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Interaction Between Nitrogen and Chemical Plant Protection in Yield Formation of Cereal Crops

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1. Introduction

Plant productivity is a result of an effect of yield promoting and yield protecting factors. The first group of the factors determines process of yield formation, including dry matter accumulation (plant growth) and differentiation of generative organs (plant development). The other group of the factors stabilizes previously created yield and protects it against reduction. Both groups of factors are influenced by weather conditions.

Among yield promoting factors nitrogen fertilization is the most important one. Nitrogen significantly increases grain yield by the influence on yield components formation at the course of plant development. The relationships are well described in the literature (Fotyma & Fotyma, 1993; Mazurek, 1999; Spiertz & Vos, 1983; Wyszyński et al., 2007). At early plant development stages nitrogen stimulates tillering process and therefore determines potential spike number per unit area and decides about final number of spikelets per spike. At stem elongation stage nitrogen protects a plant against excessive reduction of tillers and spikelets, which means that nitrogen enables big number of grains per spike. In the period before anthesis, nitrogen stimulates the effectiveness of assimilation of organs and production of biomass, which subsequently, at the grain filling stage participates in the photosynthesis process (Bertholdssson, 1999; Przulj & Momcilovic, 2001). During maturity, nitrogen affects grain quality. Restriction of N supply at any development stage can reduce grain yield by up to 65% (Zhao et al., 2009).

Despite nitrogen fertilization is the most important grain yield creating factor, the maximization of grain yield is possible only under conditions of a proper plant protection against fungal diseases. Plant protection is usually aimed at increasing the resistance to these diseases and to combat the already active pathogens. For these aims, specific programs are recommended to producers. However, the precedent purpose of the protection against fungal diseases is to preserve the yield against reduction and its stabilization (Pruszyński, 2002). In unprotected canopies fungal diseases reduce wheat potential yield by 45% on average and the losses may reach even 70% (Perrenoud, 1990; Podolska et al., 2004). Chemical protection measures extend plant green area and the duration of photosynthetic activity (Dimmok & Gooding, 2002; Ruiter & Brooking, 1996) and stimulate effects of grain yield promoting factors. The efficiency of the protection is related to the pattern of weather conditions, which simultaneously influences plant infestation by pathogens (Nowak et al., 2005). Higher precipitation, besides nitrogen fertilization and crop yields, usually favors also development of the fungal pathogens (McMullen, 2003). Deficit of precipitation restricts their development, and therefore the effect of chemical plant protection measures on grain yield is smaller (Brzozowska et al., 1996).

For best possible nitrogen utilization, all diseases should be avoided (Goulding, 2000). However, nitrogen fertilization increases the susceptibility of plants to fungal infections, and therefore the interaction between weather, nitrogen and plant protection strategy can be expected. The purpose of the study was to quantify this interaction in the production of four cereal crops: winter wheat, spring barley, winter triticale and oat under conditions of differentiated nitrogen fertilization rate.

2. Material and methods

2.1 Field site and management

The study was performed on the basis of a long term experiment in Grabów Experimental Station (E 21° 39′, N 51° 21′) of the Institute of Soil Science and Plant Cultivation in Puławy, Poland in 2004-2007. The experiment was located on a highly heterogenous soil that was classified partly as stagnic luvisol and partly as pseudo podzolic. Average soil reaction was slightly acid.

Four cereal crops winter wheat, spring barley, winter triticale and oat were grown in four-course crop rotation. The first experimental factor was the strategy of chemical plant protection against fungal diseases proposed by three companies: A, B and C and the control treatment without any protection.

Plant protection strategies differ in the selection of biologically active ingredients of the fungicides (tab. 1). However, the strategies differentiate neither the level of plant infestation by pathogens nor the grain yield of cereals. Therefore, the results for strategies were treated as the additional replications and further on the average date for all of them are presented and discussed, against the control treatment.

The second experimental factor was nitrogen rate 0, 40, 80, 120, 160 (for winter wheat) and 0, 30, 60, 90, 120 (for spring barley, winter triticale and oat). Lower fertilizer rates (30 or 40 kg N $\cdot ha^{-1}$) was applied at tillering stage (BBCH 21). Higher rates were split in two doses: 30 or 40 kg N $\cdot ha^{-1}$ at tillering stage (BBCH 21) and additional ones at stem elongation (BBCH 31). Two-factorial experiment was set up according to split-plot design in four replicates. The single plot covered the area of 28.8 m^2.

Winter cereals were sown in mid-September and the spring cereals at the beginning of April (tab. 2). Harvest time was from the end of July to the beginning of August. After harvest, at full maturity stage (BBCH 91) grain yield per plot was determined.

2.2 Disease incidence

In the vegetation periods 2005, 2006 and 2007 plant infection by fungal diseases was estimated at the plant milky maturity stage (BBCH 75-77). Infection of three upper leaves

Plant protection strategy		Active group	Rate (l·ha^{-1})	Development stage (BBCH scale)
producer	biologically active ingredient			
winter wheat				
A	Picoxystrobin 250 +Propiconazole 125 Fenpropidyna 275	strobilurins + triazols, morfolins	0.6 + 0.6	32
	Azoxystrobin 250 + Propiconazole 250, Cyprokonazol 80	strobilurins + triazoles	0.6 + 0.4	58-59
B	Carbendazim 250 Flusilazol 125 + Flusilazol 160 Fenpropimorf 375	benzimidazols, triazols + triazols, morfolins	0.8 + 0.4	32
	Flusilazol 160,7 Famoksat 100	triazols, oksazolidyns	0.75	58-59
	Flusilazol 160,7 Famoksat 100		0.75	71
C	Epoxiconazol 83 Krezoxim methyl 83 Fenpropimorf 317	triazols, strobilurins, morfolins	1.35	32
	Dimoksystrobina133 Epoxiconazol 50	strobilurins, triazols	1.2	58-59
winter triticale				
A	Propiconazole 125 Fenpropidyna 275	triazols, morfolins	0.6	32
	Propiconazole 250 Cyprokonazol 80	triazols	0.4	58-59
B	Karbendazym 250 Flusilazole 125	benzimidazols, triazols	0.8	32
	flusilazole 160,7 Fenpropimorf 375	triazols, morfolins	0.4	32
	Flusilazole 160,7 Famoksat 100	triazols, oxazolidins	0.75 0.75	58-59 71
C	Epoxiconazol 83 Krezoxim methyl 83 Fenpropimorf 317	triazols, strobilurins, morfolins	1.35	32
	Dimoksystrobina133 Epoxiconazol 50	strobilurins, triazols	1.2	58-59

Plant protection strategy		Active group	Rate ($l \cdot ha^{-1}$)	Development stage (BBCH scale)
producer	biologically active ingredient			
spring barley				
A	Picoxystrobin 250	strobilurins	0.6	49
	Propiconazole 125 Fenpropidyna 275	triazols, morfolins	0.6	49
B	Flusilazole 160 Fenpropimorf 375	triazols, morfolins	0.4	49
	Flusilazole 160,7 Famoksat 100	triazols, oksazolidyns	1	49
C	Carbendazim 250	benzimidazols	0.6	32
	Epoxinazole 83 Krezoxim methyl 310 Fenpropimorf 317	triazols, strobilurins morfolins	1.2	49
oat				
A	Propikonasol 250	triazols	0.5	43-45
B	Flusilazole 125	triazols	1	43-45
C	Carbendazim 250	bezimidazoles	0.6	43-45

Table 1. Systems of plant protection in cereal crops

Crop	Agronomical measure	Harvest year			
		2004	2005	2006	2007
Winter wheat	sowings	17.09.03	14.09.04	22.09.05	13.09.06
	harvest	12.08.04	12.08.05	28.07.06	20.07.07
Winter triticale	sowings	17.09.03	14.09.04	20.09.05	13.09.06
	harvest	9.08.04	2.08.05	28.07.06	20.07.07
Spring barley	sowings	5.04.04	7.04.05	25.04.06	3.04.07
	harvest	18.08.04	16.08.05	27.07.06	1.08.07
Oat	sowings	5.04.04	7.04.05	24.04.06	3.04.07
	harvest	16.08.04	3.08.05	28.07.06	3.08.05

Table 2. Dates of sowings and harvests by harvest years

and a spike or a panicle (in the case of oat) of main stem was determined on 25 plants as a percentage of the damaged area in the highest N rate treatments. Evaluation of culm base infection considered 4-levels scale described by Bojarczuk & Bojarczuk, 1974. Root system infection was estimated based on 5-levels according to Korbas et al., 2000 scale.

2.3 Statistical analysis

All data were statistically processed using analysis of variance by Statgraphics Centurion v. XV statistical package. The significance of differences between treatments (e.g. protection strategy, N rates and their interaction) were estimated by Tukey's test at α=0.05 confidence level. Regression analysis has been applied for calculating optimal nitrogen rate depending on protection treatments.

