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REGULAR ARTICLE

How do mineral fertilization and plant growth regulators affect yield and morphology of naked oat?

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ABSTRACT

Oat (*Avena sativa* var. *nuda*) is of an increasing interest in many parts of the world. This is why plant breeders have developed forms that are morphologically different from the current ones, such as naked, dwarf or with an increased 1000-grain-weight. In three experiments conducted at two sites, the influence of phosphorus (P) and potassium (K) fertilizers, spray application of urea and spray application of plant growth regulators (PGRs) Promalin (gibberellins + cytokinin) and Moddus (cimectacarps) on the yield and morphological traits of different oat forms were studied. At a better site, only genotype statistically influenced oat grain yield. At a poorer site, apart from genotype there were statistically significant responses to P and K fertilizers and to the application of Moddus (especially in the experiment with a dwarf cultivar). The internode and panicle length were modified mostly by cimectacarps, which shortened specific internodes, but not the panicle. The PGR Promalin had no significant effect on oat stem morphology.

Key Words: *naked oats; grain yield; stem morphology; fertilization; plant growth regulator.*

INTRODUCTION

Oat (*Avena sativa* var. *nuda*) grain and straw have more and more different ways of being utilized. This has lead to their increased cultivation. Achieving good production is made difficult by lodging. The level of oat lodging depends on many factors stimulating aboveground biomass accumulation. The most significant factors seem to be plant genotype, plant morphology, weather, and agronomic factors such as fertility, seeding rate, soil moisture, growth regulator application, and their interactions (Pinthus, 1973; Brown, et al., 1980; Muldoon, 1986, Peltonen and Peltonen-Sainio, 1997; Berry et al., 2000; De Rocquigny, 2004; Petersom et al., 2005; Peltonen-Sainio et al., 2006; Zhang et al., 2006).

Until 2005, only oats did not have registered or permitted use of plant growth regulators (PGRs) in Poland for utilization. Nevertheless, Lee et al. (1988), Rajala (2003) and

Auskalniene et al. (2006) confirmed that oat responded similarly to other grasses when treated with CGA 163 935 (cimectacarps). Peltonen and Peltonen-Sainio (1997) and Peltonen-Sainio and Peltonen (1997) did not observe any significant influence of gibberellins (GA) on the crop and its components, but there was temporary growth of foliage. Wojcieska (1992) showed a slight influence on the number of spikelets and flower fertility, but a lack of influence of GA on the crop and its components. Due to this, it was of interest to analyze the behavior of dwarf plants after application of GA, especially changes in the density of panicle bearing tillers. Tiller height is also influenced by mineral fertilizer, especially by soil and foliar N application (Wojcieska, 1992; Peltonen and Peltonen-Sainio, 1997; Berry et al., 2000; Kozłowska-Ptaszynska, 2000; De Rocquigny, 2004). Morphological modifications of oat plants have long after-effects and are also physiological (Rajala, 2003) because of the linear dependence between root dry mass and above-ground dry mass (Mc Key, 1998).

The aim of this research was to analyze differences in the morphology, grain yield and its components among different forms of naked oat (short or tall or with an increased 1,000 seed weight) resulting from P, and K fertilizers and spray application of urea and PGRs.

MATERIALS AND METHODS

The field experiments were carried out at Wierzbica (50°29′ N, 19°45′ E) and Prusy (50°07′ N, 20°04′ E) in 2003. At Wierzbica the soil of the experimental plots was a brown loam and contained 8.5 mg P 100 $g^{-1}$and 6.5 mg K 100 g^{-1}. It had a pH (H_2O) of 5.4. The physico-chemical properties of the soil in the top 0–27 cm layer were: 43% clay, 44% silt and 7% sand. We used the oat cultivar Akt and STH 4770 oat strain with an increased 1,000 seed weight, and the dwarf oat strain STH 7000. The field experiment was a 2^{5-1} fractional factorial design with two complete blocks (fundamental identity I=12345, resolution R=V). The plot area was 6 m^2. The crop and its components were estimated based on a sample area of 1 m^2. The seeding rate was 500 viable seeds m^{-2}. Experimental factors and their levels are given in Table 1.

