Cereal Research Communications 35(1), pp. 141–149 (2007)
DOI: 10.1556/CRC.35.2007.1.16

Comparison of Different Planting Methods in Relation to Grain Yield of Wheat

D. NOVOSELOVIĆ[1], G. DREZNER, A. LALIĆ, S. GRLJUŠIĆ and J. GUNJAČA[2]

[1]Agricultural Institute Osijek, P.P. 149, HR-31000 Osijek, Croatia
[2]Faculty of Agronomy, University of Zagreb, Svetošimunska cesta 25, HR-10000 Zagreb, Croatia

(Received 23 December 2005; accepted 24 November 2006)

The objective of this paper was to evaluate the adequacy of different methods of planting in small plots and compared with the grain yield rank of wheat genotypes in large plots under different planting densities. Significant differences were found among cultivars, same cultivars under different planting densities, years of testing and planting densities. The estimated values of heritability in narrow sense for grain yield were high and varied from 68 to 99 %, depending on the method of planting and planting density. Comparison of correlation among cultivar's rank between Method 1 (planting with drilling machine) and other Methods (manual planting) revealed that these relationships were dependant upon the year of testing and varied from low to high, positive or negative and from significant to non-significant. The highest correlation was found between Method 1 and Method 3 (20 kernels/hill) in both years of testing. If we wish to test a larger number of genotypes from gene bank collections or advanced lines in early phase of breeding program for grain yield on small plots we can recommend the use of hill plots with planting density as close as possible to those in large plots.

Keywords: winter wheat; genotype; grain yield; planting method; planting density

Introduction

In self-pollinated crops such as wheat (*Triticum aestivum* L.), creation of genetic variability, the methods of handling of generation material, selection and final testing of lines involve much time and resources. Therefore, the search for better and more efficient procedures to develop, select and evaluate genetic material is constant challenge to plant breeders. For maximum efficiency and progress in

* Corresponding author; E-mail: dario.novoselovic@poljinos.hr

breeding for any character, it would be advantageous to carry out selection in as early generation as possible (Whan et al. 1981). Since heritability of grain yield in early generation is low to medium (Sidwell et al. 1978; Peters et al. 1991) breeders are in favor to evaluate a larger number of lines on small plots. The advantage of such approach is that selection intensity can be increased by testing a wide spectrum of advanced lines, thus improving the response to selection. On the other hand, the lack of seeds in early generations imposes the restriction to the size of plots that can be planted. The attractiveness of using small plots lies in the reduced costs of breeding program. Contrary, there are some objections against testing in small plots due to competition effects as well as the problem of residual heterozygosity that might exist (Kramer et al. 1982).

Since there are few papers that compare directly yields of wheat genotypes from small plots to those from yield trials, the study was conducted to evaluate adequacy of certain methods of planting and planting densities in small plots compared with the genotype testing on large plots under different planting densities.

Material and Methods

Plant material

Experimental material included five cultivars of winter wheat: Nevena, Panonija, Srpanjka, Žitarka (Croatian cultivars bred by Agricultural Institute Osijek – Croatia) and Soissons (French cultivar bred by Desprez Veuve et Fils – France).

Experiment

The experiment with five cultivars was carried out as randomized complete block design with four replications during 2001/02 and 2002/03 seasons at location Osijek. Grain yield was scored using four planting methods and five planting densities (Table 1). Seeds were planted either with Hege 80 drilling machine (Method 1) or manually (Methods 2, 3, and 4). In order to avoid border and competition effects, only third row was harvested for Method 2, and two hills per plot were harvested for Methods 3 and 4.

Grain yield was expressed in kg ha^{-1} on 14% moisture content basis for the Method 1; in grams per plot for the Methods 2, 3 and 4.

Data analysis

Data analysis was performed using SAS Software procedures PROC GLM and PROC CORR (SAS Institute Inc. 1999).