2.4 Weather conditions

Weather data originated from the Grabów meteorological station located close to the experimental field (tab. 3). The data concerning precipitation and the mean daily temperature were used for calculations of Sielianow's index (K). The index is the product of the total precipitation (P) and sum of mean daily temperatures (t) in a given period:

$$K=10P/\sum t \quad (1)$$

Year	Month	Temperature ^0C	Precipitation sum (mm)	Sielianinow's index K
2004	March	2.8	45.0	5.3
	April	8.2	67.0	2.7
	May	12.0	41.3	1.1
	June	15.9	83.7	1.8
	July	18.0	112.1	2.0
	August	18.7	58.7	1.0
2005	March	-0.2	41.9	-58
	April	8.6	10.2	0.4
	May	13.5	84.0	2.0
	June	16.1	46.3	1.0
	July	20.1	132.8	2.1
	August	17.5	36.8	0.7
2006	March	-1.5	51.8	-11
	April	9.0	30.1	1.1
	May	13.6	53.4	1.3
	June	17.4	38.2	0.7
	July	22.4	10.0	0.1
	August	17.9	219.5	4.0
2007	March	6.3	38.0	1.9
	April	8.7	13.4	0.5
	May	15.2	74.6	1.6
	June	18.7	99.9	1.8
	July	19.2	75.5	1.3
	August	19.1	151.7	2.6

Table 3. Weather data in 2004-2007 vegetation seasons

It is useful for assessments of the duration and intensity of drought. The value K<1 means that a plant uses more water than it is supplied by precipitation. The value K<0.5 signifies the serious drought when evaporation two times exceeds water supply.

The weather conditions differed considerably in the study years. The vegetation season 2004 was characterized by the lowest mean daily temperature and the highest precipitation, while the season 2005 was warmer and drier. In the following 2006 vegetation season, the temperature was similar to the year 2004 but the smallest precipitation sum was recorded. The 2007 season was characterized by the highest temperature and precipitation close to the year 2005. Sielaninow's index provides better and a synthetic characteristic of the weather course. The whole seasons of 2004 year and 2007 (except for April) were rather wet, though they differed in the mean daily temperature. In 2005, the early spring was exceptionally dry but moisture conditions since May improved considerably. The whole vegetation season in 2006 was characterized by low, or very low Sielininow's index. High rainfalls were recorded already in August, after cereal harvest.

3. Results

3.1 Disease infestation

Weather conditions in study years differentiated development of fungal diseases, plant infection and efficiency of fungicides (tab. 4, 5, 6, 7). Among plant organs, leaves of studied crops appeared to be the most sensitive. Leaves of winter wheat in all years were infected by *Stagonospora nodorum, Dreschlera tritici-repentis* and *Blumeria graminis* (tab. 4). Each year, especially in 2007 and 2005, *Stagonospora nodorum* caused the highest infection (72.1% and 24.5%, respectively). *Dreschlera tritici-repentis* and *Blumeria graminis* made relatively small damages (from 0.8% in 2007 to 3.33% in 2006). Generally, leaves of winter wheat were infected the most in 2007 (75%) and the least in 2006 (12%).

Leaves of winter triticale were infected each year by *Blumeria graminis* and *Dreschlera tritici-repentis* (tab. 4). In 2005, winter triticale was infected also by *Stagonospora nodorum*, and in 2006 by *Puccinia recondita,* and in 2007 by both pathogens. Infection of winter triticale was much less serious than this of winter wheat and did not differ between years. It ranged from 6% in 2006 to 9% in 2005.

Chemical plant protection significantly reduced the infection of both winter cereals. The fungicide efficiency ranged from about 60% in 2005 and 2007 to 80% in 2006 in the case of winter wheat and from about 20% in 2007 to 70% in 2005 and 90% in 2006 for winter triticale. The efficiency depended on the type of the pathogen.

Spring barley leaves in all years were infected by *Dreshlera teres*, in 2006 by *Blumeria graminis* and in 2007 by *Puccinia hordei* as well (tab. 5). In 2005 plant infestation was very low (1.6%), and in 2006 slightly higher but the damaged area of three upper leaves was smaller than 10%. The highest infestation was recorded in 2007 and reached almost 60%. Efficiency of fungicides in 2006 was about 50%, but in 2007 almost 90%.

The leaves of oat in each year were infected by *Helminthosporium avenae* and *Puccinia coronata* (tab. 5). However the area of damaged leaves in 2005 and 2006 was small and equaled to

0.13 and 1.14%, respectively. In 2007 the infested area in not protected treatments was higher and equaled to 2.5%. The efficiency of fungicides in protection of oat against fungal diseases was generally low.

<table>
<tr><td rowspan="2">Treatment</td><td colspan="3">Winter wheat</td><td colspan="4">Winter triticale</td></tr>
<tr><td>S. nodorum</td><td>D. tritici-repentis</td><td>B. graminis</td><td>S. nodorum</td><td colspan="2">D. tritici-repentis</td><td colspan="2">B. graminis</td></tr>
<tr><td colspan="9">2005</td></tr>
<tr><td>Control</td><td>25.51</td><td>1.76</td><td>2.75</td><td>4.15</td><td colspan="2">3.15</td><td colspan="2">1.46</td></tr>
<tr><td>Protection</td><td>7.11</td><td>1.48</td><td>0.26</td><td>2.14</td><td colspan="2">0.67</td><td colspan="2">0</td></tr>
<tr><td>LSD</td><td>2.430</td><td>0.369</td><td>0.495</td><td>0.643</td><td colspan="2">0.424</td><td colspan="2">0.329</td></tr>
<tr><td colspan="9">2006</td></tr>
<tr><td></td><td>S. nodorum</td><td>D. tritici-repentis</td><td>B. graminis</td><td>P. recondita</td><td colspan="2">D. tritici-repentis</td><td colspan="2">B. graminis</td></tr>
<tr><td>Control</td><td>7.96</td><td>1.04</td><td>3.33</td><td>2.51</td><td colspan="2">2.44</td><td colspan="2">1.37</td></tr>
<tr><td>Protection</td><td>1.57</td><td>0.56</td><td>0.32</td><td>0.02</td><td colspan="2">0.61</td><td colspan="2">0</td></tr>
<tr><td>LSD</td><td>1.250</td><td>0.143</td><td>0.897</td><td>0.518</td><td colspan="2">0.338</td><td colspan="2">0.481</td></tr>
<tr><td colspan="9">2007</td></tr>
<tr><td></td><td>S. nodorum</td><td>D. tritici-repentis</td><td>B. graminis</td><td>S.nodorum</td><td>P.recondita</td><td colspan="2">D. tritici-repentis</td><td>B.graminis</td></tr>
<tr><td>Control</td><td>72.1</td><td>0.80</td><td>2.47</td><td>0.65</td><td>1.75</td><td colspan="2">4.13</td><td>0.80</td></tr>
<tr><td>Protection</td><td>29.8</td><td>0.46</td><td>0.02</td><td>0.12</td><td>0.24</td><td colspan="2">1.46</td><td>0.09</td></tr>
<tr><td>LSD</td><td>4.78</td><td>0.168</td><td>1.200</td><td>0.204</td><td>0.60</td><td colspan="2">0.648</td><td>0.252</td></tr>
</table>

Table 4. Percent of damaged winter cereal crops leaf area by fungal pathogens in 2005-2007

Treatment	Spring barley			Oat	
	D. teres	*B. graminis*	*P. hordei*	*H. avenae*	*P. coronata*
2005					
Control	1.54	0.02	0	0.12	0.01
Protection	0.33	0	0	0	0
LSD	0.347	0.026	-	0.044	0.013
2006					
Control	1.41	7.90	0	0.97	0.17
Protection	0.11	4.72	0	0.32	0.06
LSD	0.330	0.938	-	0.161	0.05
2007					
Control	19.35	0	38.54	0.85	1.69
Protection	4.45	0	2.13	1.63	0.43
LSD	2.137	-	3.244	0.526	0.231

Table 5. Percent of damaged spring cereal crops leaf area by fungal pathogens in 2005-2007

The generative parts of winter cereals were slightly infected, 2–6% of spikes area in 2005 and 2006 years and moderately infected, 8–9% of spikes area in 2007 (tab. 6). Efficiency of fungicides against spikes infestation was pretty high and reached 60-80%. Generative parts of spring crops were not infected at all in 2005 and 2006, and only slightly infected in 2007 (about 5% of barley spikes and 2% of oat panicles).

Year	Treatment	Winter wheat	Winter triticale	Spring barley	Oat
2005	Control	2.32	4.87	0	0
	Protection	2.70	1.06	0	0
	LSD	0.691	0.589	-	-
2006	Control	2.05	6.14	0	0
	Protection	0.75	1.98	0	0
	LSD	0.446	1.26	-	-
2007	Control	9.11	8.12	5.72	1.73
	Protection	3.96	2.21	2.59	1.03
	LSD	0.825	0.963	1.297	0.752

Table 6. Total percentage of damaged cereal spike and panicle area by fugal pathogens in 2005-2007

Fungal diseases infected also the stem base of plants, particularly the winter cereals. In the control treatment, as an average of 2005-2007 years the stem base of winter wheat showed the 51%, and winter triticale 44% level of infestation (tab. 7). In these years infection index of spring barley equaled to 24% and of oat to about 2% only. The level of infestation depended on the weather in study years. Generally, winter wheat and spring barley were the most infected in 2007, much less in 2006, and the least in 2005. Different pattern of stem base infestation was recorded in triticale, which was the least infected in 2007 and more seriously in the years 2006 and 2005. Stem base of oat was practically healthy. Insignificant number of stems with necrotic pots proved its small sensitivity to fungal diseases and a good value as a preceding crop for the other cereals. Fungicides with the exception of triticale and barley in dry 2006, and oat in all years significantly decreased the infections of stem base by fungal diseases. However, their efficiency was much lower than against the infestation of leaves. For winter triticale and spring barley, the protection measures were the most effective in 2005 (42% and 49%) and the least in 2006 (25% and 27%, respectively). Fungicides applied for winter wheat reduced infection by 31%, 36% and 21% in the consecutive study years. The effect in oat was not statistically proved in all study years.

The infection of the cereal crop root system was very low indeed. Infestation indexes were in the range of a few percent and did not influence crop productivity.