Table 1. Factors and their levels in experiments I and II at Wierzbica

Agronomic factor	Factor level	
	Low	High
Cultivar/strain (Experiment I)	Strain STH 4770	cv. Akt
Cultivar/strain (Experiment II)	Strain STH 7000	cv. Akt
P and K fertilization, kg ha^{-1}	0	226
N foliar fertilization, kg ha^{-1}	0	17
Moddus plant growth regulator, active ingredient, g ha^{-1}	0	100
Promalin plant growth regulator, active ingredient, g ha^{-1}	0	5.4

At Prusy the soil was loess, and contained from 10.6 to 23.2 mg P 100 g^{-1}, from 11.5 to 25.6 mg K 100 g^{-1} with a pH (H_2O) of 6.8. The physico-chemical properties of the loamy soil in the top 0–30 cm layer were as follows: 46% clay, 53% silt and 1% sand. Because of the better site, the cultivars evaluated at Prusy were shorter than the model strain. This was meant to reduce lodging. The experiment was conducted according to a 3^{4-1} Box-Behnken's fractional factorial design with two replicates with maximum resolution (R=IV, maine effects and two-factor interactions did not confound and two factor interactions did not confound with any other). The plot dimension to be harvested was 10 m^2 and the sowing density was 500 viable seed m^{-2}. Agronomic factors and their levels are given in Table 2.

Meteorological data for Wierzbica were taken from the meteorological station at Pilica, situated 10 km from the experimental field. In the case of Prusy, the source was an automatic weather station located close to the experimental field (Table 3).

Table 2. Factors and their levels in the experiment at Prusy

Agronomic factor	Factor level		
	Low	Medium	High
Cultivar/strain	Strain STH 7000	cv. Akt	Strain STH 4770
P and K fertilization, kg ha^{-1}	0	72 P	256 PK
N foliar application, kg ha^{-1}	0	9	18
Moddus plant growth regulator, active ingredient, g ha^{-1}	0	100	150

Table 3. Rainfall and air temperature, 2003

Indicator	Month				Total
	April	May	June	July	
Oat water need (Dzieżyc, 1989), mm	60.0	78.0	90.0	72.0	300.0
Wierzbica					
Rainfall, mm	50.9	95.0	29.7	94.2	269.8
Deficit/Excess, mm	-9.1	+17.0	-60.3	+22.2	-30.2
Prusy					
Rainfall, mm	40.9	92.3	40.0	44.8	218.0
Deficit/Excess, mm	-19.1	+14.3	-50.0	-27.2	-82.0
Rainfall average 1961–1990, mm	48.0	67.0	88.0	90.0	293.0
Temperature, ^{o}C	7.0	14.1	15.4	17.9	–
Temperature average 1961–1990, ^{o}C	7.9	13.1	16.2	17.5	–

At both places, the level of fertilizer used assumed a naked oat grain yield of 4 t ha^{-1} and the nutrients present at the two sites. The urea spray was 25 % of N applied to the soil (17 kg ha^{-1} at Wierzbica and 9 kg ha^{-1} at Prusy). The higher rate of urea at Prusy was the result of doubling the low rate, which approximately gave the rate that was applied at Wierzbica. Cimectacarps (CGA 163 935- trinexapac-ethyl) at 250 g 1 dm^{-3} is the active agent in the PGR Moddus. The gibberellins (A_4 + A_7 -1.8%) and cytokinin (6-benzyloadenin (N-(phenylmethyl)-1H-purine 6 amine) -1.8%) are the active agents in the PGR Promalin. All compounds were applied as a foliar spray at the first node phase (31 on the Zadoks scale).