Table 1. Description of experiment

	Method 1	Method 2	Method 3	Method 4
Harvest unit	Whole plots	Central row	2 hills/ plot	2 hills/ plot
Planting density	50 kernels m^{-2} 100 kernels m^{-2} 200 kernels m^{-2} 400 kernels m^{-2} 600 kernels m^{-2}	50 kernels m^{-2} 100 kernels m^{-2} 200 kernels m^{-2} 400 kernels m^{-2} 600 kernels m^{-2}	5 kernels/hill 10 kernels/hill 15 kernels/hill 20 kernels/hill 25 kernels/hill	5 kernels/hill 10 kernels/hill 15 kernels/hill 20 kernels/hill 25 kernels/hill
Plot length (m)	7	1.2	1.2	1.2
Number of rows	8	5	5	5
Distance between rows (cm)	13.5	20	20	20
Plot area (m^2)	7.56	1.44	1.44	1.44
Distance between plots (cm)	40	40	40	40
Number of hills/plot	–	–	16	25
Distance between hills within rows (cm)	–	–	60	30

Two different models were employed for data analysis.

First model for testing differences among treatments within method of planting was:

$$Y_{ijkl} = \mu + g_i + d_j + (gd)_{ij} + \gamma_k + (g\gamma)_{\iota\kappa} + (d\gamma)_{jk} + (gd\gamma)_{ijk} + \rho_{kl} + \varepsilon_{ijkl} \quad (1)$$

where μ is general mean, g_i is the effect of i-th genotype, d_j represents the effect of j-th planting density, γ_k is the effect of k-th year of testing, terms in brackets are respective interactions, ρ_{kl} is the effect of l-th replication in k-th year, and ε_{ijkl} values are random errors.

This model, used in ANOVA and Duncan's Multiple Range Test (DMRT) for testing differences among treatments considered replications, years, and all interaction terms involving years as random effects, while everything else was fixed.

Second model used for calculating heritability in narrow sense for individual methods of planting and planting density was:

$$Y_{ijl} = \mu + g_i + \beta_j + (g\beta)_{ij} + \rho_{jl} + \varepsilon_{ijl} \quad (2)$$

where μ is general mean, g_i is the effect of i-th genotype, β_j represents the effect of the j-th environment of testing, $(g\beta)_{ii}$ is the interaction effect of the i-th genotype and the j-th environment, ρ_{jk} is the effect of l-th replication within j-th environment, and ε_{ijl} values are random errors.

For the purpose of heritability estimation, this model was considered as random model, in order to calculate variances for all model effects. Heritability in a narrow sense was estimated using the formula for multi-environment trials given by Singh et al. (1993):

$$h^2 = \frac{\sigma_g^2}{\sigma_g^2 + \sigma_{g\beta}^2 + \sigma_e^2} \quad (3)$$

where σ_g^2 is variance of genotypes, $\sigma 2_{g\beta}$ is variance of interaction between genotype and environment and σ_e^2 is residual variance.

Results and Discussion

ANOVA results revealed that effects of year and planting density were significant irrespective of Method of planting. Differences among cultivars were significant only for the Methods 1 and 3. Interaction effects Year x Planting density and Year × Cultivar were significant only for the Methods 1 and 4. Planting density × Cultivar effect was significant only for the Method 4, while interaction term Year × Planting density x Cultivar was significant only for the Method 1 (Table 2).

Table 2. F values for grain yield under four different methods of planting

Source	df	Method 1	Method 2	Method 3	Method 4
Year	1	1296.95***	39.10***	60.71***	83.71***
Rep (Year)	6	9.59***	5.33***	11.24***	0.90 ns
Planting density	4	374.44***	3.87***	4.54***	4.88***
Cultivar	4	83.84***	0.49 ns	5.14***	1.39 ns
Year × Planting density	4	27.11***	2.22 ns	1.19 ns	2.98*
Year × Cultivar	4	5.02***	0.95 ns	0.75 ns	3.84**
Planting density × Cultivar	16	0.77 ns	1.21 ns	1.32 ns	2.11*
Year x Planting density x Cultivar	16	2.21***	0.76 ns	1.05 ns	0.84 ns

*,**,*** – significant at the level of probability p ≤ 95, 99 and 99.9%
ns – non-significant

The mean values of grain yield for all cultivars, years, methods of planting and planting densities are given in Table 3.

A rather high difference between years was found. Year 2003 was extremely dry which resulted in lower yields as compared to year 2002. In the Method 1, based on two-year average and for all planting densities, the most yielding cultivar was Soissons. The lowest yielding cultivar was Srpanjka. All cultivars significantly increased grain yield by increased planting density. Likewise, it was observed that these differences between years were less expressed at higher planting densities (Table 3).

