NARDI FUNDULEA, ROMANIA ROMANIAN AGRICULTURAL RESEARCH, NO. 33, 2016
www.incda-fundulea.ro Print ISSN 1222-4227; Online ISSN 2067-5720

EFFECT OF RETARDANTS AND NITROGEN FERTILIZATION ON WINTER WHEAT CANOPY STRUCTURE

Elżbieta Harasim, Marian Wesołowski, Cezary Andrzej Kwiatkowski, Rafał Cierpiała

University of Life Sciences in Lublin, Department of Herbology and Plant Cultivation Techniques, 20-950 Lublin, Akademicka 13, Poland. E-mail: elzbieta.harasim@up.lublin.pl

ABSTRACT

This paper presents the results of a study on winter wheat canopy architecture under the conditions of application of several retardants and two levels of nitrogen fertilization on loess soils in the south-eastern region of Poland, in the period 2004-2007. The present study investigated the effect of retardants, adjuvant and nitrogen fertilization rates on canopy architecture traits, such as: number and weight of grains per ear in different canopy layers, percentage of stems of different lengths in the canopy, and percentage contribution of individual canopy height layers to grain yield formation in winter wheat. The number and weight of grains per ear were most differentiated by the retardants Cecefon 465 SL and Antywylegacz Płynny 675 SL. The higher rate of nitrogen (150kg ha^{-1}) and the adjuvant Atpolan 80 EC also had a positive effect on grain number per ear and percentage contribution of the individual height layers of the winter wheat canopy in grain yield formation – especially in the highest canopy level. The retardants Antywylegacz Płynny 675 SL and Cecefon 465 SL increased the percentage of stems belonging to the 70-80 cm and 80-90 cm layers in the canopy as well as the percentage contribution of the above-mentioned layers to grain yield formation. The growth regulator Moddus 250 EC beneficially affected the productivity of stems belonging to the highest canopy layers (80-90 cm and above 90 cm).

Key words: *Triticum aestivum* L., canopy architecture, growth regulators, rate of nitrogen, adjuvant.

INTRODUCTION

The productivity of winter wheat depends, among others, on the yield structure of a single plant and on canopy architecture. Canopy structure is a resultant of the number of plants and ears per unit area, number of spikelets per ear, number of grains per ear, and 1000 grain weight (Bavec and Bavec, 1995). The studies of Kozłowska-Ptaszyńska (1993) and Godin (2000) proved that the canopies of cereals, including winter wheat, have a heterogeneous structure and architecture, i.e. they are composed of plants with different tillering patterns and heights. A proper canopy structure is associated with agronomic treatments, environmental conditions and weather conditions during plant growth (Buck-Sorlin et al., 2008; Chelle et al., 2007). Depending on habitat conditions, wheat plants show varied plant density and number of ears per unit area, different levels of general and productive tillering, stratification of the canopy in terms of the height of main and lateral shoots, as well as varying quantity and quality of yield obtained from individual canopy layers. These variations result from different levels of plant respiration rate, soil moisture content and air humidity, CO_2 concentration, canopy light penetration, and rate of assimilate accumulation (Nalborczyk, 1996; Evers et al., 2005). In the opinion of Gozdowski et al. (2012), a proper spatial structure of the canopy is a condition for high grain yield. By analysing the canopy architecture characteristics, we can forecast the quantity and quality of grain yield in cereals.

Among agronomic factors, fertilization with nitrogen plays a major role in determining yield, because this element has an important role in the synthesis of amino acids, proteins and nucleic acids, increases the rate of tillering in cereals and causes an increase in leaf photosynthetic area, which has a beneficial effect on the use of light energy. A sufficient amount of nitrogen in the soil also positively affects spikelet size and number of spikelets per ear, as well as number of flowers per spikelet. This factor also increases the

Received 24 October 2014; accepted 10 December 2015; First Online: February, 2016. DII 2067-5720 RAR 2016-187

percentage of fertilized flowers (Kubsik, 2000).

The aim of the present study was to determine the winter wheat canopy structure as influenced by three retardants, two levels of nitrogen fertilization, and adjuvant application.

MATERIAL AND METHODS

Plant material and growth conditions

A field study was carried out at the Czesławice Experimental Farm (51030'N; 22026'E), belonging to the University of Life Sciences in Lublin, in the period 2004-2007. It was located on grey-brown podzolic soil (sandy), designated as PWsp, slightly acidic (pH in 1M KCl – 6.3-6.6), with high or very high availability of phosphorus, potassium and magnesium.