The null hypothesis was tested by the F-test. To facilitate comparison of the influence of individual factors, standardized regression coefficients are given in the tables, together with significance levels confirming statistical significance of the relevant variable. For factors appearing at three levels a deviation from linearity was also estimated (quadratic effect coefficient). Interactions were not taken into account in both ANOVA and regression models, because most of them were not statistically significant. In the case of the fourth node and fifth internodes, statistical analysis was not conducted because of the different number of these elements in individual experimental objects (lack of orthogonality). Morphological traits were determined by measuring 15 stems from every plot.

RESULTS AND DISCUSSION

GRAIN YIELD AND YIELD COMPONENTS

The analysis of the rainfall level and distribution confirms that Wierzbica had better conditions for oat growth and development (Table 3). At Wierzbica, there were lower levels of water deficit or excess rain during each month of vegetative growth according to plant needs (apart from June). This resulted in a small rainfall deficit at Wierzbica and an almost three times higher water deficit at Prusy during vegetative crop development. Thus there was a better rainfall distribution at Wierzbica. Rainfall deficits were more frequent at Prusy compared to the long-term mean.

The results confirmed the influence of agronomic factors on naked oat yield (Tables 4 and 5). At Wierzbica, both strains STH 4770 (tall strain) and STH 7000 (dwarf strain) gave lower yields than the cv. Akt. In both cases the differences were statistically significant (0.465 and 0.394 standard deviation unit). At Prusy, the yield of STH 7000 was considerably lower than that of cv. Akt, which was slightly less than that of STH 4770. No other agronomic factor had a statistically significant effect on grain yield.

Table 4. Oat grain crop and yield components at Wierzbica. Details about treatment factors and levels are given in Table 1

Factor	Experiment I[a]			Experiment II		
	Low	High	Coefficient	Low	High	Coefficient
Grain yield (g m^{-2})						
Cultivar/strain	505.6	567.2	0.465**	500.2	567.2	0.394*
PK	509.0	563.9	0.414*	493.4	574.1	0.474**
N	544.2	528.7	-0.117	536.5	530.9	-0.033
Moddus	537.7	535.2	-0.019	572.9	494.5	-0.460**
Promalin	538.6	534.3	-0.033	536.8	530.6	-0.036
Panicle density (number m^{-2})						
Cultivar/strain	351.3	470.3	0.856**	542.6	470.3	-0.557**
PK	411.2	410.5	-0.005	488.6	524.4	0.275
N	413.1	408.5	-0.033	506.6	506.4	-0.001
Moddus	406.7	414.9	0.059	520.6	492.3	-0.218
Promalin	406.5	415.2	0.062	495.8	517.2	0.165
Grains panicle^{-1}						
Cultivar/strain	47.65	46.99	-0.054	40.16	46.99	0.494**
PK	44.53	50.12	0.456*	40.58	46.57	0.433**
N	48.13	46.51	-0.132	44.16	42.99	-0.085
Moddus	48.17	46.48	-0.138	45.78	41.37	-0.319*
Promalin	47.65	46.99	-0.054	44.83	42.32	-0.181
1000-grain-weight (g)						
Cultivar/strain	30.44	25.85	-0.828**	23.07	25.85	0.686**
PK	28.28	28.01	-0.047	25.11	23.80	-0.324*
N	27.95	28.34	0.069	24.22	24.69	0.115
Moddus	28.05	28.24	0.035	24.43	24.48	0.013
Promalin	28.13	28.16	0.005	24.39	24.53	0.034

*, ** Significant respectively at α=0.05 and α=0.01 probability level

[a] Input factor level and standardized regression coefficient

Table 5. Oat grain crop and yield components at Prusy. Details about treatment factors and levels are given in Table 2

