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Original Research

Nitrogen Fertilization and Fungicide Application as Elements of Oat Production

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Abstract

The purpose of our study was to estimate the interaction between N fertilization and a plant protection program in oat production under different weather conditions. The studies were conducted at the Grabów Experimental Station of the Institute of Soil Science and Plant Cultivation in Puławy, Poland, in 2005-07. Oat was cultivated after winter triticale at 5 different levels of nitrogen fertilizers: 0, 30, 60, 90, and 120 kg N·ha^{-1} and under 3 plant protection strategies: A, B, and C were differentiated by biologically active ingredients. Grain yield, its components and quality were examined. The maximization of oat productivity and grain quality can be possible only under proper moisture conditions at a period from the beginning of the tilling stage (BBCH 21) to the end of panicle emergence (BBCH 59). The component deciding grain yield is a high number of grains per panicle. Both nitrogen fertilization and plant protection have a combined effect on oat grain, protein, and oil yields. Maximum grain yield increase equaled 2.26 t·ha^{-1}, protein yield 282 kg·ha^{-1}, and oil yield 73 kg·ha^{-1}.

Keywords: oat, nitrogen fertilization, plant protection strategy, grain yield, grain quality

Introduction

Besides high nutritive value of grain in human and livestock diet [1-5], oat is a valuable crop due to its yield increasing and phytosanitary role in cereal crop rotations [6-10]. Although grain yield and quality is genetically determined, it is strongly modified by weather conditions [5, 7, 9, 11, 12], which affect plant development, nutrient uptake ability and photosynthesis effectiveness. Many authors [4, 13, 14] have explained that weather conditions cause changes in plant assimilation area and photosynthesis rate, which determine the quantity of storage materials in the seed, and therefore about its biomass, and as a result about grain yield per unit area. Additionally, temperature and precipitation stimulate disease infestation, and each weather anomaly can meaningly modify grain yield and quality.

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The cereal grain yield is created by three components: number of panicles per unit area, number of grains per panicle, and weight of 1,000 grains (WTG), which are often negatively correlated with each other [15, 16]. This motivates complicated relations between plants in the canopy and between plant organs. According to Mazurek [15], the number of panicles is modified mainly by agronomical measures, like nitrogen fertilization, sowing time, and rate. The number of grains per panicle is qualified genetically and by environmental factors that affect the number of fertile florets. The insufficient supply of nutrients and water during early plant development stages or poor effectiveness of photosynthesis can decrease the number of fertile flowers and the number of grains the in panicle as a result. WTG is related to the physiological functionality of the genotype and length of the assimilation period.

The role of agronomical measures is to provide optimal conditions for crop growth, and development under specific weather conditions and protection of assimilation organs and limitation of yield losses [15]. An appropriate choice of oat varieties with major yield components suitable for the region and yield-forming and protection measures can lead to success in oat production and provide a proper stand for the successive crops. Nitrogen is one of the most important factors influencing plant growth and development, and therefore final grain yield and quality of oats [5, 17]. It increases the number of panicles per unit area and panicle productivity by modifications of the number of grains per panicle and WTG and, as a result, grain yield per unit area [5, 18-22]. In most studies [22-24], the negative effect of intensive nitrogen fertilization on oat grain plumpness is evident. At early development stages of oats, plant nitrogen stimulates the creation of tillers and spikelets in panicle; at the shooting stage nitrogen protects against excessive reduction of tillers and spikelets, and therefore it enables big numbers of grains per panicle. In the period between flag leaf extension and the beginning of anthesis, nitrogen stimulates the effectiveness of assimilation organs and production of grain biomass. During maturity, nitrogen affects grain quality [7, 25]. Restriction of N supply in any development stage can reduce grain yield by up to 65% [17]. However, good effectiveness of nitrogen fertilization is possible only under appropriate temperature and precipitation conditions [18, 26].

Although the crop is attacked by a lower number of pathogens than other cereals, it still should be protected against losses of potential grain yield [27-30]. Plant protection is usually aimed at stimulating plant development and to increase resistance to fungal diseases. For these aims specific programs are recommended to producers. However, they are effective only under warm and wet weather conditions that are favorable for both grain yield increase and fungal disease infestation.