The experiment was set up as a split-split-plot design in 3 replicates, in 10 m^2 plots. Its design included treatments without retardant (control treatment) and treatments with the following retardants: Antywylegacz Płynny 675 SL (chlormequat chloride (CC) – 675 g L^{-1}), Moddus 250 EC (trinexapac-ethyl (TE) – 250 g L^{-1}) and Cecefon 465 SL (chlormequat chloride – 310 g L^{-1} + ethephon (E) – 155 g L-1), applied at the recommended rates and at rates reduced by 50 and 67%. The retardants were used at the following growth stages of winter wheat: CC at the 1st node stage (BBCH 31); TE and CC + E at the 2nd node stage (BBCH 32). The growth regulators were applied with the adjuvant Atpolan 80 EC (76% of SN 200 mineral oil) or without adjuvant.

Winter wheat, cv. Muza, was sown after vetch grown for seed. Tillage for wheat was done following good agricultural practices. Before sowing the wheat, phosphorus and potassium fertilizers were applied at the following amounts: 40 kg P ha^{-1} and 110 kg K $ha^{-1.}$ Fertilization with nitrogen as ammonium nitrate and urea was applied at the rates of 100 and 150 kg of nutrient per ha at two times: the 1st dose (60 or 95 kg) at the beginning of plant growth (BBCH 29), whereas the 2nd dose (40 or 55 kg) at the third internode stage (BBCH 33).

The whole experiment was sprayed with the herbicides Apyros 75 WG (sulphonylurea, at a rate of 20 g ha^{-1}) and Starane 250 EC (fluroxypyr 250 g L^{-1}, at a rate of 0.6 L ha^{-1}) at the full tillering stage (BBCH 29-30). The following fungicides were used against fungal diseases: Alert 375 SC (a.i. flusilazole 125 g L^{-1} + carbendazim 250 g L^{-1}) at a rate of 1 L ha^{-1} and Tilt Plus 400 EC (a.i. propiconazole 125 g L^{-1} + fenpropidin 275 g L^{-1}) at a rate of 1 L ha^{-1}. The wheat was sown in the third 10-day period of September at a seeding density of 500 germinating seeds per 1 m^2. Before sowing, seeds were treated with Dividend 030 FS (a.i. difenoconazole 30 g L^{-1}) at a rate of 300 ml of the seed dressing per 100 kg of seed.

The following components of the winter wheat canopy architecture were determined:

– percentage of stems of different lengths in the canopy;

– productivity of ears from different canopy layers expressed by number of grains per ear;

– productivity of ears from different canopy layers expressed by grain weight per ear;

– percentage contribution of individual canopy height layers to grain yield formation.

The canopy architecture was analyzed based on a sample of plants collected at the fully ripe stage from three 1m long rows in each plot (plants were collected from the middle of each row, rejecting plants on the edge of the row). Individual plants were divided into single stems and, depending on their height; stems were included in one of the following five layers:

I. shoots less than 60 cm in height;
II. from 60 to 70 cm;
III. from 70 to 80 cm;
IV. from 80 to 90 cm;
V. more than 90 cm.

Statistical analysis

The study results were statistically analyzed by analysis of variance, while the differences between means were evaluated by Tukey's test at a significance level of α=0.05. The statistical analysis was presented using Statgraphics 5.0 software.

Weather conditions at the study site

The growing seasons in the period 2004-2007 varied in rainfall intensity and distribution as well as in temperature compared to the long-term means (Table 1). The first season (2004/2005) was very warm and wet, in particular during the spring and summer growth period. In the second season (2005/2006), adverse soil moisture conditions prevailed at the time of sowing and at the beginning of autumn growth of winter wheat. It was only in December that there was abundant precipitation (55.7 mm) that replenished soil water reserves. During the season in question, the winter was exceptionally cold. Except for December, the average temperature was lower by 4.7°C than the long-term mean in January and by 1.9°C in February. The last year of the study (2006/2007) was considered to be dry. Compared to the long-term mean, the amount of precipitation was lower by 54.8 mm. On the other hand, the mean temperature for the whole growing season was higher by 2.4°C compared to the long-term mean.