Factor	Input factor level			Standardized regression coefficient of effects		
	Low	Medium	High	Linear	Quadratic	Constant
Grain yield (g m^{-2})						
Cultivar/strain	4.59	5.88	6.20	0.600**	-0.273*	0.366
PK	5.93	5.49	5.72	-0.076	0.050	
N	5.58	5.65	5.72	0.052	-0.083	
Moddus	5.78	5.63	5.56	-0.079	0.066	
Panicle density (number m^{-2})						
Cultivar/strain	723.1	601.3	536.0	-0.183	-0.025	0.241
PK	537.8	644.5	627.8	0.088	-0.117	
N	675.7	583.0	623.2	-0.051	0.014	
Moddus	568.7	644.5	597.0	0.028	-0.117	
Grains $panicle^{-1}$						
Cultivar/strain	43.93	58.30	48.82	0.119	-0.342**	0.170
PK	56.95	49.65	54.54	-0.058	0.117	
N	48.77	54.34	52.57	0.092	-0.132	
Moddus	60.04	48.40	54.16	-0.143	0.184	
1000-grain-weight (g)						
Cultivar/strain	20.57	19.88	24.63	0.385**	0.381**	-0.498
PK	20.34	21.51	21.34	0.095	0.045	
N	20.39	21.39	21.55	0.109	0.070	
Moddus	20.60	21.68	20.72	0.012	0.010	

*, ** Significant respectively at α=0.05 and α=0.01 probability level

For Wierzbica, the analysis of standardized regression coefficients allows the conclusion that there were statistically significant influences of linear effects of genotype, P and K fertilizer and application of the PGR Moddus. At the poorer site (Wierzbica) changes in the level of P and K fertilizer gave a 0.414 and 0.474 increase in standard deviation units for experiments I and II, respectively. Spray application of the PGR Moddus lowered oat grain yield especially in the dwarf strain STH 7000, by almost 80 g m^{-2} (0.460 of a standard deviation unit).

Negative effects of PGR application on dwarf oat cultivars were reported by Peltonen-Sainio et al. (1997), where, apart from a decrease in yield, there was a significant drop in the values of indices describing foliage. Rajala and Penolten-Sainio (2002) reported both increases and decreases in oat yield under the influence of PGRs. Maciorowski et al. (2006) reported no effect of PGRs on grain yield or its components. In this study, there were significant changes in panicle density caused by genotype at Wierzbica, where the panicle density of cv. Akt was almost 0.856 of a standard deviation unit higher than the panicle density of STH 4770, but it was 0.557 of a standard deviation unit lower than the panicle density of STH 7000. At Prusy, the density of fertile panicle-bearing tillers was higher, but no significant effect was observed on panicle density. As expected, the number of grains in the panicles of cv. Akt at Prusy was higher (11 grains per panicle) than at Wierzbica. For STH 7000 and STH 4770 there were four and one more grains per panicle, respectively. In the experiment at the poorer condition there was a significant influence of P and K fertilization (> 0.4 units of standard deviation). With the dwarf strain there was an influence of Moddus

(0.319 unit of standard deviation). Peltonen and Peltonen-Sainio (1997) confirmed a significant influence of CCC and GA3 on structural components, especially grains panicle^{-1}. This study confirmed a small influence of spray application of urea.

Agronomic factors that increased grains panicle^{-1} were related to a decreased 1,000 seed weight. Strain STH 4770, at both sites, had higher values of this parameter (almost 30.44 g at Wierzbica and 25.63 g at Prusy). The lowest 1,000 seed weight was from STH 7000 (23.1 g at Wierzbica and 19.9 g at Prusy). At Wierzbica, in experiment II there was a significant influence of P and K fertilization on the 1,000 seed weight (-0.324).

STEM MORPHOLOGICAL STRUCTURE

Absolute lengths of individual oat stem elements, which were statistically different, were modified by the agronomic factors analyzed (Tables 6 and 7).