According to common opinion, nitrogen fertilization increases the susceptibility of plants to fungal diseases, and therefore the interaction between nitrogen dose and plant protection strategy can be expected.

In order to provide a maximal protein and oil yield, oat grain should also meet high quality demands. However, grain protein and oil contents, which are genetically determined, are even more than quantity of grain yield dependent on many external factors, especially on weather conditions and nitrogen fertilization [7, 9, 11, 25, 31-36].

The purpose of this study was to test the effectiveness of three systems of oat protection against fungal diseases with the full range of fertilizer rates. Grain yield, its components and grain quality were the focus of this research.

Experimental Procedures

Our studies were conducted over the years 2005-07 at the Grabów Experimental Station [E 21º39', N 51º21') of the Institute of Soil Science and Plant Cultivation in Puławy, Poland. Oat variant Cwał (2005-06) and var. Szakal were cultivated in a two-factor experiment set up according to a split-plot design in four replicates. The first experimental factor was nitrogen applied at the following rates: 0, 30, 60, 90, and 120 kg N·ha^{-1} (Table 1). The second factor was plant protection strategy: A, B, and C based on triazols and morfolins, triazols and quinozolins, and benzimidazoles and triazols, respectively, and control treatment (Table 2). Lower fertilizer rate 30 kg N·ha^{-1} was applied at tilling stage (BBCH 21). Higher rates were applied in two splits: 30 or 60 kg N·ha^{-1} at tilling (BBCH 21) and additional 30 or 60 kg N·ha^{-1} at shooting (BBCH 31). The long-term experiment was located on a highly heterogeneous soil that was classified partly as stagnic livisol and partly as pseudo podzolic. In cereal crop rotation the oat was seeded after winter triticale. The single plot area equaled 28.8 m^2. After harvest at full maturity stage (BBCH 91), grain yield per plot was determined. Yield components, i.e. number of panicles per 1 m^2, number of grains per panicle, and weight of 1,000 grains (WTG), were assessed in the plant samples taken from the 1 m^2 area in the middle of each plot. Grain quality parameters, i.e. protein and oil content, were determined on 300 g samples taken from each plot in a chemistry lab. The grain crude protein content was estimated according to Kjeldahl method and total oil by the classic extractive-weight Soxhlet method. Protein and oil yields were calculated as a ratio of the grain yield to the appropriate concentrations in grain dry matter. All data were statistically processed using analysis of

Table 1. Nitrogen fertilization rate and term.

Total N rate [kg N·ha^{-1}]	1st rate			2nd rate		
	Year and days after sowing					
	2005	2006	2007	2005	2006	2007
	20	11	25	50	39	51
0	-			-		
30	30			-		
60	30			30		
90	60			30		
120	60			60		

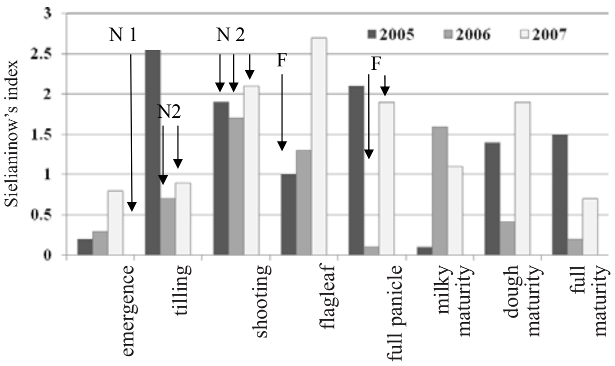

Fig. 1. Sielianinow's index in the periods between oat development stages.
N1-1st N rate, N2-2nd N rate, F-fungicides.

Table 2. Strategies of oat fungicide protection.

Year	Plant protection strategy	Active group	Biologically active ingredient [g·l⁻¹]	Rate [l·ha⁻¹]	Development stage [BBCH]	Days after sowing
2005	A	triazols	propikonasol 250	0.50	43-45	67
	B	triazols	fluzilasole 125	1.00	43-45	67
	C	benzimidazoles	carbendazim 250	0.60	43-45	67
2006	A	triazols	propikonasol 125	1.00	50-51	60
		morfolins	fenpropidin 27			
	B	triazols	fluzilasole 125	1.00	50-51	60
	C	benzimidazoles	thiophanate-methyl 310	0.80	50-51	60
		triazols	epoxiconazole 187			
2007	A	triazols	propikonasol 125	1.00	52-53	66
		morfolins	fenpropidin 27			
	B	quinozolins	proquinazid	0.15	52-53	66
		triazols	fluzilasole 125	1.00	52-53	
	C	benzimidazoles	thiophanate-methyl 310	0.60	52-53	66
		triazols	epoxiconazole 187			

variance by means of Statgraphics 5^{+} statistical package. The significance of the differences between treatments (e.g. protection strategy, N rates and their interaction) were estimated by Tukey's test at α=0.05 confidence level.