Generally, 2007 was the year of the highest fungal disease infestations of all parts of winter wheat and spring barley and generative parts of winter triticale and oat. The other parts of winter triticale, especially stem base and root system, were infected the most in 2005 and in 2006. Otherwise, in the 2006 year the infections of both winter crops leaves and winter wheat spikes and spring barley root system were very small. In 2005 year, the infections of both spring crops leaves and winter triticale spikes, winter wheat and spring barley stem base and winter wheat root system were limited. Chemical plant protection measures significantly reduced the fungal infections of all cereal crops except oat.

Treatment	Winter wheat	Winter triticale	Spring barley	Oat
2005				
Control	36.0	64.9	18.1	0.6
Protection	24.8	37.6	9.2	1.4
LSD	10.79	18.71	4.15	n.s.*
2006				
Control	50.3	50.1	24.7	4.8
Protection	32.0	37.5	18.1	2.5
LSD	11.99	n.s.	n.s.	n.s.
2007				
Control	86.4	38.4	27.70	0.4
Protection	68.1	24.3	17.7	0.4
LSD	15.38	8.80	6.85	n.s.

*not significant difference

Table 7. Infection of cereal culms by stem base pathogens in 2005-2007

3.2 Grain yield

Grain yield of cereals was influenced by weather conditions, nitrogen fertilization and plant protection against fungal diseases (tab. 8). The highest grain yield of all cereals, except oat, was recorded in a cool and wet 2004, and the smallest in dry 2006. The year 2005 proved to be more favorable than 2007, but in both years winter cereals and spring barley yielded lower than in 2004, and higher than in 2006. The yield of oat was the highest in 2004 and 2005 years, much lower in 2006, and the lowest in 2007 year. Winter cereals, except winter wheat in 2006, out yielded the spring ones. However, in the dry 2006, both forms of cereals gave a rather comparable, low yields of grain.

As an average of four years grain yield of all cereals increased significantly to the highest applied rates of nitrogen (tab. 8). However, the yield increases reached about 3,6 tone of grain for winter cereals and only about 2 tones for the spring ones. All the tested plant protection strategies proved to be effective in comparison to the control treatment. As it has been already mentioned, the differences between these strategies were rather insignificant and further on the average values for all strategies were discussed. Plant protection measures showed the highest efficiency for winter wheat and then for winter triticale and spring barley. Their efficiency for oat was practically negligible.

The most interesting are interactions between three factors influencing cereals yield. All interactions of the second order proved to be significant and are further presented on figures 1-4.

The effect of nitrogen was the highest in 2004 and the lowest in 2006 (fig. 1). In 2004 characterized by moderate temperature and higher then long-term averages, rainfall. The highest nitrogen rates increased the yield of winter cereals by almost 6 ton and spring cereals by almost 3 ton of grain. In 2006, which was the driest one, the yield increases reached about 2 tons, only and for oat less than 1 ton of grain. In 2005 and 2007, the effects of nitrogen were rather similar, though the yield level was much higher in the former year. Both these years were characterized by moderate rainfall, but 2007 was significantly warmer. For winter wheat, the optimal nitrogen rates can be estimated at 160 kg N·ha-1 in 2004, 120 kg N·ha-1 in 2005 and 2007, and at about 80 N·ha-1 in 2006. For winter triticale and spring barley, the corresponding nitrogen rates were 120, 90 and about 60 kg N·ha-1. For oat, in three study years, except 2004 with 120 kg N ·ha-1, the estimated optimal nitrogen rate was 60 kg N·ha-1 only.

Factor		Winter wheat	Winter triticale	Spring barley	Oat
Year	2004	7.30	9.00	5.13	5.01
	2005	5.70	6.60	4.21	5.20
	2006	3.05	4.43	3.39	3.60
	2007	4.81	4.76	3.78	3.25
	LSD	0.341	0.223	0.313	0.105
Nitrogen rate (N kg · ha-1)	0	3.00	4.11	2.82	3.04
	40* /30**	4.44	5.38	3.80	3.90
	80/60	5.66	6.42	4.44	4.57
	120/90	6.29	7.27	4.72	4.81
	160/120	6.68	7.79	4.87	5.00
	LSD	0.247	0.227	0.128	0.095
Plant protection strategy	control	4.87	5.84	3.88	4.21
	A	5.34	6.21	4.15	4.32
	B	5.27	6.44	4.21	4.28
	C	5.38	6.28	4.28	4.25
	LSD	0.221	0.203	0.114	0.085

*- rates for wheat / ** for the other crops

Table 8. Grain yield of cereal crops depending on the year, nitrogen rate and plant protection strategy

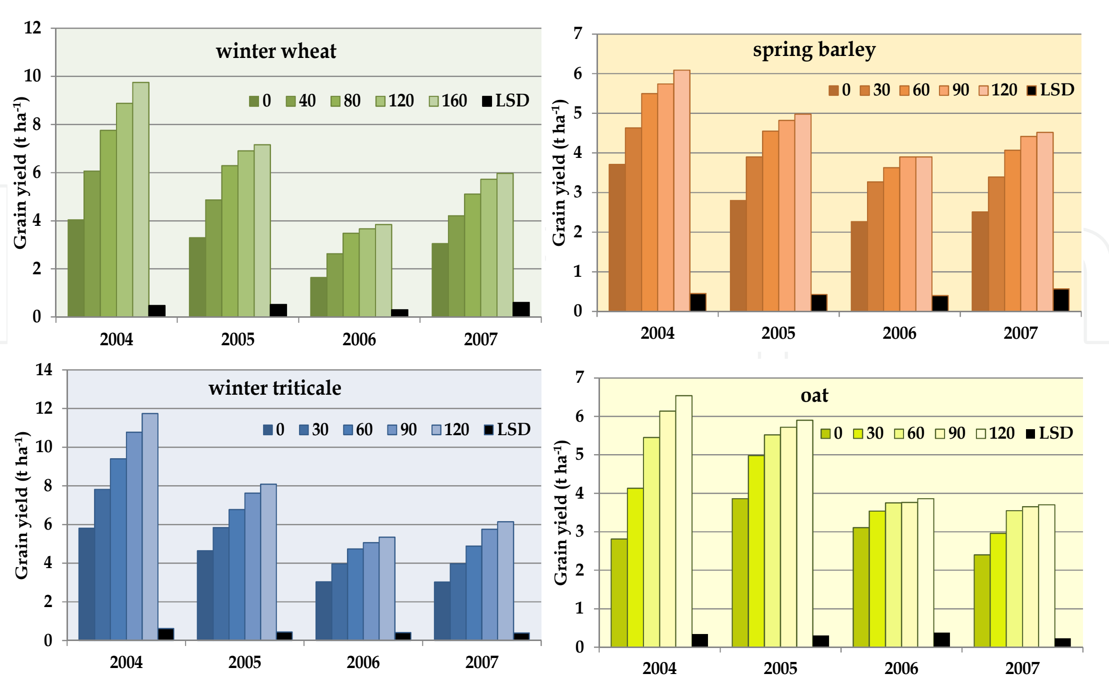

Fig. 1. Grain yield of cereal crops depending on nitrogen rate in 2004-2007

Chemical plant protection was the most effective in a wet and warm 2007 year and the least (for winter cereals) or not effective at all (for spring cereals) in the dry, though the rather cold 2006 year (fig. 2). In 2004 and 2005, the effect of plant protection measure was significant, however smaller than in 2007, for all cereals except oat. The yield increases of winter wheat and spring barley in the most prone to fungal diseases 2007 year were in the range of about 1 ton of grain per ha, while those for triticale and oat reached about 0.3 ton per ha only.

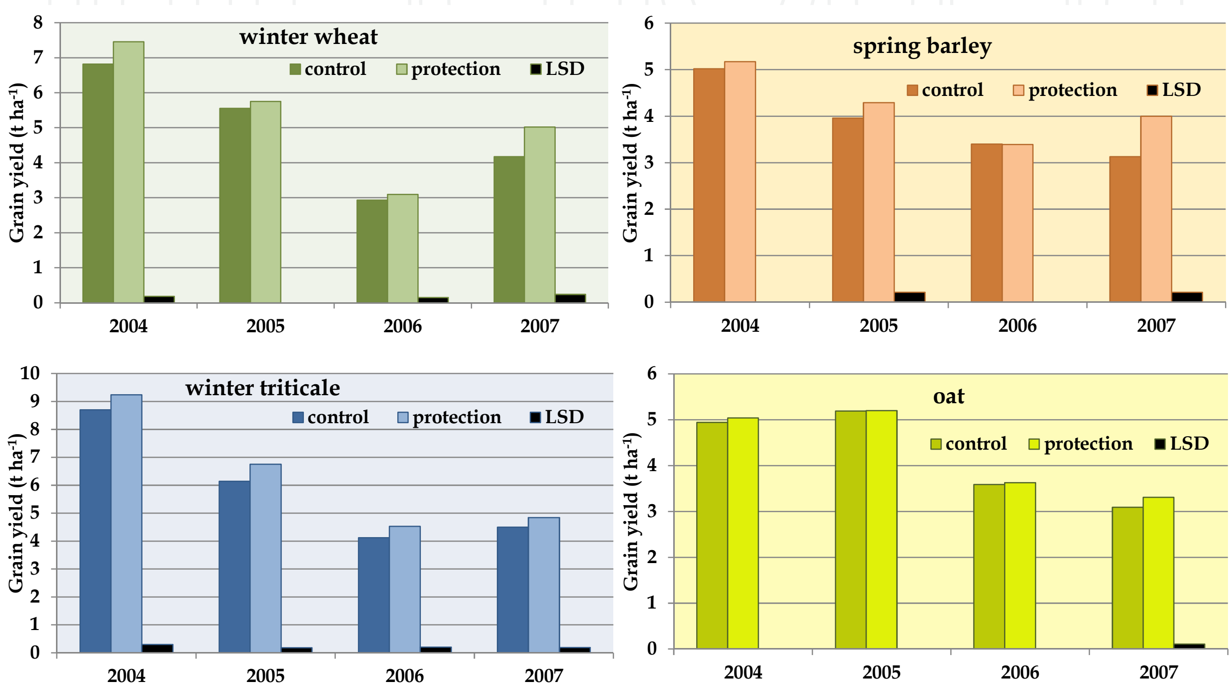

Fig. 2. Grain yield of cereal crops depending on plant protection strategy in 2004-2007

Nitrogen fertilization generally increased efficiency of plant protection measures for all cereals except oat (fig. 3). This interaction was, however, strongly depended on the weather conditions in the study years. Only oat practically each year did not respond to plant protection measures. The year 2007 was the most effective for plant protection. The effect in grain yield raised according to nitrogen rate increase from 0.5 to 1.4 t $\cdot$ha^{-1} for winter wheat, from 0.5 to 1.3 t $\cdot$ha^{-1} for spring barley and from 0.04 to 0.7 t $\cdot$ha^{-1} for winter triticale. Effect of oat plant protection ranged from 0.2 to 0.3 t $\cdot$ha^{-1}. In 2004 chemical plant protection affected practically only winter wheat and winter triticale grain yield.