Table 1. Temperature (°C) and rainfall (mm) during the vegetation seasons of winter wheat

Months	Years						Mean of years (1951-2005)	
	2004/2005		2005/2006		2006/2007			
	mm	°C	mm	°C	mm	°C	mm	°C
IX	21.1	12.5	23.1	14.7	10.1	15.1	51.6	12.6
X	26.1	9.8	4.2	8.7	31.0	9.8	40.1	7.8
XI	65.5	2.8	24.6	2.7	43.7	4.7	38.1	2.5
XII	15.8	1.1	55.7	-1.3	22.7	2.5	31.5	-1.4
I	34.8	-0.7	16.1	-8.2	83.7	2.0	22.7	-3.5
II	35.4	-4.0	24.4	-4.6	23.8	-2.0	25.6	-2.7
III	42.2	-1.1	47.4	-2.0	32.6	5.7	26.3	1.1
IV	21.2	8.4	26.1	8.5	16.4	8.2	40.2	7.4
V	146.9	13.0	68.1	13.3	46.4	14.9	57.7	13.0
VI	48.0	15.6	23.2	16.9	85.1	18.2	65.7	16.2
VII	55.8	19.8	26.6	21.1	70.0	18.8	83.5	17.8
VIII	46.2	17.0	202.5	17.4	31.4	18.8	68.6	17.1
Total / Average	559.0	7.8	542.0	5.8	496.9	9.7	551.7	7.3

RESULTS

Percentage of stems of different lengths in the winter wheat canopy

Figure 1 shows that on average, over all the applied retardants and levels of nitrogen fertilization, stems with a length from 80 to 90 cm contributed to the formation of the winter wheat canopy in 39.0%, whereas stems belonging the layer above 90 cm in 25.4%. The 70-80 cm layer was also characterized by a high contribution of its stems to canopy formation, since their percentage contribution was as much as 24.2%. The percentage contribution of the lowest canopy layers to canopy formation did not exceed 12% – for the lowest layer (less than 60 cm) it was only 3.1%. A similar situation was also found with respect to the compared levels of nitrogen fertilization, with the difference that at the lower rate of nitrogen the 70-80 cm and 80-90 cm layers dominated, producing in total 64.1% of all stems, while at the higher nitrogen rate most stems belonged to the layers of 80-90 cm and above 90 cm (in total 69.3%).

Plant height in the control plots (without retardants) was the highest and the average in three years of study was 93.0 cm. Among retardants used in the experiment the length of the stem of the winter wheat most by as much as 13.6 cm shortened Cecefon (mean 79.4 cm), then Antywylegacz Płynny (mean 81.4 cm) and least Moddus 250 EC (an average of

84.2 cm). In the case of two out of the three growth regulators used, stems from the 70-80 cm and 80-90 cm layers also played the dominant role in canopy formation. When Antywylegacz Płynny 675 SL and Cecefon 465 SL were applied, 73.5% and 71.4% of stems belonged to the above-mentioned layers. In the treatments with the retardant Moddus 250 EC, it was found that 71.9% of stems belonged to the two highest layers (80-90 cm and above 90 cm).

The applied adjuvant Atpolan 80 EC reduced the percentage of stems belonging to the highest layer (above 90 cm) from 30.7 to 20.1%. In the case of the lowest layers, this agent caused an opposite response, since the numbers of stems from the first group were found to increase by 4% under its influence, while for the second group of stems this increase was 7.4%. In the case of the other layers, this adjuvant did not contribute to numerical differences.

The analysis of the winter wheat canopy structure in the control treatment showed that the highest layers: 80-90 cm and above 90 cm, by far predominated (Figure 1).