Weather data originated from the Grabów meteorological station located close to the experimental field. The data were used for calculations of Sielianinow's index (K), which allows us to describe the relations between grain yield, its components and quality, and moisture conditions during oat development stages. The index defines proportion of precipitation sum (P) and sum of mean daily temperatures (t) during the period $K=10P/\sum t$, and it is useful for assessments of agro climatic drought duration and intensity [37]. The value K<1 means, that a plant uses more water than is supplied with precipitation. K<0.5 means that water supply is 2 times exceeded by evaporation.

Results

Weather conditions differed during the period April-July in the years under study (Table 3). The year 2005, the most favorable year for oat production, was characterized by the lowest mean daily temperature (14.6ºC) and the highest seasonal total precipitation (273 mm). Both 2006 and 2007 were not satisfactory for oat production with similar but higher mean daily temperatures (15.6ºC and 15.5ºC), and lower total precipitation (132 mm and 263 mm, respectively).

The moisture distribution during vegetation period described by Sielianinow's index showed poor conditions from sowings to full emergence in all studied years, especially in 2005 and 2006 (K=0.2 and K=0.3, respectively) (Fig. 1). Vegetation period 2005 was distinguished by excessive precipitation (K=2.6) between full emergence and the tilling stage and drought (K=0.1) at the beginning of grain filling. The year 2006 was generally dry. However, good moisture conditions (K>1) lasted in the period from shooting to full milky maturity stage. In the year 2007 dry period (K<1) stayed only from sowings to full tilling stage and at the end of grain filling. The other development stages were characterized by sufficient water supply.

Oat grain yield was significantly affected by weather conditions in study years and both experimental factors (Table 4). However, the only significant interaction

Table 3. Weather conditions in 2005-07.

Month	Mean daily temperature [ºC]				Precipitation sum [mm]			
	2005	2006	2007	Multi-year mean	2005	2006	2007	Multi-year mean
April	8.6	9.0	8.7	7.5	10.2	30.1	13.3	42
May	13.5	13.6	15.2	12.4	84.0	53.4	74.6	53
June	16.1	17.4	18.7	16.7	46.3	38.3	99.9	110
July	20.0	22.4	19.2	17.8	132.8	10.0	75.5	105

Table 4. Grain yield and yield components of oat.

Factor		Grain yield [kg·ha^{-1}]	Number of panicles per m^2	Number of grains per panicle	Weight of 1,000 grains
Year	2005	5,198	372	45.37	31.37
	2006	3,600	401	28.05	32.18
	2007	3,253	485	19.83	34.88
	LSD	390	30.7	5.805	0.688
Nitrogen rate [kg·ha^{-1}]	0	3,123	427	22.30	32.61
	30	3,826	423	28.84	32.58
	60	4,277	424	32.60	32.55
	90	4,374	409	35.89	31.49
	120	4,485	413	35.80	31.83
	LSD	104	n.s.	2.946	0.816
Plant protection strategy	control	3,970	416	30.73	32.94
	A	4,082	413	32.40	32.62
	B	4,010	430	30.50	33.05
	C	4,006	419	30.71	32.63
	LSD	93	n.s.	n.s.	n.s.

*n.s. – not-significant difference

occurred between study year and nitrogen fertilization (Fig. 2). The highest grain yield was noted in 2005 and it was similar both in 2006 and 2007 with the tendency to decrease in 2007. Nitrogen fertilization increased grain yield up to a dose of 60 kg N·ha^{-1} in 2005 and 2007, and up to 30 kg N·ha^{-1} in 2006. The efficiency of nitrogen fertilization was higher in 2005 than in both 2007 and 2006. Among the strategies of plant protection against diseases only A strategy fungicides significantly increased oat grain yield compared to the control. There was no significant interaction between nitrogen rate and plant protection strategy. Application of fungicides was effective only in 2007.