Dry weather in 2006 caused that crop protection was practically ineffective for spring crops, and the increase of winter wheat was reduced to 0.2-0.4 t $\cdot$ha^{-1}. Grain yield of winter triticale increased from 0.2 t $\cdot$ha^{-1} in the control treatment to 0.6 t $\cdot$ha^{-1} on the 90 kg N $\cdot$ha^{-1} rate. Figure 3 allows for drawing the conclusion that without nitrogen fertilization and if the nitrogen rates are low, the application of fungicide is of no use and surely would bring economic losses. Another conclusion is that oat in Polish condition does not respond to plant protection measures.

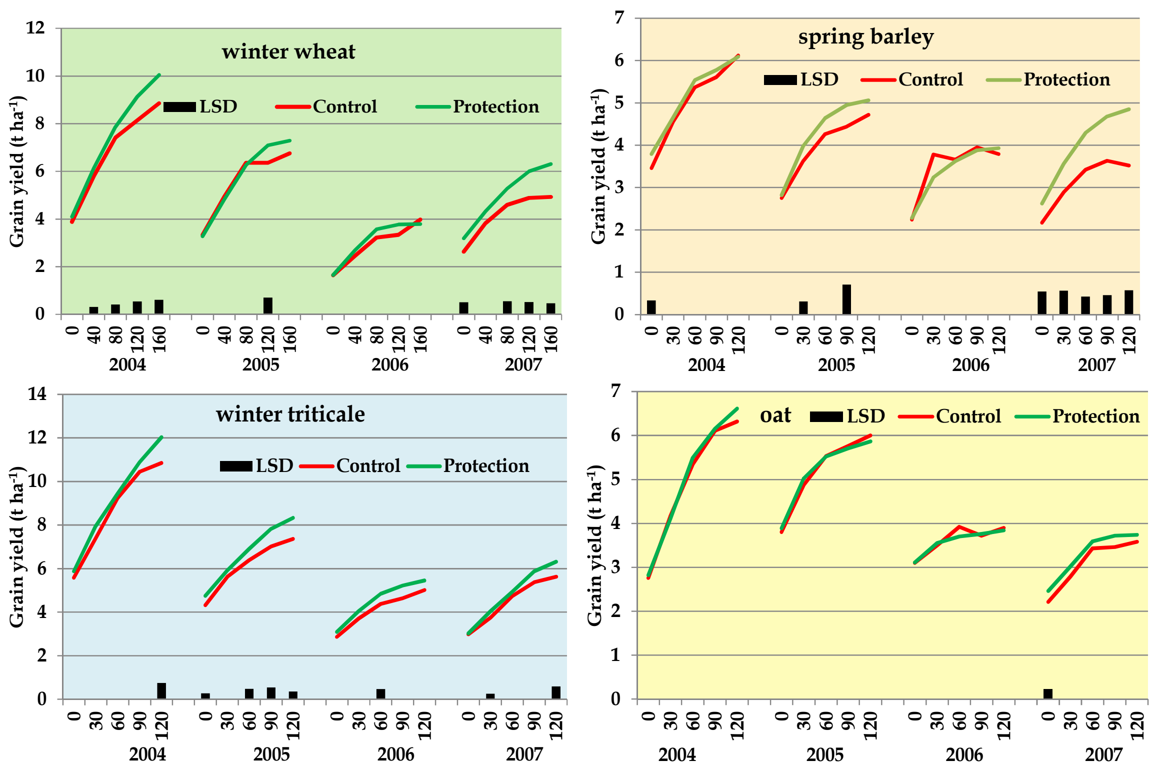

Fig. 3. Effect of nitrogen rate on efficiency of chemical plant protection in 2004-2007

Interaction of plant protection against fungal diseases and nitrogen fertilization can be further analyzed from the side of nitrogen efficiency (fig. 4). In all study years, except 2006 and for all cereals, except oat, nitrogen efficiency was higher in the treatments with fungicide application. The yield increases of winter cereals under an influence of high nitrogen rates were in the range 3 – 6 tons of grain per ha in protected treatments and 2.3 – 4.4 ton in the control. The positive interaction of nitrogen and plant protection measures was not so strong in the case of spring barley. The yield increases under nitrogen rates in protected treatments were by 0.3-0.5 ton grain per ha higher than in the control one. Besides in 2007 year, fungicide application for spring barley did not increase the efficiency of nitrogen at all. As results from figure 4, each next nitrogen rate more often gave a significant yield increase in protected treatments than in the control treatment. This problem will be more comprehensively presented in the discussion.

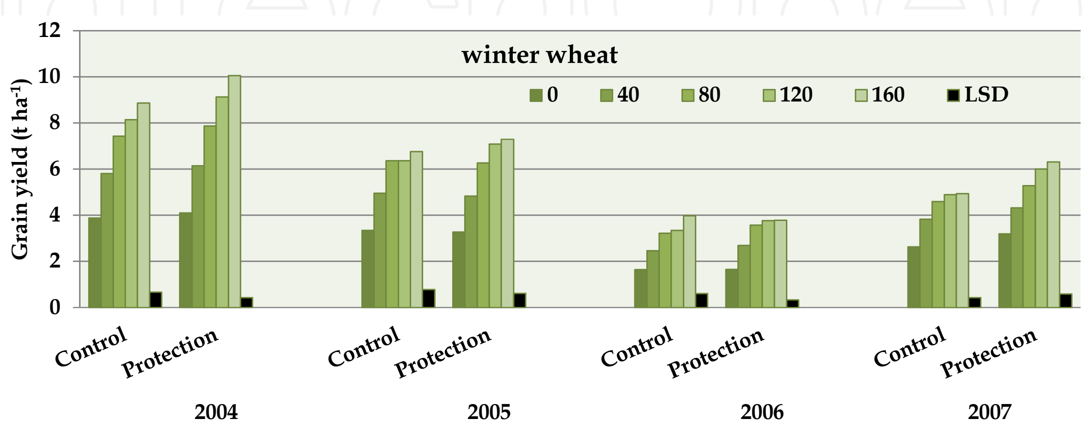

Fig. 4. Effect of plant protection on nitrogen rate efficiency in 2004-2007 (continued)

