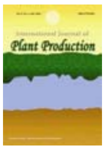

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Adjusting yield components under different levels of N applications in winter wheat

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Abstract

This work presents information on the patterns of yield determination by yield components as a function of the level of management of the crop. The data used for the analyses were obtained from 8 field experiments located across Poland in 2009 and 2010. 25 winter wheat cultivars were evaluated at two management levels, i.e., at a low input of nitrogen fertilisation and pesticides and at a higher input of these materials. Yield determination was evaluated with a path analysis conducted for each cultivar separately for each management level. The results were presented using the values of the path coefficients. The pattern of yield determination for most of the cultivars examined differed between the high-input and the low-input management levels. Under the low-input management, all three yield components contributed similarly to yield determination. Under high-input management, the effect of the number of spikes per m^2 was much greater than the effect of the weight of an individual grain.

Keywords: Grain yield; Winter wheat; Path analysis; Ternary plot.

Introduction

Study on how yield of crops is determined by yield-related traits, including yield components, is important to find the traits that influence yield variability. This information can be important in plant breeding to produce high-yielding genotypes and to optimise crop management. It has been shown that different yield formation strategies exist among wheat (*Triticum aestivum* L. var. *vulgare*) cultivars and these strategies mostly depend on the growing conditions. The most important yield component in the grain yield formation of cereals is usually the number of spikes per square metre (García del Moral et al., 2003; Rozbicki and Mądry, 1998). Differences in yield determination are not only genotypic but also environmental. In the cooler environments of northern Spain, the most influential yield component was mean individual grain weight. In contrast, the number of spikes per square metre was the most important factor in determining grain yield under the warmer conditions of southern Spain. Peltonen-Sanino et al. (2007) show that in the growing conditions found in Finland, the number of grains per unit area (a trait that integrates two main components, the number of spikes per square metre and the number of grains per spike) was the most important yield component in wheat cultivation in fertile environments. The grain yield of winter wheat may be frequently limited by environmental conditions, particularly water supply and temperature during the vegetative season and/or during grain growth and management practices and the most important of these practices is fertilization (García del Moral et al., 2003; Modhej et al., 2006; Peltonen-Sainio et al., 2007). Response and grain yield of various genotypes for environmental conditions (e.g. drought stress) and agronomical practices can be very different between genotypes of different origins (Fleury et al., 2010). Because of that it is important to evaluate wide set of wheat cultivars of different origins to obtain results which are more objective and take into consideration genetic diversity (Estrada-Campuzano et al., 2012).

The Common Catalogue of Varieties of Agricultural Plant Species of EU contain cultivars whose planting is allowed in different countries of the EU, including Poland. Therefore, it is possible to grow cultivars in Poland that originate from breeding companies throughout the EU. It is important to investigate the yield formation patterns of various cultivars planted in Poland.

One of the methods used in the evaluation of the determination of the variability of yield by yield components is classic path analysis (Wright, 1921; Wright, 1923; Wright, 1934) based on multiple regression analysis. This method is very common in agronomic research, especially in the evaluation of the determination of the grain yield of cereals, including wheat (Acreche and Slafer, 2006; Ahmed et al., 2003; García del Moral et al., 2005; Moragues et al., 2006). The principal aim of such research is the evaluation of the effects of three yield components and the evaluation of the associated patterns of yield determination.

The results presented in this work were obtained in a two-year field study with winter wheat under Polish conditions. The principal aim of the study was to assess differences between the patterns of yield determination for two levels of crop management.

Materials and Methods

Under low-and high-input conditions, 25 genotypes of winter wheat in field experiment across Poland were tested over two consecutive years, 2009 and 2010. For the purpose of this study, low-input management (LI) is defined as a lower rate of fertilisation, approximately 100 kg N per hectare (40 kg N at GS 29 + the rest at GS 49), with no fungicide protection against leaf diseases. High-input management (HI) is defined as the intensive wheat production with an additional mineral fertilisation of 40 kg N per ha to achieve the basic rate of approximately 100 kg N per hectare (depending on the locality, the basic rate of N fertilisation ranged from 80 to 134 kg per ha), two fungicide treatments against diseases and spraying against lodging. The data used for the analyses performed in this study were obtained from 8 locations at which post-registration multi-environment trials were conducted by COBORU (Research Centre for Cultivar Testing) with winter wheat in 2009 and 2010. The eight trials were located in the main Polish wheat-producing regions (Mądry et al., 2011). Each field experiment was conducted according to a split-block design with 2 replications. The experimental factors were the cultivar (25 cultivars, Table 1) and the crop management level (2 levels, LI and HI). The total number of experimental units for each combination of cultivar and management level was 32 (8 locations × 2 years × 2 replications). Area of individual plot was 15 m^2. Grain yield and yield components were measured during harvest on the basis of 1 m^2 sample from the middle of the plot. Grain yield, number of spikes and mean weight of individual grain were measured directly while mean number of grain per spike was measured indirectly as a quotient of grain yield and mean weight of an individual grain.