For manual planting, we observed that all cultivars appear as top-ranked and as bottom-ranked, depending on the applied method of planting and planting density, except cv. Soissons which never appeared as bottom-ranked. For the Method

Table 3. Grain yield of wheat cultivars under different planting methods and densities

Item	Method 1 (kg ha^{-1})				
	50 kernels/m^2	100 kernels/m^2	200 kernels/m^2	400 kernels/m^2	600 kernels/m^2
Soissons	5262$^{B(E)}$	6695$^{A(D)}$	7744$^{A(C)}$	8514$^{A(B)}$	8939$^{A(A)}$
Nevena	5337$^{A(E)}$	6392$^{B(D)}$	7333$^{B(C)}$	7969$^{C(B)}$	8355$^{B(A)}$
Panonija	4711$^{C(E)}$	6009$^{C(D)}$	7215$^{C(C)}$	7994$^{B(B)}$	8348$^{B(A)}$
Srpanjka	3914$^{E(E)}$	4769$^{E(D)}$	6052$^{E(C)}$	6795$^{E(B)}$	6975$^{D(A)}$
Zitarka	4644$^{D(E)}$	5643$^{A(D)}$	6922$^{D(C)}$	7731$^{D(B)}$	7893$^{C(A)}$
Mean for PD	4773^{E}	5901^{D}	7053^{C}	7800^{B}	8102^{A}
2002 year	6422^{A}	7230^{A}	8202^{A}	8769^{A}	8762^{A}
2003 year	3125^{B}	4573^{B}	5905^{B}	6833^{B}	7442^{B}
	Method 2 (g/plot)				
	50 kernels/m^2	100 kernels/m^2	200 kernels/m^2	400 kernels/m^2	600 kernels/m^2
Soissons	122.5$^{A\ B(C)}$	153.5$^{A(BC)}$	158.6$^{A(B)}$	174.1$^{A(AB)}$	191.9$^{AB(A)}$
Nevena	90.4$^{B(B)}$	159.2$^{A(A)}$	154.2$^{A(A)}$	160.4$^{A(A)}$	163.4$^{BC(A)}$
Panonija	102.5$^{AB(A)}$	210.2$^{A(A)}$	154.7$^{A(A)}$	169.2$^{A(A)}$	142.9$^{C(A)}$
Srpanjka	155.1$^{A\ (A)}$	133.3$^{A(A)}$	128.3$^{A(A)}$	139.6$^{A(A)}$	151.0$^{BC(A)}$
Zitarka	114.8$^{AB(B)}$	122.8$^{A(B)}$	139.4$^{A(B)}$	158.1$^{A(B)}$	220.3$^{A(A)}$
Mean for PD	117.1^{B}	155.8^{A}	147.0^{AB}	160.3^{A}	173.9^{A}
2002 year	149.6^{A}	212.1^{A}	174.7^{A}	175.3^{A}	193.4^{A}
2003 year	84.5^{B}	99.6^{B}	119.4^{B}	145.3^{B}	154.4^{B}
	Method 3 (g/plot)				
	5 kernels/hill	10 kernels/hill	15 kernels/hill	20 kernels/hill	25 kernels/hill
Soissons	77.6$^{A(B)}$	76.2$^{A(B)}$	86.1$^{A(B)}$	87.9$^{A(B)}$	113.1$^{A(A)}$
Nevena	59.1$^{B(C)}$	67.6$^{A(ABC)}$	64.7$^{C(BC)}$	88.3$^{A(AB)}$	90.8$^{B(A)}$
Panonija	78.1$^{A(A)}$	79.9$^{A(A)}$	79.5$^{AB(A)}$	70.0$^{A(A)}$	79.7$^{B(A)}$
Srpanjka	66.2$^{AB(A)}$	65.9$^{A(A)}$	70.7$^{BC(A)}$	66.0$^{A(A)}$	77.3$^{B(A)}$
Zitarka	82.1$^{A(A)}$	78.6$^{A(A)}$	78.8$^{AB(A)}$	77.2$^{A(A)}$	85.2$^{B(A)}$
Mean for PD	72.6^{B}	73.6^{B}	76.0^{B}	77.9^{B}	89.2^{A}
2002 year	81.6^{A}	89.5^{A}	86.0^{A}	85.0^{A}	101.9^{A}
2003 year	63.7^{B}	57.8^{B}	65.9^{B}	70.8^{A}	76.6^{B}
	Method 4 (g/plot)				
	5 kernels/hill	10 kernels/hill	15 kernels/hill	20 kernels/hill	25 kernels/hill
Soissons	58.3$^{A(B)}$	70.5$^{A(AB)}$	72.4$^{AB(A)}$	67.1$^{BC(AB)}$	75.3$^{A(A)}$
Nevena	52.5$^{A(B)}$	70.2$^{A(A)}$	78.1$^{A(A)}$	69.1$^{ABC(A)}$	74.4$^{A(A)}$
Panonija	62.7$^{A(BC)}$	75.1$^{A(AB)}$	51.3$^{C(C)}$	80.5$^{A(A)}$	67.7$^{AB(AB)}$
Srpanjka	66.2$^{A(A)}$	70.4$^{A(A)}$	65.6$^{B(A)}$	59.5$^{C(A)}$	58.9$^{B(A)}$
Zitarka	59.3$^{A(B)}$	77.3$^{A(A)}$	68.7$^{AB(AB)}$	78.9$^{AB(A)}$	73.7$^{A(AB)}$
Mean for PD	59.79^{B}	72.7^{A}	67.2^{A}	71.0^{A}	70.0^{A}
2002 year	68.4^{A}	87.8^{A}	72.1^{A}	82.5^{A}	76.9^{A}
2003 year	51.1^{B}	57.6^{B}	62.3^{B}	59.5^{B}	63.0^{B}