Yield components were strongly related to weather conditions in study years and nitrogen fertilization, while plant protection had practically no influence (Table 4). Weather conditions differentiated the effects of both nitrogen fertilization and plant protection systems on the number of panicles per m^2. The highest effect of nitrogen and plant protection was noted in 2007.There was also a significant interaction between nitrogen fertilization and plant protection system (Fig. 3). It depended on significant increase of panicle number by C and B fungicides compared to A at 120 kg N·ha^{-1} rate.

Weather conditions also influenced the effect of nitrogen fertilization on the number of grains per panicle (Fig. 4). The rates up to 90 kg N·ha^{-1} significantly increased the number of grains per panicle in 2005 and 2007, and there was only a marginal effect (up to 30 kg N·ha^{-1}) in 2006 (Fig. 4). The most effective nitrogen fertilization was in 2005, when the

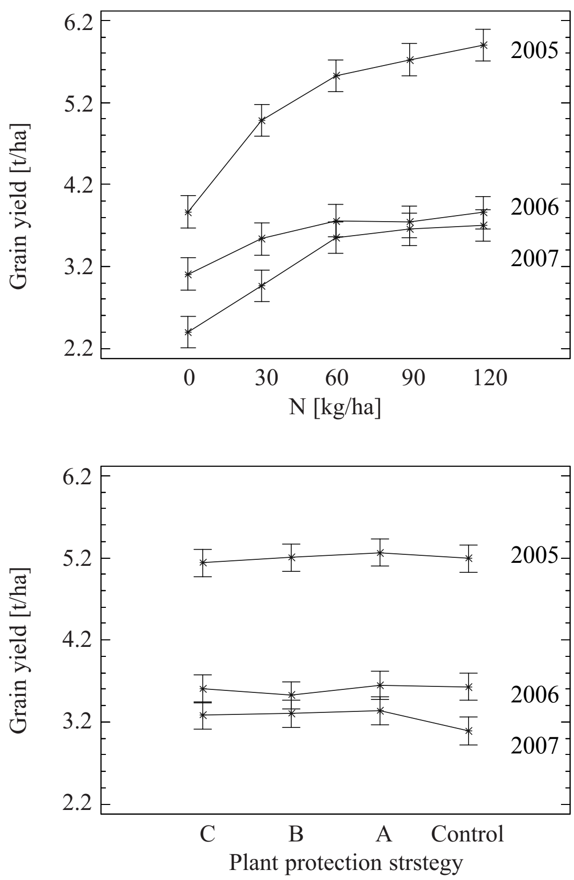

Fig. 2. The effect of interactions between study years and nitrogen fertilization and plant protection on oat grain yield.

number of grains per panicle increased by about 24. Plant protection was effetive also only in 2005 for all strategies at the lowest (0 and 30 kg N·ha^{-1}) nitrogen rates, for C strategy at 60 kg N·ha^{-1} and for A fungicides at the highest (90 and 120 kg N·ha^{-1}) nitrogen rates.

WTG significantly decreased under the influence of nitrogen fertilization in all study years and it was not affected by the fungicides (Table 4).

Grain protein and total oil contents were influenced by both weater conditions in the study years, nitrogen fertilization and plant protection system (Table 5). The highest protein content in grain was noted in the warm and dry year 2006 and the smallest – in a warm and wet 2007. Nitrogen fertilization each year increased protein content up to 120 kg N·ha^{-1} by about 0.7%. Among plant protection systems only C fungicides increased grain protein content compared to control. Oil content was at the highest level in 2005 (i.e. the most profitable year for oat production and, simultaneously, to grain yield). It decreased in the following years. Among plant protection strategies only B fungicides significantly decreased oil content. There was no significant interaction between nitrogen fertilization and plant protection programs for both parameters.