Cultivar/strain generally influenced the length of individual internodes at both sites. This resulted in different stem lengths. At Wierzbica, cv. Akt was 20 cm (0.627 of a standard deviation unit) shorter than STH 4770 and at the same time much taller than STH 7000 (0.658 of a standard deviation unit). Similar interdependencies were also observed in panicle length and of terminal node length. At Prusy, choice of cultivar/strain modified the length of all oat stem elements and, like at Wierzbica, the tallest was STH 4770 and the shortest STH 7000. Phosphorus and K fertilizer, at Wierzbica, increased individual internode length. Fertilizer also gave a statistically significant increase in panicle length, which accords with the increased number of seeds. Similarly, statistically significant results were seen in cv. Akt by Witkowicz et al. (2007). They showed that the number of grains in the panicle was determined to 43% by length and 56% by the number of spikelets, while the contribution of number of branches was negligible (1%). This was not observed at Prusy, but significant quadratic effects for this source of variability were established. This can be explained by the negative results of P fertilization (at a medium level) compared with both the control (lower level of P) and P and K fertilization (at a high level).

The results show that the PGR Moddus was the main factor modifying oat stem morphology at both sites. At Wierzbica, length of all stem elements decreased, in both experiments, except for the panicle. Similar responses to application of Moddus were observed at Prusy. However, the significant quadratic effect of this source of variability suggests there is no need for a high rate (150 g ha^{-1} active ingredient). Generally the PGR Promalin had no effect on the length of individual elements of the naked oat stem. Rajala and Peltonen-Saino (2002) reported that the dwarf oat cv. Pal did not respond to PGRs. Stem length was increased sometimes after application of CCC.

The situation slightly differs in the case of the influence of agronomic factors on individual stem elements expressed in relative values (Tables 8 and 9). The analysis of these values allows for observation of the drop of the share of specific stem elements in actual stem length. An exception occurs in the case of the 5th internode. Its more frequent appearance was in the tall strain STH 4770. At Wierzbica, application of Moddus was the only factor that had similar effects in both experiments. It was related to a statistically significant decrease of the share of specific internodes of actual stem length. At the same time, there was an increased share of panicle length to total length of stem. These results were considerably greater in the experiment with the tall strain STH 4770, which are expressed in the values of the standardized regression coefficients (Table 8). There are statistically significant differences in the share of individual stem elements between cv. Akt and strain STH 7000. The more favorable structure of the dwarf strain is the result of less partition to specific internodes in actual stem length and higher partition to panicle length of total stem length by 0.415 standard deviation unit (almost 3 cm). The lack of differences between cv. Akt and STH 4770 indicates a similarity in morphology of aboveground parts of these two oat forms.

Table 6. Length of specific oat stem elements (cm) at Wierzbica. Description of treatment factors and levels are given in Table 1