^{A,B,C,D,E} – different letters denote significant difference at the level of probability ≤ 95% according to DMRT
(^{A,B,C,D,E}) – letters within brackets denote significant differences within cultivars across different planting densities at the level of probability ≤ 95% according to DMRT
PD – planting density

2 the most yielding cultivars were Srpanjka (50 kernels/m^2), Panonija (100 kernels/m^2), Soissons (200 and 400 kernels/m^2) and Žitarka (600 kernels/m^2). For the Method 3 the most yielding cultivars were Žitarka (5 kernels/hill), Panonija (10 kernels/hill), Soissons (15 and 25 kernels/hill) and Nevena (20 kernels/hill). For Method 4 the most yielding cultivars were Srpanjka (5 kernels/hill), Žitarka (10 kernels/hill), Nevena (15 kernels/hill), Panonija (20 kernels/hill) and Soissons (25 kernels/hill). Significantly lower grain yields were found only under the planting density of 5 kernels/hill (Table 3).

The estimated heritability values (%) for grain yield were medium to high and varied from 68 to 99 %, depending on the method of planting and planting density (Table 4). These values are higher than those previously reported by other authors (Drezner 1996; Novoselović et al. 2004). Such a high values indicated that almost all of the genetic variability between cultivars was fixed to additive and additive*additive components. From the quantitative genetic theory, when we deal with near homozygous material the expected response to selection should not be impeded by the estimates of heritability, but from practical breeding point of view greater attention should be devoted to design and management of experiment in order to get these estimates as precise as possible.

Table 4. Heritability in narrow sense (%) and their standard error estimates for grain yield under different methods of planting and different planting densities

Planting density	Method 1	Method 2	Method 3	Method 4
1*	98 ± 1.0	90 ± 8.0	90 ± 8.8	84 ±13.1
2	98 ± 2.0	93 ± 6.9	85 ±12.1	68 ±28.3
3	99 ± 1.0	84 ±14.3	94 ± 5.1	94 ± 5.7
4	97 ± 2.1	86 ±11.3	89 ± 9.3	92 ± 8.0
5	97 ± 2.1	90 ±10.3	95 ± 4.3	93 ± 5.9

*see section Material and Methods for corresponding planting densities

The results obtained, when we compared ranks among cultivars for grain yield between Method 1, on one side, and other Methods, suggested strong influence of the year on the magnitude and significance of coefficients of correlations (four significant correlations in 2002 year vs. 21 significant correlations in 2003). Second feature of these correlations was that higher values were found between higher densities of the Method 1 and higher planting densities of other Methods (Tables 5, 6 and 7).