Analysis of variance was conducted to evaluate effects of examined factors on yield and its components.

Table 1. Set of cultivars used in experiment and their origin.

Number	Name of cultivar	Year of registration	Country of origin	Breeding institution
1	Akteur	2007	Germany	Deutsche Saatveredelung AG
2	Alcazar	2006	France	Secobra Recherches
3	Anthus	2006	Germany	KWS Lochow GmbH
4	Bogatka	2004	Poland	DANKO Hodowla Roślin sp. z o.o.
5	Boomer	2006	France	RAGT Seeds Ltd.
6	Figura	2007	Poland	DANKO Hodowla Roślin sp. z o.o.
7	Finezja	2002	Poland	DANKO Hodowla Roślin sp. z o.o.
8	Garantus	2007	France	RAGT 2n
9	Jenga	2008	Germany	Nordsaat Saatzucht GmbH Saatzucht Langenstein
10	Kohelia	2008	Poland	Małopolska Hodowla Roślin-HBP sp. z o.o.
11	Legenda	2005	Poland	Poznańska Hodowla Roślin sp. z o.o.
12	Ludwig	2006	Austria	Saatzucht Donau Ges.m.b.H. & CoKG
13	Markiza	2007	Poland	Hodowla Roślin Strzelce sp. z o.o. Grupa IHAR
14	Meteor	2007	Germany	Lantmännen SW Seed Hadmersleben GmbH
15	Mulan	2008	Germany	Nordsaat Saatzucht GmbH Saatzucht Langenstein
16	Muszelka	2008	Poland	DANKO Hodowla Roślin sp. z o.o.
17	Nadobna	2003	Poland	Poznańska Hodowla Roślin sp. z o.o.
18	Naridana	2006	Poland	Poznańska Hodowla Roślin sp. z o.o.
19	Ostroga	2008	Poland	DANKO Hodowla Roślin sp. z o.o.
20	Rapsodia	2003	France	RAGT 2n
21	Satyna	2004	Poland	Małopolska Hodowla Roślin-HBP sp. z o.o.
22	Smuga	2004	Poland	DANKO Hodowla Roślin sp. z o.o.
23	Tonacja	2001	Poland	Hodowla Roślin Strzelce sp. z o.o. Grupa IHAR
24	Turkis	2006	Germany	Lantmännen SW Seed Hadmersleben GmbH
25	Wydma	2005	Poland	Hodowla Roślin Smolice sp. z o.o. Grupa IHAR

The data for each cultivar were analysed separately with a path analysis, i.e., a multiple regression based on standardised data. The following linear model was used for the analyses:

$$Y = \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon_i$$

Where Y- standardised value of grain yield (in g per m^2);

X_1, X_2 and X_3-standardised values of yield components (i.e., the number of spikes per m^2, mean number of grains per spike and mean weight of an individual grain).

β_1, β_2, β_3-path coefficients, i.e., the partial regression coefficients for standardised data.

The analyses were performed with Statistica 7.1 (StatSoft, 2005), SAS 9.1 (SAS Institute, 2007) and R software (R Development Core Team, 2011).

Results and Discussion

The weather conditions during the two-year field trial are shown in the Figure 1. These weather conditions did not reflect the typical climate of Poland. The primary deviation from average weather conditions during these years is a shortage of rainfall at the beginning of the spring vegetative period of the wheat. The summed annual precipitation in the years of the experiments was 578 mm in 2008/2009 and 769 mm in 2009/2010. The average long-term annual precipitation for all trial locations was 563 mm, similar to the long-term average of 560 mm for Ukraine. These values are much lower than are those occurring in Western Europe, e.g., an average of 796 mm per year in France, 778 mm per year in the Netherlands and 1220 mm per year in the United Kingdom (FAO, 2012). The vegetative season for wheat in Poland is much shorter than the vegetative season in Western or Southern Europe. The shorter vegetative season in Poland is due primarily to the longer winter and lower temperatures (TIAMASG, 2012).