Yield of both grain protein and oil decreased in the following study years and weather conditions differentiated the nitrogen fertilization effect (Table 5, Fig. 5). Protein yield in 2005 increased according to N rate increase. In 2006 and, especially, in 2007 it increased up to 60 N·ha^{-1} and higher N rates did not influence grain protein content. As a consequence, at treatments from 60 to 120 kg N·ha^{-1} protein content did not differ much in 2006 and 2007, and diminished considerably compared to 2005. Oil yield per unit area increased up to the rate of 60 kg N·ha^{-1} in 2005 and 2007, and only up to 30 kg N·ha^{-1} in 2006. It caused a small difference between oil yield in 2005 and 2006 at the control increased at the higher-rate treatments and considerable

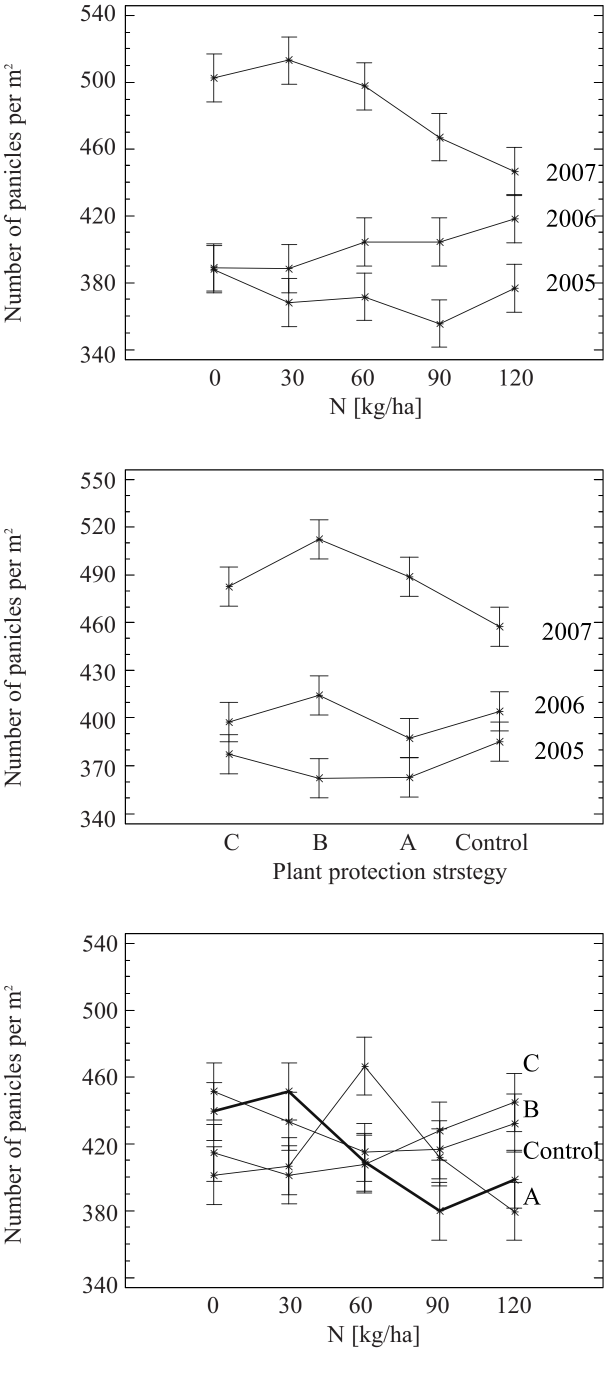

Fig. 3. The effect of interactions between study year, nitrogen fertilization, and plant protection on the number of oat panicles per m^2.

