (ANDERSEN and OLSEN, 1992) and Belgian (BODSON, 1986) conditions.

By increasing seeding rate (350, 500, 650 and 800 seeds per m^2) number of seeds per ear decreased (34, 32, 31 and 30, respectively) on the average for all cultivars and years. Similar trend was observed in 1994, 1995 and 1996, when the influence was not significant. The highest number of kernels per plant was at the lowest seeding rate (450, 600 and 750 seeds per m^2) on the average for 36 cultivars in Poland (MAZUREK and PODOLSKA, 1995). Decreasing number of kernels per ear with increasing seeding rate confirmed KREFT (1988), ELLEN (1990), WOLLRING (1990), ANDERSEN and OLSEN (1992), BEUERLEIN and LAFEVER (1989), BODSON (1986) and others.

Effect of seeding rate (350, 500, 650 and 800 seeds per m^2) on 1000-kernel weight was significant (except in1990 and 1996) and caused decreasing from 45,41 g to 44,2 g, 43,67 g and 42,99 g, respectively. Also in the USA increasing seeding rate (from 167 to 670 seeds per m^2) caused linear decreasing of 1000-kernel weight and number of kernels per ear (BEUERLEIN and LAFEVER, 1989). Decreasing 1000-kernel weight and number of kernels per ear with increasing seeding rate was confirmed in the Netherlands by ELLEN (1990) where negative correlation existed between 1000-kernel weight and number of kernels per ear (r = -0,62***). Between 1000-kernel weight and number of kernels per ear a negative correlation was noted also in Slovenia (r = -0,382**). Higher seeding rates resulted in lower 1000-kernels weight. The same trends were found in results of KREFT (1988), BODSON (1986), WOLLRING (1990) etc. But in the conditions of Sweden, differences in 1000-kernel weight among different seeding rates were not found (ANDERSEN and OLSEN, 1992).

Grain protein content was rather similar with different seeding rates. There is a slight trend of decreasing grain protein content with increasing seeding rate (13,20 %, 13,10 %, 13,01 % and 13,06 % at 350, 500, 650 and 800 seeds per m^2 respectively). Higher protein content was found at lower seeding rate in Poland (KREFT et al. 1989) and in Germany (KURTEN et al., 1982). By increasing seeding rate a trend of slightly decreasing sedimentation value from 45 to 44, 43 and 43 ml was noticed at 350, 500, 650 and 800 seeds per m^2 respectively. Decreasing sedimentation value by increasing seeding rate was found in Poland, too (KREFT et al., 1989). Increasing seeding rate had significant influence on decrease of test weight just in 1989 and 1997. Also in Sweden between 350 and 450 seeds per m^2 there were no differences in the test weight, but at 550 seeds per m^2 the trend showed for 1,5 kg lower test weight (ANDERSEN and OLSEN, 1992).

5. Conclusion

On the base of seven years of investigation it is concluded that less than 500 seeds per m^2 can be recommended for all investigated (spread) winter wheat cultivars under optimal sowing date in Slovenian humid continental area in comparison with official recommended seeding rate from 600 to 800 seeds per m^2.

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