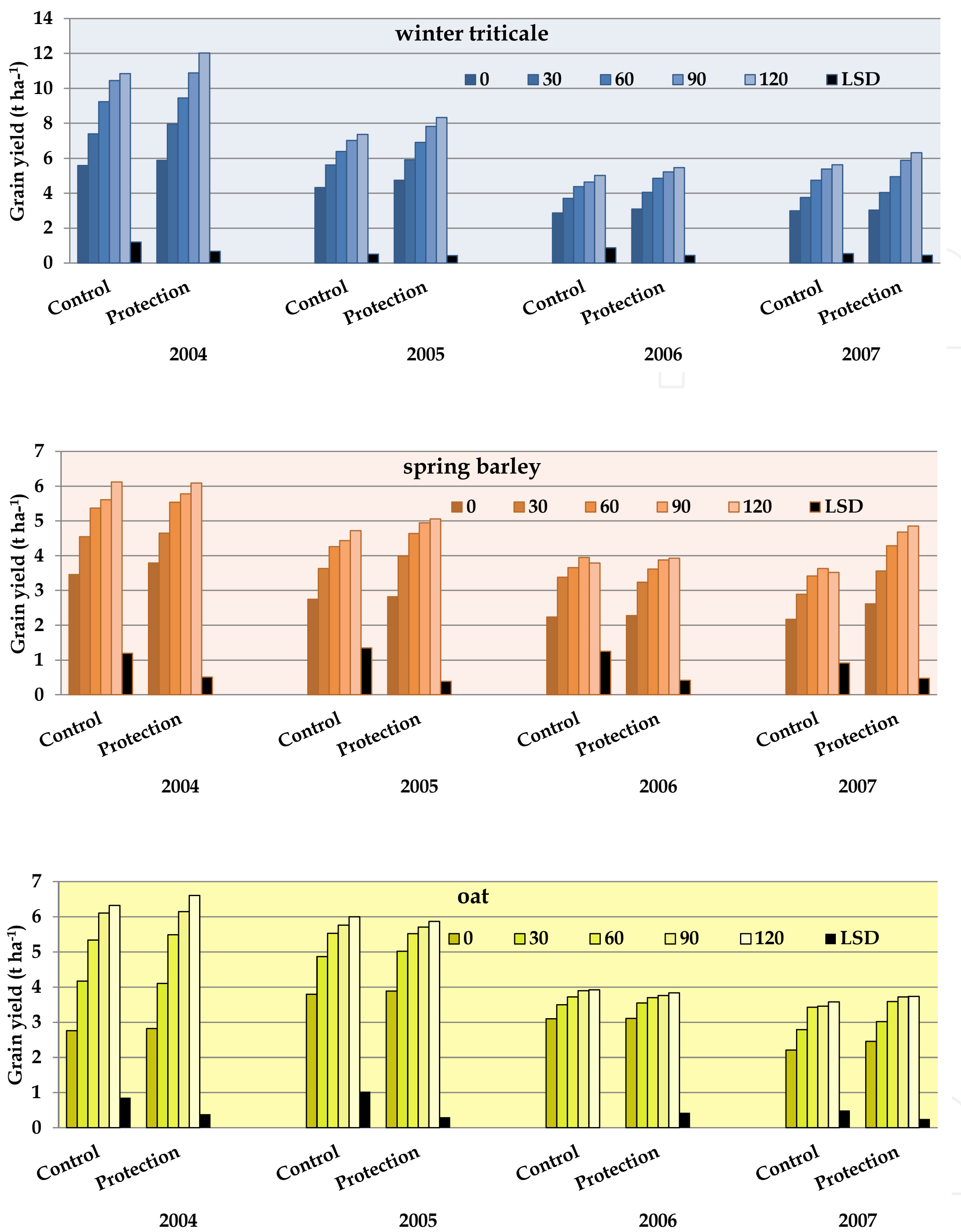

Fig. 5. Effect of plant protection on nitrogen rate efficiency in 2004-2007

4. Discussion

Water availability in the growing season in Poland affects significantly plant growth and yield (Grzebisz, 2004). In the own study efficiency of plant protection measures and nitrogen efficiency were also modified by weather conditions. Hence, the interactions between weather, nitrogen and plant protection measures, including the yield level are quite complicated.

4.1 Weather conditions, diseases infestation and crop protection

It is practically known that climatic conditions and each weather anomaly (e.g. drought) might restrict development of pathogens (Garret, et al., 2006; Jaczewska-Kalicka, 2008; Korbas, 2008). Unfortunately, due to technical reasons crop infestation by fungal diseases was not estimated in 2004 year. The best conditions for disease infestation of leaves, stem base, and generative plant parts of winter wheat and spring barley crops were noted in 2007. However, this year was not so favorable for development of stem base diseases on triticale. The year 2007 was characterized by high temperatures and precipitation in the whole vegetation season, except for April. Even in this year, the infestation of oat plant by all fungal diseases were negligible. The poorest conditions for leaf and generative plant parts infection of winter crops were noted in dry 2006. However, that does not concern the stem base diseases, which develop the best in this particular weather conditions. It reveals another problem in investigation on fungal diseases, namely different susceptibility of plant parts depending on the weather course (Błażej &Błażej, 2000; Garrett, et al., 2006; Jaczewska, 1993 & Jaczewska-Kalicka, 2008). Anyway, among the studied crops, except barley in 2007, leaves were much less infected then culm base (tab. 9). The level of infection depends considerably on the cereal crop. The cereals grown in the experiment can be ranked as follow in descending order concerning the sensitivity to fungal infection: winter wheat>winter triticale>spring barley>oat.

Chemical plant protection measures significantly reduced the infections of all cereals, except oat, with fungal diseases (tab. 9). The efficiency of fungicides against leaf disease were higher than against the culm diseases. It should be noted that all studied protection strategies considered rather protection against diseases of leaves and spikes than stem base and root system.

Year	Treatment	Winter wheat		Winter triticale		Spring barley		Oat	
		leaf	culm	leaf	culm	leaf	culm	leaf	culm
2005	control	29.6	36.0	8.76	64.9	1.56	18.1	0.13	0.6
	protection	8.85	24.8	2.81	37.6	0.33	9.2	0	1.4
Efficiency %		70	30	68	44	79	49	100	0
2006	control	12.3	50.3	6.32	50.1	9.31	24.7	1.14	4.8
	protection	2.45	32.0	0.63	37.5	4.83	18.1	0.38	2.5
Efficiency %		80	36	90	25	49	27	67	48
2007	control	75.4	86.4	2.35	38.4	57.9	27.70	2.54	0.4
	protection	30.3	68.1	1.82	24.3	6.58	17.7	2.06	0.4
Efficiency %		60	21	23	37	89	37	19	0

Table 9. Leaf and culm infection of cereals in the years 2005-2007

4.2 Weather conditions and grain yield

The highest average yields of all cereal crops was recorded in a relatively cool and wet 2004. For winter cereals it was a combining effect of direct influence of favorable weather conditions on plant growth and development, very high nitrogen efficiency and positive effect of plant protection measures. The last of mentioned factor seems to be insignificant for spring cereals, particularly oat. These results are confirmed by Nowak et al., 2005, who has found a similar combining effect of weather conditions and the level of plant infestation by pathogens on the cereals grain yield. Unfortunately, the data concerning plant infestation in this year are unavailable. The next good, and for oat very good, was 2005 year. In this year, high yield of grain were recorded already in control treatment and the efficiency of nitrogen fertilization was high. In 2005, the March and April were very dry but later on moisture conditions favored plant growth and development. As a matter of fact the level of plant infestation by pathogens was pretty high but so was the efficiency of fungicides. In 2007 in spite of favorable weather conditions the yields of all cereals were lower than in 2005. For winter wheat and spring barley it can be explained by the highest infection of plants by pathogens in experimental period. The infection of winter triticale plants was in fact on average level but the efficiency of fungicides against culm diseases was rather low. For the whole experimental period the lowest yields of all cereals were achieved in the cold and dry 2006 year. It is a combining effect of limitation in plant growth and development, as well as low nitrogen efficiency and high level of culm base infestation by pathogens. Low yields of cereal crops in dry years are well documented in the literature (Ferrante et al., 2008; Hura et al., 2007; Jessop, 1996; Okuyama, 1990; Pecio, 2002; Rodriguez-Pérez et al., 2007 & Savin, 1996).

Special attention should be dedicated to oat. This crop gave low yields both in cold and dry 2006 year as well as in the moist and hot 2007 year. Oat, other cereal crops unlikely, requires lower temperatures and high air moisture for proper growth and development (Givens et al., 2004; Welch, 1995). According to Doehlert et al., 2001 the highest oat yield is obtained under conditions of warm, sunny weather in the spring and cooler summer, without excessive precipitation at grain filling stage. The results of Michalski et al., 1999 showed the decrease of oat productivity in line with increasing the temperature in the period between April and July with May as the month of the highest oat sensitivity. Our results confirmed that relationships. Higher temperatures in 2006 and 2007 years in the critical period of oat development decreased grain yield considerably. Furthermore, the highest mean temperature in May 2007 decreased grain yield comparing to 2006, independently of higher precipitation.

Our results suggest that weather conditions can modify yield of cereal grain more than infestations by fungal diseases. Grain yield of cereal crops and its variability between years is a result of many factors co-operating each with other throughout the whole vegetation period (Jaczewska-Kalicka, 2008). Garret et al., 2006, Gooding & Lafever, 1991, Mazurek, 1999 & Welch, 1995 claim that weather conditions effect the plant development, nutrient uptake ability and photosynthesis effectiveness. They cause the changes in plant assimilation area and photosynthesis rate, which decides upon the quantity of storage materials in the seeds, and therefore, about its weight and grain yield per area unit. Adequate moisture conditions before anthesis enable plants to accumulate storage materials, which might be used for grain filling. After anthesis, plants stay green for longer time, which extends the period of grain filling stage and increases final grain yield (Coles et al., 1991).

Weather conditions in the study years explain only partly the differences between cereal grain yields. Our results confirmed the opinion of the other authors (Doehlert et al. 2001; Peterson et al. 2005), that grain yield is determined mainly genetically, and in turn it is strongly modified by weather conditions. Saastamonien et al. (1989) showed, that different cultivars of cereal crops can adopt to climatic changes in different ways. In the own research, the choice of varieties changed in experimental years. In 2004-2006, winter wheat variety Rywalka was grown, and in 2007 variety Turnia, both yielding on the similar level. The cultivars of spring barley were Justina and Rywalka. In the studies of Noworolnik (2003), Justina was distinguished by a high yield. Winter triticale was represented by Woltario (2004-2006) and Zorro varieties, both yielding on similar level. Among cultivars of oat, lower yielding Cwał variety was grown in the years 2005-2006, and high yielding Szakal cultivar in 2004 and 2007.

4.3 Nitrogen fertilization

Good supply of nitrogen decides upon proper plant growth and development (Fotyma, 1988; Spiertz & Vos, 1983). Availability of nitrogen for crop depends on the mineral nitrogen reserves in soil, supplemented by fertilizers and on soil moisture conditions. Supply of nitrogen also considerably influences plant susceptibility to pathogens, particularly fungal diseases (Krauss, 2001; Poschenrieder et al., 2006). In the own research, due to the application of five nitrogen rates, it was possible to interpret quantitatively the effect of nitrogen, using regression equations. The relations between cereal grain yield and nitrogen rates were the best approximated by a polynomial of second order (fig. 6). The model was previously used by Fotyma, 1997; Fotyma, 1988; Fotyma, 2000 & by Fotyma & Filipiak, 2008.