Factor	Experiment I[a]			Experiment II		
	Low	High	Coefficient	Low	High	Coefficient
1st internode						
Cultivar/strain	8.79	6.60	-0.332**	6.53	6.60	0.011
PK	7.45	7.94	0.074	6.06	7.06	0.162**
N	7.79	7.59	-0.030	6.46	6.65	0.030
Moddus	7.67	7.71	0.005	6.59	6.53	-0.008
Promalin	7.86	7.52	-0.050	6.63	6.48	-0.023
2nd internode						
Cultivar/strain	12.39	12.75	0.056	11.28	12.75	0.240**
PK	12.37	12.77	0.060	11.48	12.56	0.174**
N	12.40	12.74	0.052	11.71	12.34	0.103*
Moddus	13.31	11.83	-0.225**	12.92	11.13	-0.292**
Promalin	12.60	12.54	-0.009	11.86	12.18	0.052
3rd internode						
Cultivar/strain	19.29	22.50	0.235**	13.23	22.50	0.660**
PK	20.81	20.97	0.012	17.65	18.07	0.030
N	20.19	21.60	0.103*	17.27	18.46	0.085**
Moddus	22.68	19.10	-0.262**	19.29	16.43	-0.204**
Promalin	20.91	20.88	-0.002	18.00	17.72	-0.019
4th internode						
Cultivar/strain	33.29	34.04	0.029	19.44	34.04	0.664**
PK	32.57	34.76	0.106*	26.76	26.72	-0.001
N	32.95	34.38	0.060	26.02	27.46	0.064*
Moddus	37.00	30.33	-0.298**	29.71	23.77	-0.268**
Promalin	33.47	33.86	0.022	26.14	27.34	0.062*
5th internode						
Cultivar/strain	40.34	32.10	-0.534	23.48	32.10	0.636
PK	36.38	36.07	0.011	27.86	27.72	0.008
N	35.87	36.57	-0.041	26.79	28.79	0.115
Moddus	40.56	31.89	-0.448	31.46	24.13	-0.415
Promalin	36.30	36.14	0.048	28.10	27.49	0.034
Terminal internode						
Cultivar/strain	42.88	35.92	-0.398**	24.26	35.92	0.641**
PK	39.08	39.72	0.036	30.21	29.97	-0.013
N	38.72	40.08	0.077*	29.17	31.00	0.100**
Moddus	44.02	34.78	-0.528**	33.76	26.42	-0.404**
Promalin	39.27	39.53	0.015	30.20	29.97	-0.013
Panicle						
Cultivar/strain	21.60	17.75	-0.504**	16.12	17.75	0.274**
PK	19.10	20.25	0.151**	16.57	17.30	0.125**
N	19.54	19.80	0.034	17.03	16.84	-0.033
Moddus	19.67	19.67	-0.001	17.03	16.84	-0.033
Promalin	19.72	19.62	-0.014	17.06	16.81	-0.043
Stem						
Cultivar/strain	117.31	97.10	-0.627**	76.14	97.10	0.658**
PK	105.80	108.61	0.087**	85.31	87.93	0.082**
N	106.60	107.81	0.037	85.53	87.71	0.068*
Moddus	114.05	100.36	-0.425**	92.85	80.39	-0.391**
Promalin	107.91	106.50	-0.044	87.25	85.99	-0.039

*, ** Significant respectively at α=0.05 and α=0.01 probability level

[a] Input factor level and standardized regression coefficient

Table 7. Length of specific oat stem elements (cm) at Prusy. Description of treatment factors and levels are given in Table 2

Factor	Factor level			Standardized regression coefficients of effects		
	Low	Medium	High	Linear	Quadratic	Constant
1st internode						
Cultivar/strain	7.95	7.78	8.85	0.105*	0.103*	-0.128
PK	8.14	7.83	8.54	0.047	0.099*	
N	7.63	8.19	8.28	0.076	-0.000	
Moddus	7.44	8.44	7.92	0.056	-0.064	
2nd internode						
Cultivar/strain	9.68	11.03	11.69	0.181**	-0.025	-0.033
PK	11.45	10.26	11.59	0.013	0.126**	
N	10.27	11.11	10.94	0.061*	-0.040	
Moddus	10.67	11.05	10.67	0.000	-0.028	
3rd internode						
Cultivar/strain	12.12	17.16	16.15	0.269**	-0.199**	0.078
PK	15.98	14.73	17.89	0.117**	0.124**	
N	14.50	16.23	16.12	0.100**	-0.076*	
Moddus	16.72	15.11	16.33	-0.024	0.073	
4th internode						
Cultivar/strain	15.92	30.52	24.55	0.263**	-0.381**	0.254
PK	27.89	23.31	28.20	0.008	0.093**	
N	25.11	25.39	26.48	0.042	-0.042	
Moddus	29.83	23.58	25.68	-0.128**	0.076*	
5th internode						
Cultivar/strain	22.43	35.50	36.78	0.608	-0.297	0.258
PK	33.38	32.24	32.91	-0.039	-0.012	
N	33.24	32.30	32.92	-0.025	-0.029	
Moddus	36.46	30.94	32.63	-0.243	0.133	
Terminal internode						
Cultivar/strain	22.84	37.09	37.54	0.596**	-0.370**	0.357
PK	34.17	32.97	35.13	0.039	-0.007	
N	33.77	33.95	33.41	-0.014	-0.094*	
Moddus	39.08	31.58	33.22	-0.238**	0.114**	
Panicle						
Cultivar/strain	16.91	18.80	21.01	0.293**	0.053	-0.187
PK	19.26	18.54	19.22	-0.003	0.094*	
N	18.22	19.25	18.71	0.034	-0.017	
Moddus	18.87	18.77	19.11	0.017	0.058	
Stem						
Cultivar/strain	77.25	99.67	111.85	0.728**	-0.122**	0.045
PK	95.85	96.03	101.14	0.111**	0.044	
N	95.56	98.26	96.62	0.022	-0.057*	
Moddus	102.42	95.02	96.78	-0.118**	0.090**	