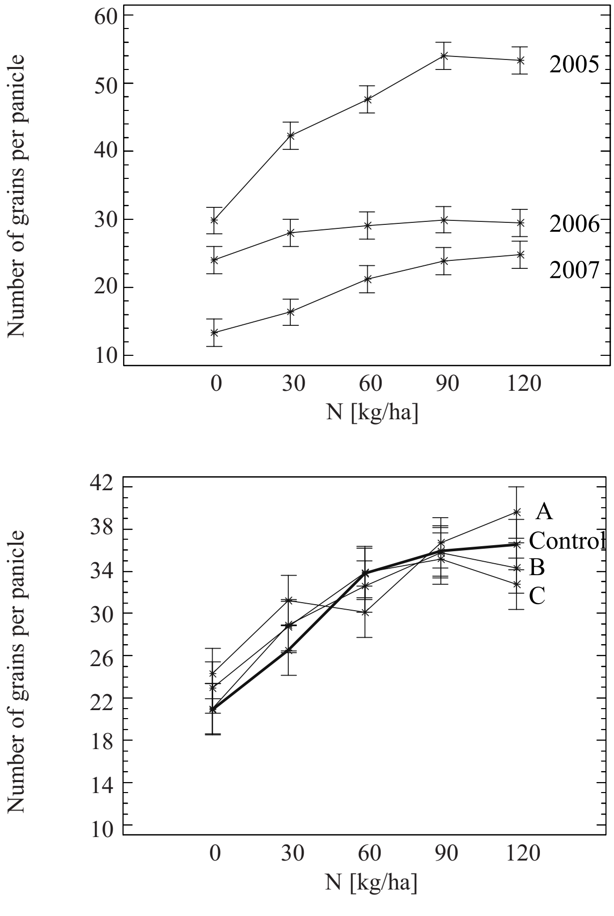

Fig. 4. The effect of interactions between study year and nitrogen fertilization, and plant protection on the number of grains per panicle.

Table 5. Parameters of oat grain quality.

Factor		Grain protein content [%]	Grain oil content [%]	Protein yield [kg·ha-1]	Oil yield [kg·ha-1]
Year	2005	11.43	7.50	596	196
	2006	11.97	3.98	431	145
	2007	10.80	3.01	353	98
	LSD	0.126	0.318	47.6	13.0
Nitrogen rate [kg·ha-1]	0	11.07	4.84	348	116
	30	11.18	5.03	429	143
	60	11.44	4.82	489	157
	90	11.54	4.85	505	157
	120	11.78	4.63	529	158
	LSD	0.111	n.s.	14.5	4.6
Plant protection strategy	control	11.36	4.97	453	145
	A	11.37	4.89	465	149
	B	11.42	4.56	460	146
	C	11.46	4.92	462	146
	LSD	0.100	0.318	n.s.	n.s.

*n.s. – not-significant difference

smaller oil yield in 2007 became closer to 2006. Among plant protection systems only A showed a slight tendency to increase both yields.

Discussion

In all study years, variations in oat parameters, i.e. grain yield, its components and quality were strongly dependent on weather conditions. 2005 was recognized as profitable for oat production while both 2006 and 2007 were not profitable. 2005 was cool and wet and 2007 was warm and wet. 2006 was warm and dry.

Besides similar precipitation, 2005 and 2007 were differentiated by the pattern of moisture conditions during the vegetation period. According to Doehlert et al. [11] the best oat yields with high quality grain are generated by warm, bright (high solar radiation) spring weather and cooler summer weather without excessive rains during grain filling. The results of Michalski et al. [12] showed the decrease of oat productivity according to mean temperature increase in the period from April to July, and May was the most important month. The discussed results confirmed the relationships. The higher temperatures of the mentioned period in 2006 and 2007 than in 2005 decreased oat yield. Additionally, the highest mean temperature in May 2007 decreased yield compared to 2006 despite the higher precipitation sum.

The results of the studies confirm the opinion of many authors that grain yield is genetically determined but is strongly modified by weather conditions [9, 11].