The results obtained in the experiments with winter wheat were affected strongly by the weather conditions. During both seasons, the most influential weather factor was precipitation (Figure 1), which affected grain yield as well as its components. Factors connected with weather and other environmental conditions i.e. year and location had significant effect ($P<0.001$) on grain yield and all components (Table 2).

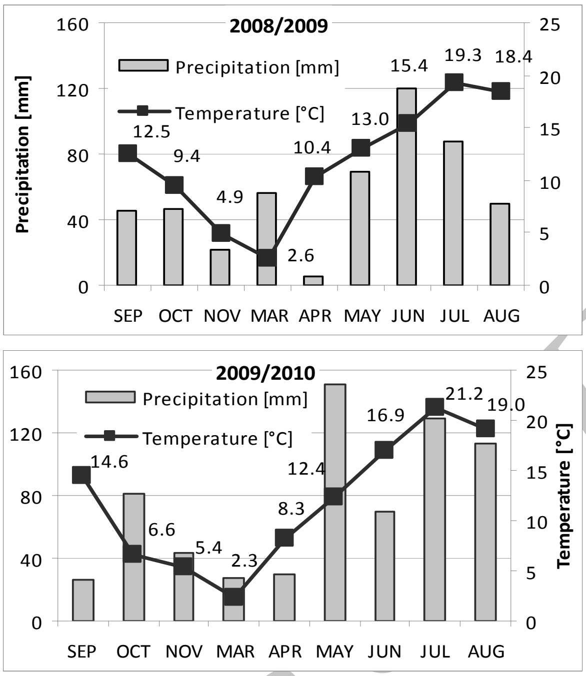


Figure 1. Monthly average of weather conditions for eight locations for two growing seasons.

Table 2. Results of analysis of variance for grain yield and its components.

Source of variation[*]	df	Grain yield	Number of spikes per m^2	Number of grains per spike	Weight of individual grain
		P-values			
Y (year)	1	<0.001	<0.001	0.001	<0.001
L (location)	7	<0.001	<0.001	<0.001	<0.001
Y×L	7	<0.001	<0.001	<0.001	<0.001
I (input level)	1	<0.001	<0.001	0.323	<0.001
I×Y	1	0.702	0.804	0.592	<0.001
I×L	7	<0.001	0.011	0.241	<0.001
I×Y×L	7	<0.001	<0.001	0.203	<0.001
G (genotype)	24	<0.001	<0.001	<0.001	<0.001
G×Y	24	0.028	<0.001	<0.001	<0.001
G×L	168	<0.001	0.049	<0.001	<0.001
G×Y×L	168	<0.001	<0.001	<0.001	<0.001
I×G	24	0.002	0.349	0.009	<0.001
I×G×Y	24	0.967	0.917	0.225	<0.001
I×G×L	168	0.728	0.478	<0.001	<0.001
I×G×Y×L	168	0.218	0.219	0.005	<0.001

[*] Selected sources of variation are presented; effects of blocks and interactions with blocks were omitted.

The mean yield produced by the cultivars planted in all 8 locations differed between the two levels of management practices. High-input management (+40 kg of nitrogen fertilisation and yield protection against fungi) produced a value of grain yield that was almost one tonne per hectare higher than the value produced by low-input management (776 g per m^2 and 680 g per m^2, respectively). The path coefficients were calculated for each cultivar to assess the direct effects of each yield component. Positive relationships were found between grain yield and all three yield components.

The results of the path analysis (Table 3) showed a very strong direct effect of the number of spikes per m^2 on grain yield, a relatively strong effect of the number of grains and a relatively weak effect of the weight of an individual grain for both management levels. These results show that yield variability is determined primarily by the first two yield components, i.e., the number of spikes and the number of grains per spike. The path coefficient analysis revealed that the grain yield under both the low-input and high-input management regimes was determined primarily by the number of spikes per square metre. This yield component predominantly influenced the grain production of winter wheat in Poland. These results are consistent with those of other authors who have compared other cultivars of winter wheat under similar conditions (Okuyama et al., 2004). Although the most important yield component in both treatments was the number of spikes per square metre, differences were found in the strength of the influence of this component on yield. At the low-input management level (LI), the yield contributions from the number of spikes per m^2 and the number of grains per spike were almost equal, with a weaker contribution from the weight of an individual grain. Intensive management practices proved a much more diverse pattern of yield formation. The mean direct effect of the number of spikes per m^2 on yield was stronger in HI than in LI (path coefficients were equal to 0.882 and 0.820, respectively). The effects of the number of grains per spike was stronger in LI than in HI (0.809 and 0.735, respectively). The effect of the weight of an individual grain was much weaker in HI than in LI (0.574 and 0.700, respectively). However, this general statement does not appear to describe the yield formation pattern for all the cultivars tested. Specifically, Cv. Smuga did not follow this general pattern. In this cultivar, the number of grains per spike made the most significant contribution to grain yield. Kozak et al. (2007) found that grain yield in winter triticale in this same region cannot be characterised by any general pattern of influence by the components of yield because the process by which grain yield is determined by its components differs among many winter triticale genotypes, even those with similar structure. This process might be controlled genotypically.