Applied regression model characterized by a "flat" part around the breaking point, usually overestimates the real effect of nitrogen on grain yield (Cerrato & Blackmer, 1990). For this reason, optimum N rate was calculated for 90% of maximal grain yield, according to the method described by Barłóg et al., 2008. Optimal nitrogen rates, securing this yield level, calculated from the regression equations are presented in table 10. In few cases, these rates were extrapolated and are included for general orientation only. From this table, several conclusions can be drawn. Optimal nitrogen rates were always higher for winter than for spring cereals. For spring barley and oat, nitrogen rates can be limited to about 100 kg N $\cdot ha^{-1}$, while for winter cereals it should be increased by about 50%.

Optimal N rate depends strongly on the weather and in the vegetation season 2004, characterized by average Sielianinow's index K=1.9, for winter cereals this rate exceeds the top rate applied in the experiment. Optimal nitrogen rates for crops protected against fungal diseases, were also high in the years 2005 and 2007 with ample rainfall and Sielianinow's index in spring exceeding K=1.5. In the very dry 2006, the optimal nitrogen rates could be limited to about 100 kg $N\cdot ha^{-1}$, even for winter cereals. Another very important conclusion is that optimal N rates for winter cereals, and in favorable weather conditions for spring cereals as well, were higher in the treatments with fungicide application. This regularity did not concern a very dry year of 2006, characterized by a very low efficiency of plant protection measures. The regularity is with agreement with other authors (Grzebisz, 2008; Jaczewska, 1993 & Noworolnik, 2003).

Year	Winter wheat		Winter triticale		Spring barley		Oat	
	control	protection	control	protection	control	protection	control	protection
2004	162	212*	130	207*	122	115	116	129
2005	127	149	124	178*	109	93	99	93
2006	116	122	124	112	79	93	86	89
2007	118	178*	148*	195*	85	109	96	95

* rates extrapolated beyond the highest rate in the experiment

Table 10. Optimal nitrogen rate securing 90% of maximal grain yield

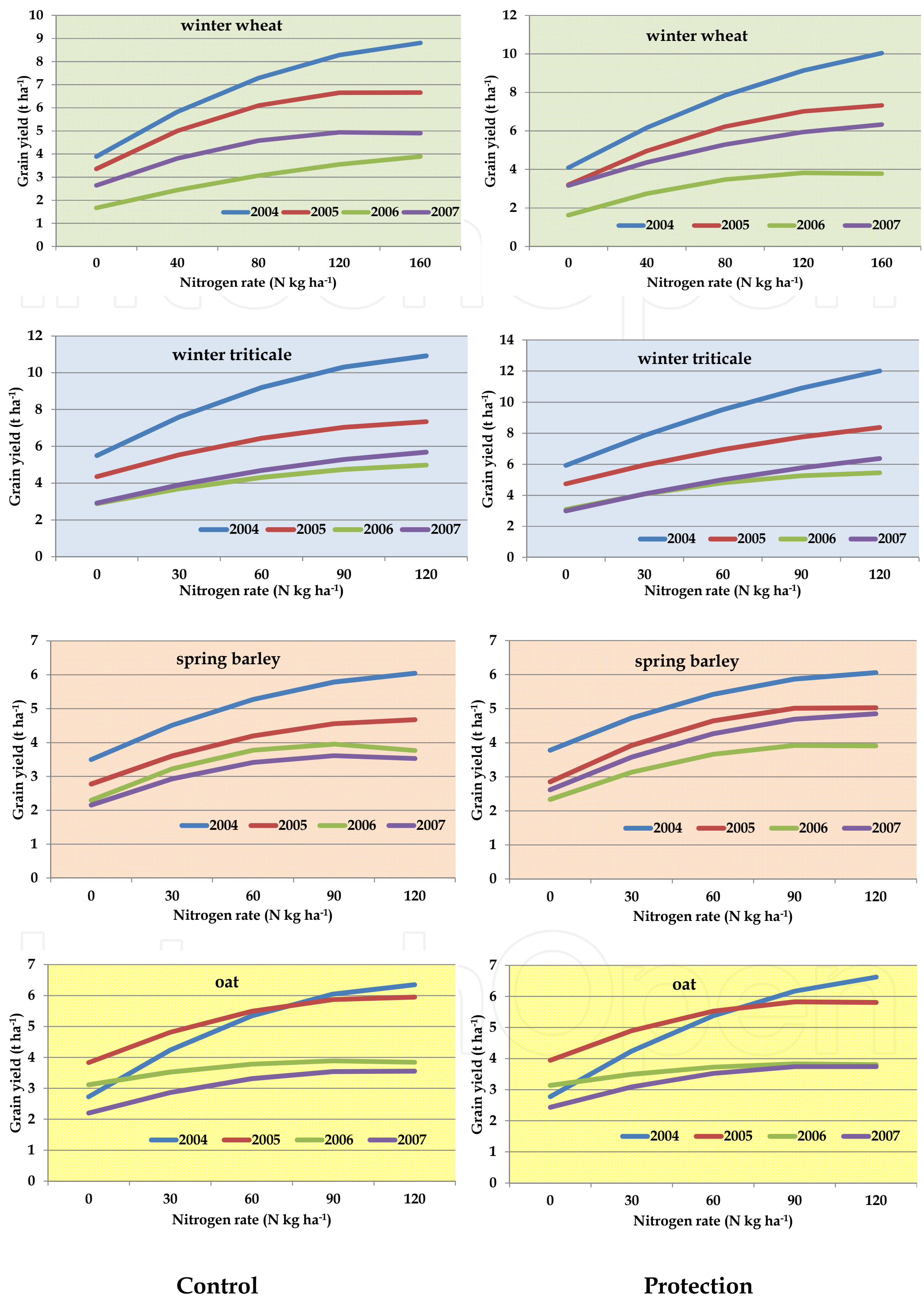

Fig. 6. Regression curves for the relationships between grain yield and nitrogen fertilization rate

Another useful index for comparing nitrogen effect on cereal yield depending on weather conditions, nitrogen rate and plant protection measures is NUE (nitrogen use efficiency) (Potarzycki, 2010). This index gives the information on the yield increase per one kilogram of applied nitrogen (Nf) (Moll et al., 1982), and can be further used for economic calculations (fig. 7). The analysis of NUE confirms already discussed relation between the nitrogen efficiency and weather as well as fungicide's application. Positive interaction between nitrogen rates and fungicides application is confirmed by many authors (Bradley et al., 2002 & Delin et al., 2008). For the good nitrogen utilization, pest and diseases should be kept under control (Goulding, 2000). Gooding et al. 2005 & Ruske et al., 2003 have reported that grain yield, crop biomass, grain nitrogen and thereby nitrogen use efficiency increase with decreasing incidence of fungal diseases and/or with crop protection.

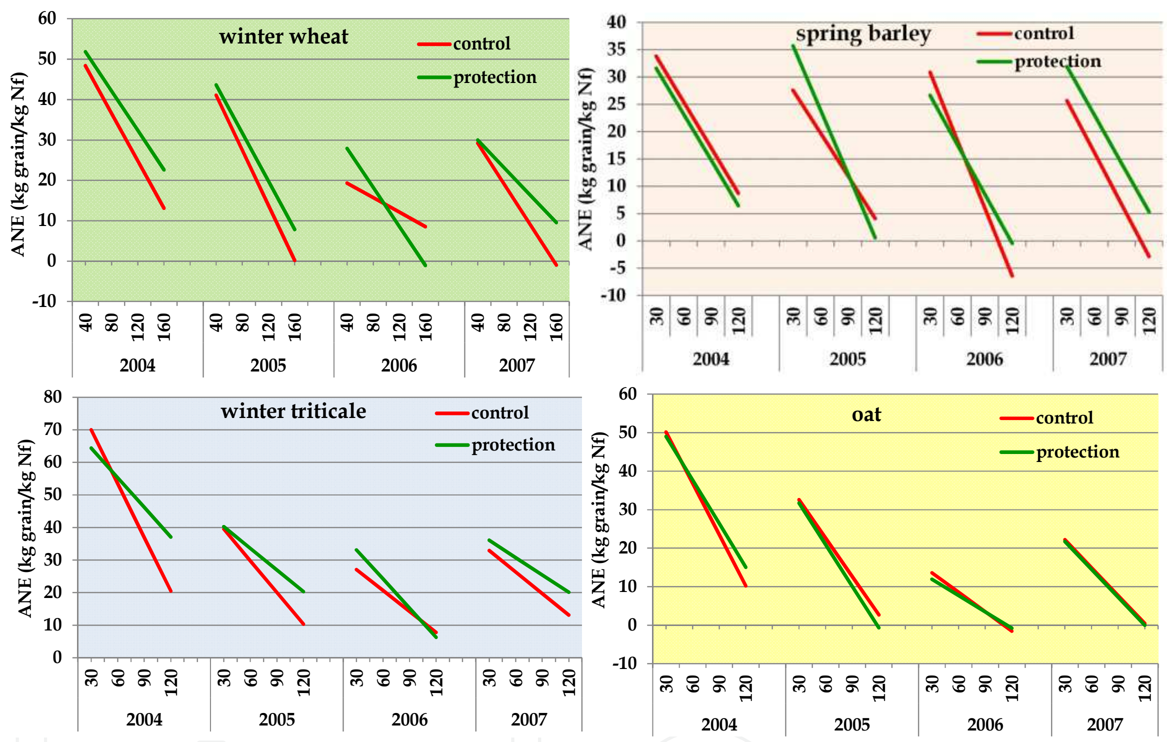

Fig. 7. Agronomic Nitrogen Efficiency (kg of grain per kg Nf) in relation to nitrogen rate and crop protection

4.4 Interaction and concurrence between nitrogen and plant protection measures

Interaction is a purely statistic term, used in processing the results of investigations by analysis of variance. In the further consideration more proper seems to be the term of concurrence, which does not have a strict statistical sense. The result concurrence between two factors can be synergistic, antagonistic and/or additive. The type of relation between nitrogen fertilization and plant protection measures will be analyzed here on the basis of the data presented in table 11. This table does contain neither the data for all cereals in 2006 year, nor the data for oat in all study years. It has previously been shown that this year was extremely dry and was characterized by a low efficiency of nitrogen fertilizer and practically no effect of plant protection measures.