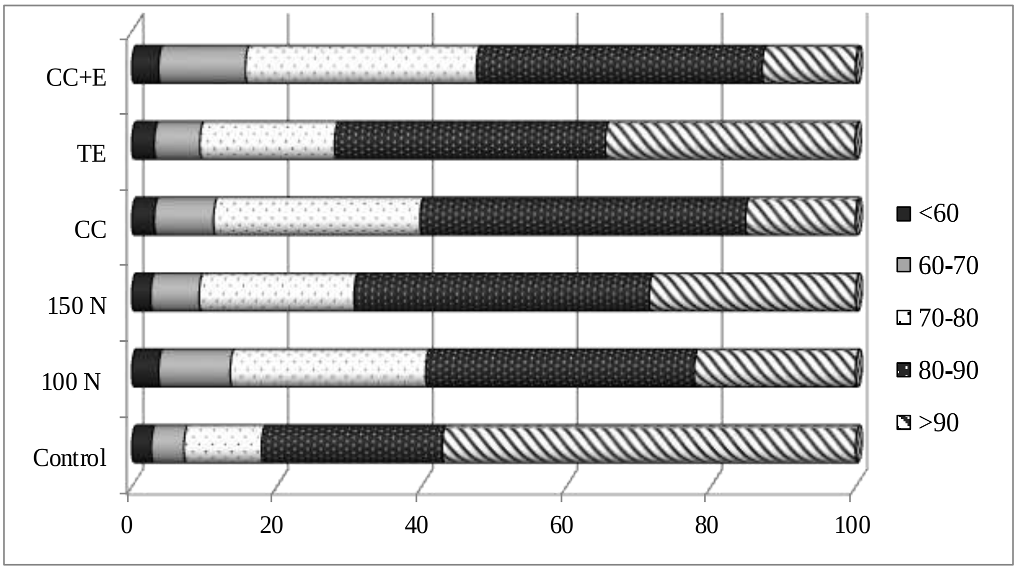

Figure 1. The share of various stem lengths in winter wheat canopy (%).
Mean of 3 years

Percentage contribution of individual canopy height layers to grain yield formation in winter wheat

Under the conditions of the present experiment, the winter wheat canopy should be considered to have been even (Figure 2). This is evidenced by the fact that the two highest layers distinctly dominated, as they accounted together for 73.2% of the total grain yield; the layer with stems 80-90 cm long accounted for 42.3%, whereas the layer with stems above 90 cm for 30.9%. Stems belonging to the lower layers contributed to the wheat grain yield in 26.8%, but the percentage contribution of the lowest layer (below 60 cm) was only 0.8% of the total grain yield. The application of the growth regulators in the present experiment resulted in a similar distribution of winter wheat grain yield. In the treatments with Antywylegacz Płynny 675 SL and Cecefon 465 SL, the 80-90 cm and 70-80 cm layers were the major contributors to yield formation. On the other hand, stems belonging to the layers above 90 cm and 80-90 cm predominated in the formation of grain yield in the treatments with the growth regulator Moddus 250 EC. They accounted for as much as 82% of the total grain yield. As far as the level of nitrogen fertilization is concerned, stems belonging to the two highest layers of the canopy were found to have the greatest contribution to the total grain yield. A similar situation was also observed under the influence of the adjuvant Atpolan 80 EC used in the experiment (Figure 2).

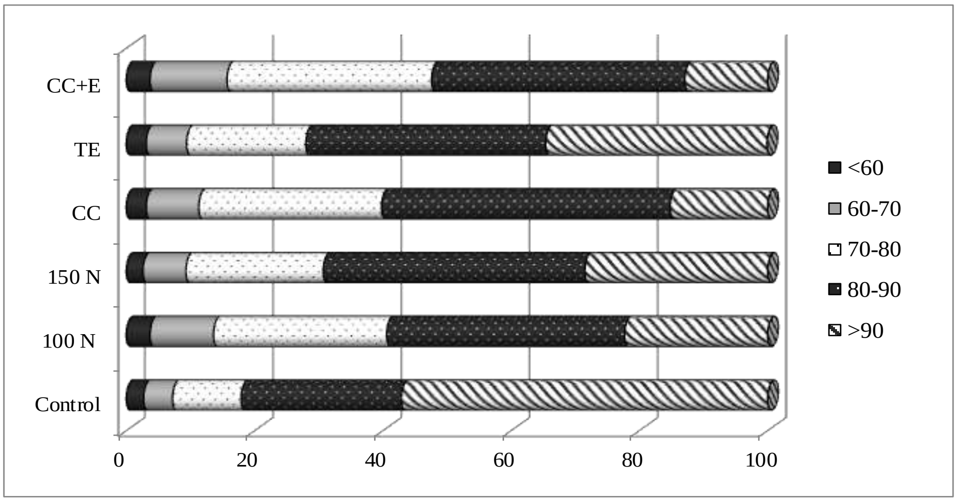

Figure 2. The share of canopy layers in forming grain yield of winter wheat (%). Mean of 3 years