Table 3. Path coefficients (β_i) and coefficients of determination (R^2) for examined cultivars of winter wheat for two management levels.

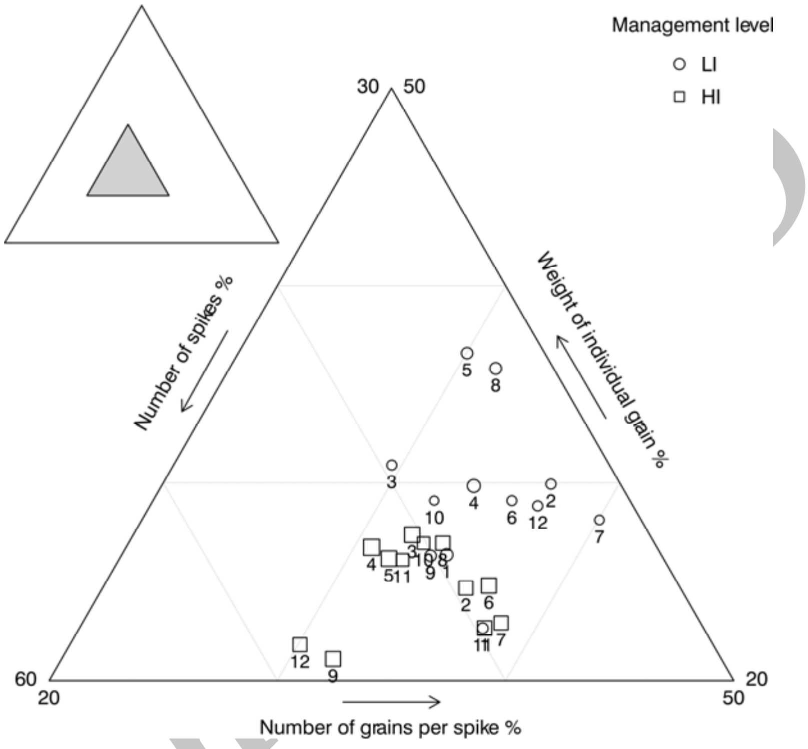
Cultivar	Low-input management level (LI)				High-input management level (HI)			
	(β_1) Number of spikes per m^2	(β_2) Number of grains per spike	(β_3) Weight of individual grain	(R^2) Coefficient of determination	(β_1) Number of spikes per m^2	(β_2) Number of grains per spike	(β_3) Weight of individual grain	(R^2) Coefficient of determination
Akteur	0.720	0.868	0.692	0.980	0.667	0.786	0.648	0.956
Alcazar	0.787	0.765	0.536	0.991	1.016	0.804	0.728	0.983
Anthus	0.851	0.870	0.646	0.940	0.699	0.613	0.540	0.983
Bogatka	0.919	0.798	0.615	0.958	0.825	0.787	0.472	0.971
Boomer	0.850	0.952	0.770	0.973	0.915	0.834	0.573	0.956
Figura	0.857	0.641	0.670	0.987	0.916	0.731	0.621	0.983
Finezja	0.770	0.688	0.757	0.983	1.044	0.839	0.666	0.981
Garantus	0.779	0.615	0.518	0.969	0.914	0.434	0.454	0.990
Jenga	0.895	0.827	0.732	0.960	1.090	0.789	0.685	0.974
Kohelia	0.891	0.801	0.976	0.941	0.911	0.689	0.567	0.976
Legenda	0.746	0.758	0.617	0.993	0.833	0.801	0.539	0.990
Ludwig	0.695	0.875	0.615	0.961	0.763	0.755	0.451	0.987
Markiza	0.976	0.890	0.690	0.965	0.946	0.728	0.567	0.982
Meteor	0.933	0.830	0.745	0.972	0.707	0.726	0.676	0.988
Mulan	0.953	0.928	1.049	0.956	0.891	0.767	0.612	0.979
Muszelka	1.086	0.908	0.712	0.973	0.973	0.660	0.436	0.991
Nadobna	0.607	0.801	0.849	0.976	0.929	0.759	0.708	0.964
Naridana	0.846	0.709	0.639	0.954	0.824	0.676	0.554	0.992
Ostroga	0.847	0.804	0.483	0.961	0.867	0.679	0.546	0.981
Rapsodia	0.786	0.818	0.609	0.969	0.890	0.642	0.609	0.983
Satyna	0.666	0.836	0.818	0.966	0.925	0.870	0.571	0.978
Smuga	0.571	0.763	0.469	0.988	0.620	0.752	0.356	0.985
Tonacja	0.824	0.892	0.696	0.982	1.025	0.641	0.465	0.976
Turkis	0.611	0.705	0.813	0.985	0.850	0.731	0.589	0.985
Wydma	1.033	0.884	0.788	0.985	1.009	0.890	0.714	0.965
Mean	0.820	0.809	0.700	0.971	0.882	0.735	0.574	0.979