*, ** Significant respectively at α=0.05 and α=0.01 probability level

Table 8. Share of individual oat stem elements at current height (%) at Wierzbica. Description of treatment factors and levels are given in Table 1

Factor	Experiment I[a]			Experiment II		
	Low	High	Coefficient	Low	High	Coefficient
2nd internode						
Cultivar/strain	59.20	66.93	0.429**	64.95	66.93	0.106*
PK	63.53	62.61	-0.051	66.70	65.19	-0.081
N	62.36	63.77	0.078	65.69	66.19	0.026
Moddus	64.57	61.57	-0.167**	67.38	64.50	-0.154**
Promalin	62.71	63.42	0.039	65.50	66.39	0.047
3rd internode						
Cultivar/strain	47.38	53.75	0.431**	43.12	53.75	0.622**
PK	50.99	50.15	-0.057	49.51	47.35	-0.126**
N	49.93	51.20	0.085*	48.19	48.67	0.028
Moddus	51.45	49.68	-0.120**	48.76	48.11	-0.038
Promalin	50.46	50.66	0.014	48.69	48.18	-0.030
4th internode						
Cultivar/strain	44.37	45.45	0.081	38.22	45.45	0.464**
PK	44.67	45.16	0.045	42.78	40.89	-0.119**
N	44.47	45.37	0.068	41.67	42.00	0.018
Moddus	46.16	43.67	-0.194**	42.68	41.00	-0.105**
Promalin	44.61	45.22	0.053	41.34	42.34	0.069
5th internode						
Cultivar/strain	41.09	37.31	-0.366	36.18	37.31	0.060
PK	39.89	38.51	-0.040	37.77	35.72	-0.169
N	39.21	39.19	-0.084	36.22	37.27	0.102
Moddus	40.88	37.52	-0.233	38.29	35.20	-0.216
Promalin	39.25	39.15	0.043	37.24	36.25	-0.064
Terminal internode						
Cultivar/strain	44.84	45.07	0.017	40.56	45.07	0.307**
PK	45.13	44.77	-0.027	43.55	42.07	-0.101*
N	44.30	45.60	0.097*	42.28	43.35	0.073
Moddus	46.87	43.03	-0.287**	43.97	41.65	-0.158**
Promalin	44.49	45.41	0.069	42.76	42.86	0.007
Panicle						
Cultivar/strain	18.43	18.47	0.005	21.25	18.47	-0.415**
PK	18.16	18.74	0.099*	19.75	19.97	0.032
N	18.45	18.46	0.001	20.26	19.46	-0.120**
Moddus	17.19	19.72	0.432**	18.61	21.11	0.376**
Promalin	18.40	18.51	0.019	19.88	19.84	-0.006

*, ** Significant respectively at $\alpha=0.05$ and $\alpha=0.01$ probability level

[a] Input factor level and standardized regression coefficient

Table 9. Share of individual oat stem elements at current height (%) at Prusy. Description of treatment factors and levels are given in Table 2