Number of grains per ear in different layers of the winter wheat canopy

On average, regardless of the type and rates of retardants, as well as irrespective of the levels of nitrogen fertilization and adjuvant application, winter wheat plants belonging to the highest canopy layer (above 90 cm) produced the highest number of grains per ear (39.7 grains) (Figure 3). The lower layers were characterized by lower grain number per ear, but the value of this trait decreased gradually. It reached an average number of 36.6 grains per ear in the 80-90 cm layer, in the case of the 70-80 cm and 60-70 cm layers this number was, respectively, 29.1 and 20.5 grains per ear, while under the conditions of the lowest (below 60 cm) layer it was only 12.0 grains per ear. A similar trend in grain number per ear was observed when the growth regulators used in the experiment were compared. However, a significantly higher average number of grains (by 12.1%), compared to the control treatment, was obtained only after the application of the retardant Cecefon 465 SL. Antywylegacz Płynny 675 SL increased grain number per ear by 6.8% relative to the control treatment, but this difference was within the error margin. On the other hand, the retardant Modus 250 EC produced a similar effect to that of the control treatment. The higher rate of nitrogen (150 kg ha^{-1}) and the applied adjuvant Atpolan 80 EC had a more beneficial effect on number of grains per ear. These factors increased grain number per ear when wheat plants belonged to the highest canopy layers.

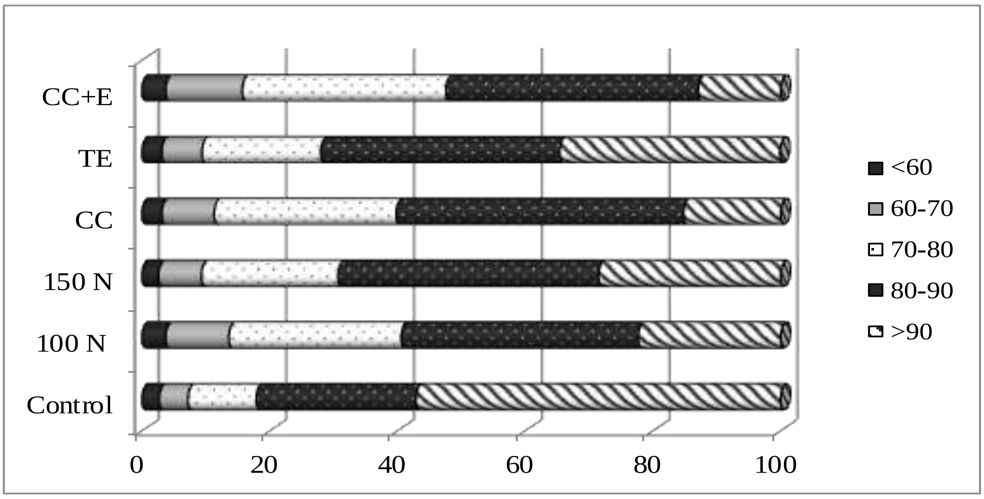

Figure 3. Number of grains per ear in different layers of the winter wheat canopy. Mean of 3 years (*LSD*$_{(0.05)}$ for years = n.s.; retardants = 2.82; canopy levels =1.70; N dose = n.s.; adiuvant = 0.76)

Grain weight per ear in different layers of the winter wheat canopy

The situation in the case of grain weight per ear was similar to grain number per ear. This means that this trait had the highest values under the conditions of the layer above 90 cm and significantly decreased with a reduction in winter wheat plant height (Figure 4). The difference between the highest and lowest layer was as much as 78.5%. As regards the growth regulators used in the experiment, a significant increase in the weight of grains per ear, relative to the treatment without retardant (0.97 g), was only found in the treatment with Cecefon 465 SL – 1.10 g. Antywylegacz Płynny 675 SL caused an increase in grain weight on the margin of significance – 1.04 g, whereas the retardant Moddus 250 EC slightly reduced the average grain weight per ear relative to the control treatment.

At both levels of nitrogen fertilization, a similar grain weight per ear was found and therefore this difference was not significant. On average, this value was 1.01 g. In the case of each retardant at all the rates, the highest grain weight per ear was obtained for the two highest layers of the canopy. A similar situation was found in the treatment with and without adjuvant (Figure 4).