As one can conclude from this table, the main factor deciding upon yield increasing is nitrogen fertilization, while the effect of plant protection measures is much lower. However, similarly to Smagacz & Kuś, 2010, the effect of nitrogen, with few exceptions, was higher for protected cereals and the effect of plant protection was higher for cereals well supplied with nitrogen. On the average, the concurrence between the nitrogen and plant protection measures was of additive character. The combined effect of nitrogen fertilization and plant protection was the highest in 2004 year characterized by rather cold and wet weather.

Year	Nmax – N0		Protection – Control		Combine effect	Cumulative effects	
	control	protection	N0	Nmax	2 + 5	2 + 4	3 + 5
1	2	3	4	5	6	7	8
Winter wheat							
2004	4.98	5.95	0.22	1.19	6.17	5.20	7.14
2005	3.42	4.02	-0.07	0.53	3.95	3.35	4.55
2007	2.34	2.14	0.01	-0.19	2.15	2.35	1.95
Winter triticale							
2004	5.27	6.15	0.30	1.18	6.45	5.57	7.33
2005	3.04	3.58	0.43	0.97	4.01	3.47	4.55
2007	2.15	2.37	0.22	0.44	2.59	2.37	2.81
Spring barley							
2004	2.66	2.30	0.33	-0.03	2.63	2.99	2.27
2005	1.97	2.24	0.07	0.34	2.31	2.04	2.58
2007	1.46	1.65	0.04	0.14	1.69	1.50	1.79

Table 11. Yield increases between the extreme treatments (ton grain·ha^{-1})

Winter cereals were more responsive to nitrogen fertilization and plant protection in comparison to spring barley, not to mention the unresponsive for protection oat. The own results are in some contradiction to those of Fotyma, 1999 and Grzebisz, 2008, who have found synergistic type of concurrence between the amount of applied N and wheat protection. The additive effect of nitrogen and fungicide follows the Law of Optimum (Claupen, 1993). Therefore, it should not be surprising than even in a very dry 2006, some effects of fungicide application were recorded, but they were reduced due to drought, which in turn decreased uptake of nitrogen. Nitrogen stimulates grain developing process and plant protection extends the period of a photosynthesis (Dimmok & Gooding, 2002; Ruiter & Brooking, 1996). Pruszyński, 2002, accented stabilizing but not promoting yield character of plant protection. It means that under conditions of poor plant infestation by pathogens, plant protection measures are unnecessary. However, abandoning the fungicide application under conditions of heavy infestation by pathogens can lead to complete yield lost.

5. Conclusion

Four study years represented satisfactorily the changeability of weather conditions in Poland. In the three of these four years, the routine programs of cereal's protection against fungal diseases, recommended by leading chemical companies, proved to be effective for winter wheat, winter triticale and spring barley. Oat practically does not respond positively to plant protection measures independently of weather. In the very dry year, all cereal crops except winter triticale do not need to be protected against fungal diseases. Nitrogen is the main factor deciding upon the yield increases of winter and spring cereals. Optimal nitrogen rates are always higher for winter than for spring cereals and depend considerably on the weather. There is a positive interaction between nitrogen and plant protection measures. Fungicide application is practically useless in cereals not well supplied with nitrogen from mineral fertilizers. The concurrence between nitrogen and fungicide application is of additive character.

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7. References

Barłóg, P., Grzebisz, W., Łukowiak, R. & Cyna, K. (2008). An analysis of response of four winter cereals to increasing rates of fertilizer nitrogen. *Nawozy i Nawożenie Fertilizers and Fertilization*, Nr 32, pp. 7-17, ISSN 1509-8095

Bertholdsson, N.O. (1999). Characterization of malting barley cultivars with more or less stable protein content under varying environment conditions. *European Journal of Agron*omy, Vol. 10, No. 1, January 1999, pp. 1–8, ISSN 1161-6301

Błażej, Ja. & Błażej, Jó. (2000). The effect of production technologies on spring barley and oats health. *Pamiętnik Puławski*, No. 120, pp. 23-30, ISSN 0552-9778

Bojarczuk, J. & Bojarczuk, M. (1974). Interaction between wheat varieties and strains of the fungi *Cercosporella herpotrichoides* Fron. *Hodowla Roślin Aklimatyzacja i Nasiennictwo,* No. 18, pp. 313-325

Bradley, R.S., Lun, G., Foulkes, J., Sherman, V., Spink, J. & Ingram, J. (2002). Management strategies for high yields of cereals and oilseed rape. HGCA Conference: Agronomic Intelligence: the basis for profitable production, p.18

Brzozowska, I., Brzozowski, J. & Sarnowski, J. (1996). The effectiveness of protective and integrated protective-fertilizer treatments in winter wheat production. *Fragmenta Agronomica*, No. 4, pp. 59-67, PL ISSN 0860-4088

Cerrato, M.E. & Blackmer, A.M. (1990). Comparison of models for describing corn yield response to nitrogen fertilizers. *Agronomy Journal*, No. 82, 138-143, ISSN 0002-1962

Claupen, W. (1993). Nitrogen fertilization and chemical plant protection in a long-term field experiment and the yield response laws of Liebig. Liescher. Wollny and Mitescherlich. *Journal of Agronomy and Crop Science*. Vol. 171, No. 2, September 1993. pp. 102-113, ISSN 1439-037X

Coles, G.D., Jamieson, P.D. & Haslemore, R.M. (1991). Effects of moisture stress on malting quality in Triumph barley. *Journal of Cereal Science. No.* 14, pp. 161–177, ISSN 0733-5210

Delin, S., Nyberg, A., Kindén, B., Ferm, M., Torstensson, G., Lerenius, C. & Gruvaeus, I. (2008). Impact of crop protection on nitrogen utilization and losses in winter wheat production. *European Journal of Agronomy*. No. 28, pp. 361-370, ISSN 1161-0301

Dimmok, J.P.R.E. & Gooding M.J. (2002). The effects of fungicides on rate and duration of grain filling in winter wheat in relation to maintenance of flag leaf green area. *The Journal of Agricultural Science*. Vol. 138, No. 01, pp. 1-16, ISSN 0021-8596

Doehlert, D.C., McMullen, M.S. & Hammond, J.J. (2001). Genotypic and environmental effects on grain yield and quality of oat grown in North Dakota. *Crop Science*. Vol. 41, September 2001, pp. 1066-1072, ISSN 0011-183X

Ferrante, A., Savin, A. & Slafer, G.A. (2008). Wheat and barley floret development in response to nitrogen and water availability. *Italian Journal of Agronomy,* Vol. 3, No. 3 supplement, July-September 2008, pp. 205-206

Fotyma, E. (1988). The respond of field crops to nitro gen fertilization. I. Cereals. *Pamiętnik Puławski*. No. 93, pp. 37-60, ISSN 0552-9778

Fotyma, E. (1997). The efficiency of nitrogen fertilization of some arable crops. *Fragmenta Agronomica*, No. 1, pp. 46-66, PL ISSN 0860 -4088

Fotyma, E. (2000). Utilization of production functions in the determination of crop nitrogen fertilization requirements. *Nawozy i Nawożenie Fertilizers and Fertilization,* No. 4, pp. 51-61, ISSN 1509-8095

Fotyma, M & Filipiak, K. (2008). Comparison of several production functions for describing winter wheat response to nitrogen fertilizers. *Nawozy i Nawożenie Fertilizers and Fertilization,* No. 32, pp. 31-44, ISSN 1509-8095

Fotyma, M. & Fotyma, E. (1993). The field components of spring cereals In dependence on nitro gen fertilization. *Fragmenta Agronomica*. No. 4, pp. 101-102, PL ISSN 0860-4088

Fotyma, M. (1999). Nitrogen Take and utilization by Winter and spring wheat. *Pamiętnik Puławski*. No. 118, pp. 143-151, ISSN 0552-9778

Garret, K.A., Dendy, S.P.; Frank. E.F.; Rouse. M.N. & Travers. S.E. (2006). Climate change effects on plant disease: genomes and Ecosystems. Annual Review of Phytopathology. No. 44, 489-509, ISSN 0066-4286

Givens, D.I., Davies, T.W. & Laverick, R.M. (2004). Effect of variety. nitrogen fertilizer and various agronomic factors on the nutritive value of husked and naked oats grain. Animal Feed Science and Technology. No. 113, 169-181, ISSN 0377-8401

Gooding, M.J., Gregory, P.J., Ford, K.E. & Pepler, S. (2005). Fungicide and cultivar effect post anthesis pattern on nitrogen uptake remobilization and utilization efficiency in wheat. *The Journal of Agricultural Science*. Vol. 143, No. 06, pp. 503-518, ISSN 0021-8596

Gooding, R.W. & Lafever, H.N. (1991). Yield and yield components of spring oat for various planting dates. *Journal of Production Agriculture*, Vol. 4, No. 3, pp. 382-385, ISSN 08908524

Goulding, K. (2000). Nitrate leaching from arable and horticultural land. *Soil Use and Management*. Vol. 16, Issue Supplement s 1, pp. 145-151, ISSN 1475-2743

Grzebisz, W. (2004). Potassium in plant production. Verlagsgesllschaft fuer Ackerbau mbH. Kassel, Germany, p. 88

Grzebisz, W., Łykowski, W. & Szczepaniak, W. (2008). Effect of nitrogen rates and plant protection levels on winter wheat grain yielding patterns. *Nawozy i Nawożenie Fertilizers and Fertilization*, No. 32, pp. 45-56, ISSN 1509-8095.