Grain yield is affected by all of the environmental conditions (e.g. water availability in soil) influencing the growth of the wheat plant and by the interaction of these conditions with the plant's genetic makeup (Karamanos et al., 2012). Grain yield is also a function of the number of spikes per unit area, the number of grains per spike and the average weight per grain (Poehlman, 1979).

According to Moragues et al. (2006) differences in climatic conditions between northern and southern areas of the Mediterranean basin have produced contrasting patterns of yield formation in genotypes that have evolved in these separate regions. Grain weight was the most important yield component in the north. In the south, yield depended more strongly on the number of spikes per m^2 in genotypes adapted to warmer and dryer conditions.

Sticksel et al. (2000) indicated that the nitrogen supply during the growing season plays an important role in the strategy of yield formation. A low initial nitrogen dose in tandem with high fertilisation during stem elongation regularly produced a high grain yield. Low rates of fertiliser application (70 kg $N{\cdot}ha^{-1}$) in the early spring at stages to GS 32 were associated with the highest values of harvest index. High amounts of fertilisation (100-130 kg $N{\cdot}ha^{-1}$ in early spring to GS 32) resulted in high plant densities, particularly in the tiller categories with grain yield >2 and 1-2 g per spike. In our study, the number of spikes per square metre was significantly higher for the HI level, where the N application rate was higher. The high N status of this level was reflected in the higher survival of tillers with ears. This result is consistent with the findings of Sinclair and Jamieson (2006) and Ye et al. (2011). Triboi et al. (2006) confirmed that if the sink capacity (number of grains) is limited by early drought or high temperature, the duration of grain filling can be shortened. It is also possible that grain yield decreases despite an increase in single-grain dry mass. For a given environment, the genetic yield potential is determined by the production of biomass, especially after anthesis, and its harvest index. Yield improvement can also be achieved by increasing the storage of C and N at anthesis or by decreasing the rate of leaf senescence. An enhanced sink storage capacity could be one possible way to increase grain yield (Triboi et al., 2006).

In this study, differences between different patterns of yield determination for each input level of management were presented graphically with the ternary plot method (Figure 2). For this purpose, only the 12 cultivars of winter wheat most commonly grown in Poland were presented. We can distinguish different patterns of yield determination that depend on the management level. For level LI, the yield effects of the number of spikes per m^2 and of the number of grains were very similar, on average (share of the effects 35.2 and 34.7 %, respectively), whereas the effect of the weight of an individual grain was slightly lower (31.1%). For level HI, the differences between the values of path coefficients for each of the components were more visible. The component that had the highest effect, on average, was the number of spikes per m^2 (share of the effect 40.3%). The number of grains (33.6%) had a weaker effect on yield variability, and the weight of an individual grain had the weakest effect (26.2%).



Point size indicates quantity of grain yield for each cultivar
Cultivars: 1-Bogatka; 2-Boomer; 3-Figura; 4-Jenga; 5-Kohelia; 6-Legenda; 7-Ludwig; 8-Mulan; 9-Muszelka; 10-Naridana; 11-Ostroga; 12-Tonacja

Figure 2. Ternary plot presenting patterns of yield determination by its components for cultivars for two management levels (LI and HI).

Conclusions

A path coefficient analysis revealed that grain yield under both management levels (LI, low-input and HI, high-input) was determined primarily by the number of spikes per square metre.

However, the pattern of yield determination for most of the cultivars examined differed between the high-input management level (HI) and the low-input management level (LI). Under low-input management, all three yield components shared very similarly in the determination of yield. Under high-input management, the effect of the number of spikes per m^2 was much greater than the effect of the weight of an individual grain.

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