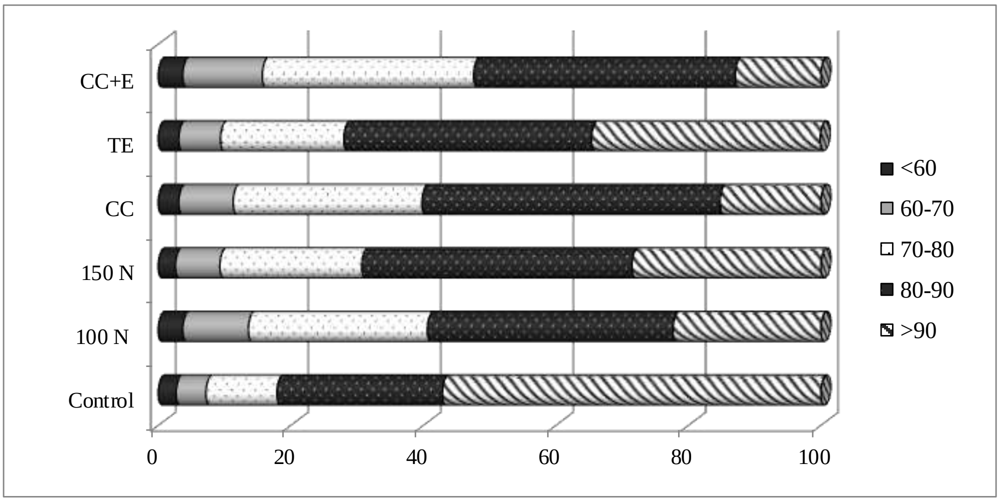

Figure 4. Grain weight per ear in different layers of the winter wheat canopy (g). Mean of 3 years
($LSD_{(0.05)}$) for: years = 0.030; retardants = 0.111; canopy levels = 0.067; N dose = n.s.; adiuvant = 0.030)

DISCUSSION

Cereal crop canopies are characterized by intra-field variation in the spatial structure parameters as well as in final yield and its components (Wyszyński and Michalska, 2007). The studies of Kozłowska-Ptaszyńska (1991) and Gozdowski et al. (2012) showed that spring barley grain yield was determined by canopy evenness, i.e. the occurrence of plants with a similar height of ear-bearing shoots and a similar number of productive shoots. The present study on the canopy architecture of the winter wheat cultivar ‘Muza’ proved that in the experiment under discussion the two highest layers dominated, since they accounted for 73.2% of all stems; it was 42.3% in the case of the layer with a stem length of 80-90 cm, whereas for the highest layer (above 90 cm) – 30.9%. The method of application of nitrogen fertilizers causes changes in winter wheat canopy architecture (Drouet, 2007). The research of Podolska (2004) demonstrated that winter wheat fertilized at tillering as well as at stem elongation or heading produces the largest number of high and medium stems. In the present study, a predominance of the highest layers was found at both levels of nitrogen fertilization, but with the difference that in the treatment fertilized with the higher nitrogen rate (150 kg ha^{-1}) the percentage of stems belonging to the two highest layers was 77.5%, whereas in the plots with the lower rate (100 kg ha^{-1}) it was 69%. The dominance of the longest stems in the crop canopy was also confirmed by the results of the investigation of the productivity of ears from the individual canopy layers and subsequently the contribution of these layers to the formation of winter wheat grain yield. On average, regardless of the experimental factors, stems with a height of more than 90 cm contributed to the winter wheat grain yield in 25.4%, whereas stems with a length of 80-90 cm in 39%. The 70-80 cm layer also had a significant proportion in the total grain yield (24.2%). A similar situation was found in the case of the compared levels of nitrogen fertilization and in the treatments with adjuvant, since stems from the three highest canopy layers were of key importance in the formation of the total grain yield of winter wheat.