Hura, T., Grzesiak, K., Hura, K., Thiemt, E., Tokarz, K. & Wędzony, M. (2007). Physiological and biochemical to tools useful In drought-tolerance detection in genotypes of winter triticale: accumulation of ferulic acid correlates with drought tolerance. *Annals of Botany,* No. 100, pp. 767-775, ISSN: 0305-7364

Jaczewska, A. (1993). Yield loss of Winter wheat due to foliar and ear diseases. *Materiały XXXIII Sesji Naukowej IOR*, II, pp. 147-150, ISBN 83-901356-2-0

Jaczewska-Kalicka, A. (2008). Influence of climate changes on yielding and cereal protection in Poland. *Progress in Plant Protection/Postępy w Ochronie Roślin,*. Vol. 48, No. 2, pp. 415-425, ISSN 1427-4337

Jessop, R.S. (1996). Stress tolerance in newer triticales compared to other cereal. Triticale: today and tomorrow. D*evelopments in Plant Breeding*, No. 5, pp. 419-427, ISSN 1381-673X

Jończyk, K. (1999). Effectiveness of chemical diseases control in winter wheat and rye cultivation. *Pamiętnik Puławski,* No. 114, pp. 151-158, ISSN 0552-9778

Korbas, M. Ławecki, T.. Kubiak,. K. & Różalski, K. (2000). Root infection of wheat caused by *Gaeumannomyces graminis* in Western Poland. *Progress in Plant Protection/Postępy w Ochronie Roślin,* Vol.40, No.1, pp.201-205, ISSN 1427-4337

Krauss, A. (2001). Potassium and biotic stress. Presented at the 1st Fauba-Fertilizar-IPI Workshop on Potassium in Argentina's agricultural systems. 20-21 November, Buenos Aires, Argentyna, 11 p

Mazurek, J. (1999). Biological basis of cereal crops yielding. *Pamiętnik Puławski*, No. 114, pp. 261-273, ISSN 0552-9778

McMullen, M. (2003). Tan spot and Septoria/Stangospora diseases of wheat. In: *North Dakota State University Extension Servis*. May 2008. Available from: http://www.ag.ndsu.nodak.edu/minot/pest/2003%20Wheat%20Disease%20Survey.htm

Michalski, T., Idziak, R. & Menzel, L. 1999. Effect of weather conditions on oats yields. Żywność Nauka Technologia Jakość Supl., PTTŻ Kraków, Vol. 1, No. 18 Suppl., pp. 46-52, ISSN 1425-6959

Moll, R.H., Kamprath, E.J. & Jackson, W.A. (1982). Analysis and interpretation of factors which contribute to efficiency of nitrogen utilization. *Agronomy Journal,* No. 74, pp. 562-564, ISSN 0002-0962

Nowak, W., Sowiński, J., Pietr, S.J.& Kita W. (2005). The effect of plant protection treatments on the quality of winter wheat grain. *Pamiętnik Puławski*, No. 139, 117-127, ISSN 0552-9778

Noworolnik, K. (2003). The effect of some agricultural factors on spring barley yielding in various environment conditions. *Pamiętnik Puławski. Monographies and Scientific Papers*, No. 8, pp. 67, ISBN 83-88031-03-1

Okuyama, L.A. (1990). Grain yield and yield components of triticale and wheat as a function of water stress. *Agronomio do Parana*, Vol. 14, No. 94, pp. 53-56, ISSN 0103-8478

Pecio, A. (2002). Environmental and agrochemical limitations of the grain yield and quality of malting barley. *Fragmenta Agronomica*, No. 4, pp. 4–112, PL ISSN 0860-4088

Perrenoud, S. (1990). Potassium and plant health (*IPI Research Topics*), No. 3. 2nd rev. Edition, IPI, Bazylea, Switzerland, 365 p., ISSN 0379-0495

Peterson, D.M., Wesenberg, D.M., Burrup, D.E. & Ericson, C.A. (2005). Relationships among agronomic traits and grain composition in oat genotypes grown in different environments. *Crop Science*, Vol. 45, pp. 1249-1255, ISSN 0011-183X

Podolska, G., Stypuła, G. & Stankowski, S. (2004). Yield and grain quality of winter wheat depending on different plant protection intensity. *Annales Universitas Mariae Curie-Skłodowska Lublin – Polonia*, Vol. LIX, No. 1, pp. 269-279

Poschenrieder, Ch., Tolra, R. & Barcelo. J. (2006). Can metals defend plants against biotic stress. *Trends in Plant Science*, Vol. 11, No. 6, pp. 288-295, ISSN 1360-1385

Potarzycki, J. (2010). Improving nitrogen use efficiency of maize by better fertilizing practices. Review paper. *Nawozy i Nawożenie – Fertlizers and Fertilization*, No. 39, pp. 5-20, ISSN 1509-8095

Pruszyński, S. (2002). Productive and ecological conditioning of plant protection against diseases and pests. *Pamiętnik Puławski,* No. 130, pp. 607-618, ISSN 0552-9778

Przulj, N. & Momcilovic, V. 2001. Genetic variation for dry matter and nitro gen accumulation and translocation in two-row spring barley. I. Dry matter translocation. *European Journal of Agron*omy, Vol. 15, No 4, pp.241–254, ISSN 1161-0301

Rodriguez-Pérez, J-E., Sahagun-Castellanos, J., Mora-Aguilar, R., Peña-Lomel.A. & Trujillo-Pérez, A. (2007). Yield response to drought of triticale and wheat. ASA-CSSA-SSSA 2007 International Annual Meetings, November 4-8, New Orleans, Louisiana, A Century of Integrating Crops, Soils & Environment. ASA celebrating 100 years, Tu. Nov. 6, 2007, pp. 158-11

Ruiter, J.M. & Brooking, I.R. (1996). Effect of sowing date and nitrogen on dry matter and nitrogen partitioning in malting barley. *New Zealand Journal of Crop & Horticultural Science*, Vol. 24, No. 1, pp. 65-76, ISSN 0114-0671

Ruske, R.E., Gooding, M.J. & Jones, S.A. (2003). The effects of triazole and strobilurin fungicide programmes on nitrate uptake. partitioning. remobilization and grain N accumulation in winter wheat cultivars. *The Journal of Agricultural Science*, Vol. 140, No. 04, pp. 395-407, ISSN 0021-8596

Saastamoinen, M., Kumpulainen, J. & Nummela, S. (1989). Genetic and environmental variation in oil content and fatty acid composition of oats. *Cereal Chemistry*, Vol. 66, No. 4, pp. 296-300, ISSN 0009-0352

Savin, R.S. & Nicolas, M.E. (1996). Effects of short periods of drought and high temperature on grain growth and starch accumulation of two malting barley cultivars. *Australian Journal of Plant Physiology, No.* 23, pp. 201–210, ISSN 0310-7841

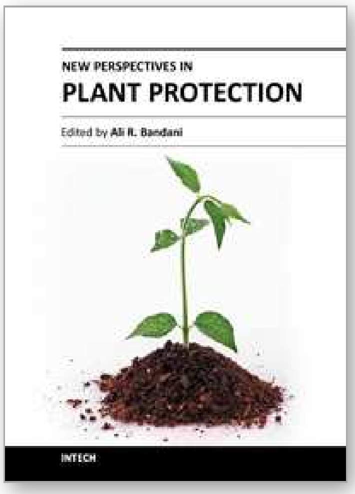
Smagacz, J & Kuś, J. (2010). Influence of cereal crop rotation of yielding of cereals and selected chemical soil properties. *Fragmenta Agronomica,* Vol. 27, No. 4, pp. 119-134, PL ISSN 0860-4088

Spiertz, J.H.J. & de Vos, N.M. (1983). Agronomical and physiological aspects of the role of nitrogen in yield formation of cereals. *Plant and Soil*, No. 75, October 1983, pp. 379-391, ISSN 0032-079X

Welch, R.W. (1995). The chemical composition of oats. In: Welch R.W. (Ed). *The Oat Crop: Production and Utilization*. Chapman and Hall. London, pp. 278-320, ISBN 0 412 37310 6

Wyszyński, Z., Gozdowski, D., Pietkiewicz, S. & Łoboda, T. (2007). The influence of different forms and rates of nitrogen fertilization on grain yield and yield components of spring barley cv. *Rasbet. Fragenta Agron*omica, No. 2, pp. 418–426, PL ISSN 0860-4088

Zhao, G.Q., Ma, B.L. & Ren, C.Z. (2009). Response of nitrogen uptake and partitioning to critical nitrogen supply in oat cultivars. *Crop Science*, Vol. 49, No. 3, May-June 2009, pp. 1040-1048, ISSN 0011-183X



New Perspectives in Plant Protection

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Crop losses by pests (insects, diseases and weeds) are as old as plant themselves but as agriculture are intensified and cropping patterns including the cultivation of high yielding varieties and hybrids are changing over time the impact of the pests becoming increasingly important. Approximately less than 1000 insect species (roughly 600-800 species), 1500 -2000 plant species, numerous fungal, bacterial and nematode species as well as viruses are considered serious pests in agriculture. If these pests were not properly controlled, crop yields and their quality would drop, considerably. In addition production costs as well as food and fiber prices are increased. The current book is going to put Plant Protection approaches in perspective.

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