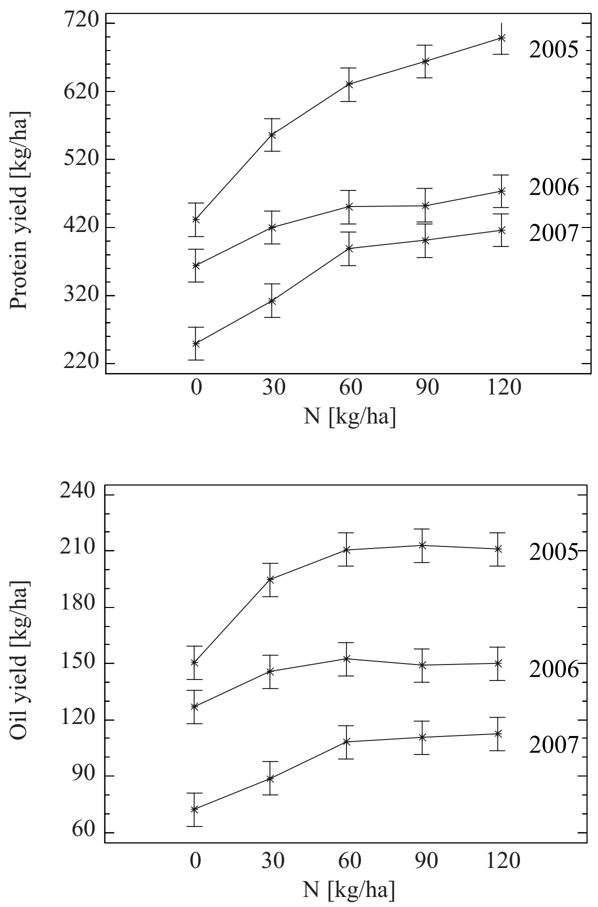

Fig. 5. The effect of interaction between study year and nitrogen fertilization on grain protein and oil yields.

Table 6. Contribution and share of yield components in the difference between oat grain yield in 2005, 2006, and 2007.

Yield and yield components	Year		Effects of yield components		
			contribution		share
	2006	2005	t·ha^{-1}	%	%
Grain yield [t·ha^{-1}]	3.60	5.20	-	-	-
Panicles per 1 m^2	401	372	-0.12	-3.31	-7
Grains per 1 panicle	28.1	45.4	1.77	49.1	110
WTG	32.3	31.4	-0.05	-1.34	-3
Total			1.60	44.4	100
Estimation error			12.7		
	2007	2005	t·ha^{-1}	%	%
Grain yield [t·ha^{-1}]	3.25	5.20	-	-	-
Panicles per 1 m^2	485	372	-0.13	-3.97	-7
Grains per 1 panicle	19.8	45.4	2.14	65.94	110
WTG	34.8	31.4	-0.06	-1.96	-3
Total			1.95	60.00	100
Estimation error			7.46		
	2006	2007	t·ha^{-1}	%	%
Grain yield [t·ha^{-1}]	3.60	3.25	-	-	-
Panicles per 1 m^2	401	485	0.69	19.2	197
Grains per 1 panicle	28.1	19.8	-0.57	-15.7	-162
WTG	32.3	34.8	0.23	6.30	65
Total			0.35	9.72	100
Estimation error			11.9		

Saastamoinen [32] pointed that oat cultivars adopt to climatic changes in different ways. Lower yielding Cwał cultivar was cultivated in more profitable years for oat grain yield (2005-06) and high yielding Szakal cultivar – in an unsatisfactory 2007.

The highest grain yield in 2005 resulted from a great number of grains per panicle, while the number of panicles per unit area and weight of 1,000 grains were the smallest that year. In the year of the lowest oat productivity (2007), both the lowest number of grains per panicle and the highest number of panicles per m^2 and WTG were recorded. This confirms compensation by the plant for the reduced number of panicles per unit area.

The contribution of structural yield components in the differentiation of grain yield dependent on two levels of studied factor can be best estimated by the method proposed by Rudnicki [16]. The data in Table 6 showed that the differences in grain yield between 2005 and two other years resulted almost exclusively from the high number of grains per panicle, which compensated successfully for the lower number of panicles per square meter. The compensation phenomena and other complicated relations between plants in the canopy and between plant organs are well known in literature and were described by many authors [14-16]. The difference between grain yield in 2006 and 2007 resulted mainly from different panicle number per unit area. The reasons for differentiation of both yield components are lying in the weather condition patterns during their initiation, i.e. at the tilling stage. The period from plant emergence to full panicle emergence in 2005 was characterized by sufficient moisture conditions that enabled utilization of nitrogen supply and initiation of florets at tilling stage (K=2.6) and prevented their reduction at the following stages. Drought (K=0.1) at the beginning of milky maturity stage limited photosynthesis and the biomass accumulation processes, and as a result decreased WTG. The smallest number of grains per panicle was noted in 2007, resulting from the deficit of precipitation in the period from sowing till the end of tilling. Limited panicle initiation and even sufficient moisture conditions at succeeding stages did not help. A smaller number of grains per panicle in 2006 compared to 2005 was due to worse moisture conditions at tilling (K=0.7) and, later on, drought at anthesis (K=0.1) restricted the number of fertile florets.

Table 7. Maximal effect of nitrogen fertilization and plant protection (SYNGENTA program) on grain yield.