None of the correlations between Method 1 and Method 2 were significant in 2002 year. In 2003 year, significant correlation was found with the planting den-

Table 5. Spearman's rank coefficients of correlations (r) between Method 1 and Method 2 for grain yield among tested cultivars

	50 kernels m^{-2}	100 kernels m^{-2}	200 kernels m^{-2}	400 kernels m^{-2}	600 kernels m^{-2}
			2002 year		
50 kernels m^{-2}	–0.70	0.60	–0.20	0.30	–0.30
100 kernels m^{-2}	–0.50	0.50	0.10	0.50	–0.10
200 kernels m^{-2}	–0.50	0.50	0.10	0.50	–0.10
400 kernels m^{-2}	–0.10	–0.10	0.30	0.70	0.50
600 kernels m^{-2}	–0.50	0.50	0.10	0.50	–0.10
			2003 year		
50 kernels m^{-2}	0.10	0.80	0.90	0.90	1.0
100 kernels m^{-2}	0.0	0.90	0.80	1.0	0.90
200 kernels m^{-2}	0.10	0.70	0.50	0.90	0.70
400 kernels m^{-2}	0.10	0.70	0.50	0.90	0.70
600 kernels m^{-2}	0.10	0.70	0.50	0.90	0.70

When r = 0.90 – significant at the level of probability p ≤ 95%

Table 6. Spearman's rank coefficients of correlations (r) between Method 1 and Method 3 for grain yield among tested cultivars

	5 kernels/hill	10 kernels/hill	15 kernels/hill	20 kernels/hill	25 kernels/hill
			2002 year		
50 kernels m^{-2}	–0.40	–0.30	–0.30	0.90	0.80
100 kernels m^{-2}	–0.20	0.0	0.0	0.80	0.90
200 kernels m^{-2}	–0.20	0.0	0.0	0.80	0.90
400 kernels m^{-2}	0.60	0.80	0.80	0.40	0.70
600 kernels m^{-2}	–0.20	0.0	0.0	0.80	0.90
			2003 year		
50 kernels m^{-2}	0.30	0.30	0.30	0.90	0.10
100 kernels m^{-2}	0.10	0.50	0.40	1.0	0.0
200 kernels m^{-2}	0.20	0.80	0.70	0.90	0.10
400 kernels m^{-2}	0.20	0.80	0.70	0.90	0.10
600 kernels m^{-2}	0.20	0.80	0.70	0.90	0.10

When r ≥ 0.90 – significant at the level of probability p ≤ 95%

sity at 400 kernels/m^2 of Method 2. The lowest correlation was found with the lowest planting density (Table 5). When we compare the Method 1 and the Method 3 in 2002 year, the highest correlations were found with planting densities of 20 and 25 kernels/hill. In 2003 year, the best correlation was with 20 kernels/hill (Table 6). In 2002 year, correlation between the Method 1 and the Method 4 were poor. However, in 2003 year similar as with the Method 3, the best correlation was with 20 kernels/hill (Table 7). Poor or non-significant correlation found between ranks of genotypes based on means between single row and large plot trials can be explained by small number (only five) of tested cultivars in ex-

Table 7. Spearman's rank coefficients of correlations (r) between Method 1 and Method 4 for grain yield among tested cultivars

	5 kernels/hill	10 kernels/hill	15 kernels/hill	20 kernels/hill	25 kernels/hill
2002 year					
50 kernels m^{-2}	–0.70	–0.60	0.20	0.10	0.30
100 kernels m^{-2}	–0.50	–0.70	–0.10	0.0	0.40
200 kernels m^{-2}	–0.50	–0.70	–0.10	0.0	0.40
400 kernels m^{-2}	–0.30	–0.10	–0.30	0.40	0.80
600 kernels m^{-2}	–0.50	–0.70	–0.10	0.0	0.40
2003 year					
50 kernels m^{-2}	–0.41	0.50	–0.10	0.70	0.87
100 kernels m^{-2}	–0.31	0.80	–0.50	0.90	0.87
200 kernels m^{-2}	0.10	0.90	–0.60	1.0	0.62
400 kernels m^{-2}	0.10	0.90	–0.60	1.0	0.62
600 kernels m^{-2}	0.10	0.90	–0.60	1.0	0.62