The number and weight of grains per ear showed the highest values for the highest layer. The values of these traits significantly decreased with a reduction in the height of the canopy layers. The higher rate of nitrogen (150 kg ha^{-1}) and the applied adjuvant Atpolan 80 EC had a more beneficial effect on grain number per ear. The higher were winter wheat plants, the more these experimental factors increased grain yield per ear. The weight of grains per ear was similar at both fertilization levels and hence these values did not differ statistically. Referring the results of the present study to the literature data, it should be noted that they confirmed the information of other authors, according to whom ears from shoots in the highest canopy height classes play a key role in yield formation, irrespective of the plant model (single-shoot, two-shoot or natural plants) and plant density per unit area (Podolska and Mazurek, 199; Sułek, 2001; Evers, 2005). In one of her studies, Podolska (1998) proved that the canopy architecture of winter wheat depended on soil quality and seeding density. At a density of 450 plants per 1 m^2, the largest amount of high plants of the winter wheat cultivar 'Kamila' was found on soils classified as very good wheat soil complex (black earth), good wheat soil complex (brown alluvial soil and brown soil derived from loess), and very good rye soil complex (typical brown soil). On medium soils (the following soil complexes: defective wheat soil complex – rendzina soil; good rye soil complex – typical brown soil; and poor rye soil complex – acid brown soil), the number of high plants was definitely lower, while this number was the lowest in the case of very poor rye soil complex derived from acid brown soils. The highest percentage of low plants was found on the poorest soil. In the opinion of the above cited author, an increase in plant density from 600 to 750 plants per 1 m^2 resulted in an increased frequency of low plants, but only on the best soils. On the poorest soils, an increase in the density of winter wheat plants caused an opposite effect, that is, a reduced occurrence of low plants in the canopy in favour of high plants. In the opinion of this author, the grain yield per ear changed depending on soil, plant density, plant height and type. Shortened stems of winter wheat were always characterized by lower productivity, which was expressed by a lower number of spikelets per ear as well as by lower grain number and weight per ear.

The studies of Hotsonyame (1997), as well as of Podolska and Mazurek (1999), proved that adverse changes in the canopy architecture of various winter wheat cultivars were caused by delayed sowing time. The shifting of sowing time from the third 10-day period of September to the first or second 10-day period of October resulted in a shortening of the length of main and lateral shoots of plants and increased the percentage of low plants in the canopy, characterized by lower ear productivity in relation to longer stems. In turn, Kozłowska-Ptaszyńska (1993) and Conry (1998) did not find different sowing times to have an effect on grain yield of cereal plants. According to these authors, this trait was determined by the properties of the genotype.

In the opinion of Bos and Neuteboom (1998) as well as Doroszewski (1999), winter wheat canopy architecture is shaped by environmental conditions, which are modified to a varying degree by agronomic factors. Plant habit is determined, among others, by the availability of water, nutrients and solar radiation. According to Podolska (1995), the reason for lower productivity of shorter winter wheat stems is the fact that such shoots are more shaded in the canopy by high plants growing next to them and due to this the amount of light falling per unit area of leaf is lower in these shoots. Such a situation causes adverse changes in plant morphogenesis, which are manifested in a reduced number of grains per spikelet and per ear. In the opinion of Evers et al. (2010), lower productivity of shorter stems is also associated with their lower accumulation of products of photosynthesis to be used in seeds being formed. The research showed that a high yield of winter wheat can be expected from a plantation with an even canopy height and proper ear density per unit area. An important role is also attributed to nitrogen fertilization, since it contributes to increase productive tillering and thereby to an increase in the number and weight of grains per ear.

CONCLUSIONS

From the present investigation the following conclusions may be drawn:

(a) The winter wheat canopy architecture was determined by all experimental factors. The retardants Antywylegacz Płynny 675 SL and Cecefon 465 SL increased the percentage of stems belonging to the 70-80 cm and 80-90 cm layers in the canopy as well as the percentage contribution of the above-mentioned layers to grain yield formation. The growth regulator Moddus 250 EC beneficially affected the productivity of stems belonging to the highest canopy layers (80-90 cm and above 90 cm);

(b) The highest ear productivity, expressed in grain number and weight, was obtained after the application of the retardant Cecefon 465 SL. Antywylegacz Płynny 675 SL increased the number and weight of grains per ear to a small extent, while Moddus 250 EC slightly decreased grain weight per ear relative to the control treatment;

(c) The higher nitrogen rate (150 kg ha^{-1}), in combination with the adjuvant, increased grain number per ear and percentage contribution of the individual height layers of the winter wheat canopy in grain yield formation – the higher was the canopy layer to which plants belonged, the higher was the increase.

Acknowledgement

Research supported by the Ministry of Science and Higher Education of Poland as part of the statutory activities of the Department of Herbology and Plant Cultivation Techniques, University of Life Sciences in Lublin.

REFERENCES

Bavec, N., Bavec, F. 1995. *The effect of winter wheat (Triticum aestivum L.) plant density on the field and its components.* Fragm. Agron., 2 (46): 136-137.

Bos, H.J, Neuteboom, J. H. 1998b. *Morphological analysis and tiller number dynamics of wheat (Triticum aestivum L.): responses to temperature and light intensity*. Ann. Bot., 81: 131-139.