Year	Grain yield [t·ha^{-1}] increase as a result of			
	nitrogen fertilization	plant protection (A strategy)	additive	combined
2005	2.04	0.07	2.11	2.26
2006	0.75	0.01	0.76	0.80
2007	1.30	0.25	1.55	1.57
Average	1.36	0.11	1.47	1.54

The smaller number of panicles per unit area, which decreased grain yield in 2007 in comparison to 2006, resulted from drought at the period from sowing to the end of tilling (0.3>K>0.7), and then at panicle emergence (K=0.1). Additionally, drought (0.2>K>0.4) at grain maturity stages limited its biomass and hastened the harvest.

Moisture conditions differentiated the effect of nitrogen supply. The highest nitrogen efficiency was recorded in 2005 and the smallest in 2007 and 2006. Optimal nitrogen rates, which provided 95% of maximal grain yield in 2005-07, were 65, 48, and 33 kg N·ha^{-1}. In 2005 all rates of nitrogen fertilization were effective mainly for the number of grains per panicle. That means that moisture conditions enabled utilization of nitrogen supply at the tilling and shooting stages. In 2006 nitrogen at rates up to 120 kg N·ha^{-1} influenced panicle number, and the number of grains increased only up to 30 kg N·ha^{-1}. In 2007 nitrogen increased grain numbers per panicle. The structural efficiency of nitrogen calculated for 1 kg N·ha^{-1} equaled 3.50 panicles per m^2 and 0.51 grains per panicle in 2005, 4.07 panicles and 0.296 grains per panicle in 2006, and 4.38 panicles and 0.23 grains per panicle in 2007.

Plant protection was effective only in 2007, the only year when fungicides were applied at panicle emergence under high moisture conditions (K=2.7) that lasted until dough maturity stage. Under conditions of better utilization, higher nitrogen rates fungicides stimulated panicle numbers per unit area. Despite the positive interaction between nitrogen fertilization and plant protection, the combined influence of both factors on grain yield occurred (Table 7).

Both protein and oil contents were differentiated by weather conditions in the study years and by agronomical measures. Although weather conditions in 2005 and 2006 were evidently different, it should be noticed that the same Cwał cultivar was cultivated. The highest WTG produced under profitable moisture conditions at the grain filling stage in 2007 was combined with smaller protein and oil contents. The phenomena is well known in literature and it depends on the relationships between endosperm and storage material accumulation in grain [38]. The smallest grain (WTG) formed under drought conditions at milky maturity stage in 2005 was rich in these ingredients. The response of protein and oil yields was in agreement with grain yield.

Nitrogen fertilization increased grain protein content and protein and fat yields and showed a negative effect on fat content. According to the linear regression curve, the increase of nitrogen dose by 1 kg N·ha^{-1} increased grain protein content by 0.0059%, decreased fat content by 0.002% and increased protein yield by 1.46 kg·ha^{-1} and fat yield by 0.32 kg·ha^{-1}.

Plant protection against fungal diseases caused only the tendency to increase grain protein and fat yields. Among studied strategies, A was more effective. Similar to grain yield, nitrogen fertilization and plant protection against fungal diseases showed the combined influence of both factors on protein and oil yield (Table 8).

Conclusions

1. Oat grain yield and quality are positively correlated and both are dependent on the moisture conditions during the vegetation period.
2. The component determining grain yield is a high number of grains per panicle. High yield can be achieved by a moderate number of panicles per m^2 (about 400).
3. Maximization of crop productivity and grain quality is possible only under proper moisture conditions in the period from the beginning of the tilling stage (BBCH 20) to the end of panicle emergence (BBCH 59). Adequate moisture conditions enable the effects of nitrogen fertilization and plant protection measures.
4. Nitrogen fertilization and plant protection have a combined effect on oat grain yield and quality.
5. Oat protection systems against fungal diseases show similar effects on grain yield and quality.

Table 8. Maximal effect of nitrogen fertilization and plant protection (SYNGENTA program) on protein and fat yields.

Year	Protein and oil yields [kg·ha^{-1}] increase as a result of							
	nitrogen fertilization		plant protection (A strategy)		additive		combined	
	protein	oil	protein	oil	protein	oil	protein	oil
2005	267	61	2	6	269	67	282	73
2006	110	23	5	0	115	23	120	22
2007	167	40	27	5	194	45	200	45
Average	181	41	11	4	193	45	201	47

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