When $r \geq 0.90$ – significant at the level of probability $p \leq 95$ %

periment, soil heterogeneity and genotype by environment interaction. Goldringer et al. (1994) reported non-significant correlation between unadjusted wheat genotype means for six-row plots and single row plot trial. However, in order to improve yield selection in early generation they suggested using plot covariate derived from height difference between neighbours. Contrary, Frey (1965) observed for oat that row plots were more precise for yield estimate than hill plots, but he suggested that early generation testing can be done efficiently with hill plots. Kramer et al. (1982) found that selection efficiency was improved with wide spacing of single row plots in comparison with normal spaced single row plots. In this case, better correlations (Method 1 vs. Method 3) were also found when spacing of hill plots was wider.

Khadr et al. (1970) found that comparison between hill plots and row plots gave equal results, but they accentuated the advantage of lower costs per experimental unit of using hill plots. Ellison et al. (1985) found high genetic correlation ($r = 0.84$) between harvest index in hill plots and total biological yield in large plots at the same site. Due to that reason, they advocated the use of hill plots in advanced stage of wheat breeding program for indirect selection for grain yield by measuring harvest index, suggesting that the response from selection can be increased by 40 % with an initial screening using hill plots, but with recommendation to use multi-location trials. For selection purposes in early generation yield testing Seitzer and Evans (1978) found that number of lines that was better than control was dependant upon the cross rather than the method of planting (hill plots vs. two single rows).

Conclusion

Results of the experiment showed significant differences for grain yield among wheat cultivars, same cultivars under different planting densities, years of testing and planting densities on small and large plots.

The estimated heritability values were medium to high and varied from 68 to 99%.

In general, grain yields of hill plot methods correlated better with grain yields in large plots as compared to single row method. These correlations were highly influenced by the year of testing.

If we wish to test a larger number of genotypes from gene bank collections or advanced lines in early phase of wheat breeding program for grain yield on small plots we can recommend the use of hill plot trials with planting density as close as possible to those in large plots as preliminary step in identifying high-yielding genotypes.

References

Drezner, G. 1996. Selekcija pšenice (*T. aestivum L.*) u ranim generacijama zavisno o kriterijima izbora (Effects of selection in relation to different selection criteria in early generations of wheat). PhD thesis, University of Zagreb, Osijek.

Ellison, F.W., Latter, B.D.H., Anttonen, T. 1985. Optimal regimes of selection for grain yield and harvest index in spring wheat. Euphytica **34**:625–639.

Frey, K.J. 1965. The utility of hill plots in oat research. Euphytica **14**:196–208.

Goldringer, I., Brabant, P., Kempton, R.A. 1994. Adjustment for competition between genotypes of single-row trials of winter wheat (*Triticum aestivum)*. Plant Breed. **112**:294–300.

Khadr, F.H., Kassem, A.A., Elkhishen, A.A. 1970. Hill versus row plot for testing wheat lines. Crop Sci. **10**:449–450.

Kramer, Th., Van Ooijen, J.W., Spitters, C.J.T. 1982. Selection for yield in small plots of spring wheat. Euphytica **31**:549–564.

Novoseloviæ, D., Bariæ, M., Drezner, G., Gunjaèa, J., Laliæ, A. 2004. Quantitative inheritance of some wheat plant traits. Genet. Mol. Biol. **27**(1):92–98.

Peters, B., Spanakakis, A., Weber, W.E. 1991. Efficiency of early selection for yield performance in wheat. Plant Breed. **107**:97–104.

SAS Institute Inc. 1999. SAS/STAT Software, Version 8. SAS Institute, Cary, NC.

Seitzer, J.F., Evans, L.E. 1978. Yield gains in wheat by the pedigree method of selection and two early yield tests. Z. Pflanzenzüchtg. **80**:1–10.

Sidwell, R.J., Smith, E.L., McNew, R.W. 1978. Heritability and genetic advance of selected agronomic traits in a winter cross. Cereal Res. Comm. **6**(2):103–111.

Singh, M., Ceccarelli, S., Hamblin, J. 1993. Estimation of heritability from varietal trials data. Theor. Appl. Genet. **86**:437–441.

Whan, B.R., Rathjen, A.J., Knight, R. 1981. The relation between wheat lines derived from F2, F3, F4 and F5 generations for grain yield and harvest index. Euphytica **30**:419–430.