Buck-Sorlin, G., Hemmerling, R., Kniemeyer, O., Burema, B., Kurth, W., 2008. *A rule-based model of barley morphogenesis, with special respect to shading and gibberellic acid signal transduction.* Ann. Bot., 101: 1109-1123.

Chelle, M., Evers, J. B, Combes, D., Varlet-Grancher, C., Vos, J., Andrieu, B., 2007. *Simulation of the three-dimensional distribution of the red:far-red ratio within crop canopies*. New Phytol., 176: 223-234. http://dx.doi.org/10.1111/j.1469-8137.2007.02161.x

Conry, M., 1998. *Influence of seed rate and sowing date on the field and grain quality of Blenheim spring malting barley in the south-east of Ireland*. J. Agric. Sci., 130: 307-315.

Doroszewski, A., 1999. *Control of winter wheat by reflected radiation*. Pam. Puł., 118: 121-130.

Drouet, J-L., Page`s, L., 2007. *GRAAL-CN: A model of growth, architecture and allocation for carbon and nitrogen dynamics within whole plants formalised at the organ level*. Ecol. Model., 206: 231-249.

Evers, J.B., Vos, J., Fournier, C., Andrieu, B., Chelle, M., Struik, P.C., 2005. *Towards a generic architectural model of tillering in Gramineae, as exemplified by spring wheat (Triticum aestivum).* New Phytol., 166: 801-812.

Evers, J.B., Vos, J., Yin, X., Romero, P., van der Putten, P.E.L., Struik, P.C., 2010. *Simulation of wheat growth and development based on organ-level photosynthesis and assimilate allocation*. J. Exp. Bot., 61(8): 2203-2216. http://dx.doi.org/10.1093/jxb/erq025

Godin, C., 2000. *Representing and encoding plant architecture: a review*. Ann., Forest Sci., 57: 413-438. http://dx.doi.org/10.1051/forest:2000132

Gozdowski, D., Wyszyński, Z., Kalinowska-Zdun, M., Pągowski, K., Pietkiewicz, S., 2012. *Variability of spatial formation of spring barley canopy in different environmental and growing conditions. Part. II. Canopy architecture*. Fragm. Agron., 29 (3): 20-30.

Hotsonyame, G. K, Hunt, L. A., 1997. *Effects of sowing date, photoperiod and nitrogen on variation in main culm leaf dimensions in field-grown wheat.* Can. J. Plant Sci., 78: 35-49.

Kozłowska-Ptaszyńska, Z., 1993. *Changes in the structure and architecture of plant canopy of two- and six-rowed spring barley cultivars as influence by seeding date*. Pam. Puł., 102: 53-63.

Kozłowska-Ptaszyńska, Z., 1991. *The structure and architecture of spring wheat canopy depending on the technology of cultivation*. IUNG Puławy, R (288): 13-33.

Kubsik, K., 2000. *Production and economic evaluation of nitrogen application techniques in winter wheat and spring barley*. Fragm. Agron., 1 (65): 98-107.

Nalborczyk, E., 1996. *Selection and use of modern control equipment for field experiments. Part I. Measurement of gas exchange, spatial structure and energy balance of photosynthetically active radiation in crop canopy.* Zesz. Probl. Post. Nauk Roln., 447: 81-90.

Podolska, G., 1995. *The study on the winter wheat canopy architecture*. Biul. IHAR, 194: 99-113.

Podolska, G., 1998. *Productivity and canopy architecture of winter wheat depending on soil condition and plant density*. Roczniki AR Poznań, 52: 67-76.

Podolska, G., 2004. *Effectiveness of agricultural practices in exploitation of the potential of winter wheat yielding*. Biul. IHAR, 231: 55-64.

Podolska, G., Mazurek, J., 1999. *Plant model and canopy architecture of winter wheat under different sowing terms and methods of nitrogen application. II. Yielding, field components and canopy architecture*. Pam. Puł., 118: 491-505.

Sułek, A., 2001. *The effect of sowing density on canopy architecture of spring wheat cv. Sigma grown on various soils*. Biul. IHAR, 220: 69-79.

Wyszyński, Z., Michalska, B., 2007. *Variability of soil parameters, Fielding on spring wheat and spring barley production plantations*. Fragm. Agron., 1 (93): 269-277.