Factor	Factor level			Standardized regression coefficients of effects		
	Low	Medium	High	Linear	Quadratic	Constant
2nd internode						
Cultivar/strain	55.31	58.36	56.30	0.331	-0.956*	0.574
PK	58.35	56.29	57.74	-0.206	0.540	
N	57.07	57.42	56.57	-0.164	-0.277	
Moddus	58.61	56.51	56.99	-0.539	0.376	
3rd internode						
Cultivar/strain	40.68	47.53	44.54	0.160**	-0.236**	0.109
PK	44.79	44.60	46.79	0.082*	0.027	
N	44.66	45.20	45.63	0.040	-0.026	
Moddus	47.46	43.50	46.51	-0.039	0.125**	
4th internode						
Cultivar/strain	34.38	45.28	39.46	0.206**	-0.433**	0.362
PK	42.86	40.64	41.02	-0.075*	-0.025	
N	42.65	40.42	41.72	-0.038	-0.004	
Moddus	45.13	39.22	41.83	-0.134**	0.099**	
5th internode						
Cultivar/strain	36.02	42.12	40.19	0.280	-0.346	0.460
PK	40.94	40.34	39.12	-0.093	-0.119	
N	41.58	39.75	39.75	-0.129	-0.037	
Moddus	42.23	38.89	40.97	-0.150	0.110	
Terminal internode						
Cultivar/strain	37.89	45.94	41.30	0.167**	-0.424**	0.450
PK	44.65	42.25	42.53	-0.104**	-0.030	
N	43.51	42.64	42.82	-0.034	-0.072*	
Moddus	46.72	41.25	42.62	-0.202**	0.076*	
Panicle						
Cultivar/strain	21.79	18.78	18.72	-0.257**	0.192	-0.286
PK	21.00	19.50	18.85	-0.104**	0.061	
N	19.05	19.68	19.51	0.039	0.028	
Moddus	18.51	19.80	19.77	0.106**	0.006	

*, ** Significant respectively at α=0.05 and α=0.01 probability level

The results show that application of Promalin had no effect on stem morphology. Phosphorus and K fertilizers and spray application of urea caused changes that did not allow for explicit deductions. At Prusy, there were statistically significant linear effects for choice of cultivar/strain, P and K fertilization and application of Moddus (Table 9). The greatest partition of specific stem elements in its actual length was observed in cv. Akt. Slightly lower shares occurred in STH 7000, but in STH 4770 the shares were much lower (except for the partition of panicle length to total stem length). With regards to quadratic effects cultivar/strain choice and application of Moddus were significant. The influence of the first of the two above factors results from the sequence of levels of the factor. The influence of

Moddus is evident, as increasing the rate from 100 to 150 g ha^{-1} of active ingredient did not cause any further increase in the share of individual stem elements in actual length.

CONCLUSIONS

At the better site, cultivar was the only factor that had a statistically significant influence on stem morphology. At the poorer site, apart from cultivar choice, P and K fertilizer and the PGR Moddus (especially in the experiment with the dwarf cultivar) had a significant influence. This was confirmed by the standardized regression coefficients.

The change in panicle density, under the influence of cultivar, was statistically different only at Wierzbica. Furthermore, we confirmed the influence of P and K fertilizer and the PGR Moddus on grain yield components for that location.

Absolute values of internode and panicle length were modified by the experimental factors. This resulted in differentiation of stem length. Moddus had the strongest influence on stem morphology. Its influence was similar at both sites and was manifested as a shortening of specific internodes. However, panicle length was unchanged. The experiment at Prusy confirmed that there was no need for a higher dose of Moddus. The PGR Promalin had no significant effect on oat stem morphology. Estimation of relative values describing oat stem morphology at Wierzbica indicated a significant influence of the PGR Moddus. In both experiments, Moddus decreased the share of individual internodes in actual stem length with an increase in the share of panicle length. Consequently, the influence of Moddus increased during the period of onthogenesis and caused a greater decrease in successive internodes, thus changing their proportions in stem structure. The analysis of stem morphology allows the conclusion that the dwarf strain STH 7000 is a form of oat that differs significantly from the other oats studied in this work. Promalin did not cause any change in relative values, while the other factors influenced them in a way that did not allow for explicit deductions to be made

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