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WEATHER-BASED SPRING WHEAT YIELDING FORECASTING

Bożena Michalska, Agnieszka Witos
Department of Agricultural Meteorology, Agricultural University, Szczecin, Poland

ABSTRACT

The research draws on 1970-1998 decade rainfall, maximum, minimum and average air temperature, relative air humidity recorded at 1 p.m. and insolation; all of them reported by 6 Meteorological Office (IMGW) stations and by one agricultural meteorological station and on spring wheat yielding reports provided by Provincial Statistical Office (WUS). Multiple regression was used to define the relationship between yield and weather components over respective periods. The regression equations developed for the Zachodnie Pomorze Province can be applied to forecast spring wheat yielding. Preliminary forecasts are available late in May, whereas precise forecasts late in June and July.

Key words: spring wheat, weather components, yielding forecasts

INTRODUCTION

The commercial value of spring wheat, despite its lower yielding and higher yielding instability, is comparable to that of winter wheat. Spring wheat plantation area in the former Szczecin Province, which covers the greatest part of the current Zachodnie Pomorze Province, has been increasing steadily. In 1990 wheat plantations accounted for 20,900 ha, in 1998 - 40,400 ha, whereas in 1999 in the Zachodnie Pomorze Province - for 73,200 ha, the second highest plantation area after the Mazowsze Province (79,800 ha) countrywide. Some plantation area increase trends are observed in the other former provinces of the current Zachodnie Pomorze Province, yet there are not as clear-cut as in the former Szczecin Province.

Spring wheat growth, development and yielding are considerably determined not only by soil type but also by weather conditions. Plants, in their initial growth period, use post-winter soil water resources, hence, according to Panek [12], generally too high rainfall prior to sowing on wheat-complex soils. The highest water demand period lasts about 4 decades; the second decade coincides with early ear formation. Spring wheat yields highest whenever, 30 days prior to ear formation, rainfall amounts to 80-90 mm [4]. Mean multi-year grain yield losses due to rainfall shortage over that period in Poland are estimated from about 0.05 to 0.25 $t \cdot ha^{-1}$, while in the Zachodnie Pomorze Province about 0.2 $t \cdot ha^{-1}$ [4]. However spring grain yield due to excessive and insufficient soil moisture from April to July is lower by 15%, as compared with the average grain yield [7]. Spring wheat hardly tolerates high temperatures both over shooting and over ripening, which results in a lower dry matter accumulation rate and in grain deterioration [14]. A significant impact of insolation on the spring wheat yield cultivated on wheat-complex soils is recorded from tillering to ear formation all over Poland, while from ear formation to wax maturity - mainly in the South-East. On rye-complex soils the impact is observed prior to plant emergence and from tillering to ear formation [9].

Changing weather patterns, especially intensifying unfavourable weather conditions affect plant yield and its quality.

The aim of the present research was to define quantitative relationships between spring wheat yields and weather conditions as well as to develop regression equations to determine spring wheat grain yield a few decades before harvest.

MATERIAL AND METHODS

1970-1998 decadal and monthly rainfall, maximum, minimum and average air temperature, soil temperature, insolation and relative air humidity were obtained from Decadal Bulletins of Agricultural Meteorology [1]. Figure 1 presents rainfall and air temperature distribution and Figure 2 - air temperature and humidity distribution over successive years. The spring wheat yield values for the four former provinces of Szczecin, Koszalin, Piła and Gorzów Wielkopolski were taken from statistics made available by the Statistical Office (GUS) [2]. The values calculated for the respective Zachodnie Pomorze Province weather components were represented by weighted means of the values provided by 7 stations (Świnoujście, Koszalin, Resko, Szczecin, Lipki, Szczecinek, Gorzów Wielkopolski), while spring wheat yields were represented by the yield weighted mean of the values for the four former provinces. 1971-1990 spring wheat plant development phase timing, recorded by Rarwino, Białogard, Prusim and Przelewice, were obtained from the Słupia Wielka Research Centre for Cultivars. The impact of weather components on spring wheat yield over successive periods was defined over decades, months and longer periods. The selection of weather components for final equations was made by eliminating non-significant effects. The relationships were defined and final regression equations developed with Statgraphics 5.0. Statistical equations were verified over 1981-1990, excluding from regression equation successive years for which the forecast error was defined.

Fig. 1. Rainfall and mean air temperature from March 11 to August 20 in the Zachodnie Pomorze Province over 1970-1998.

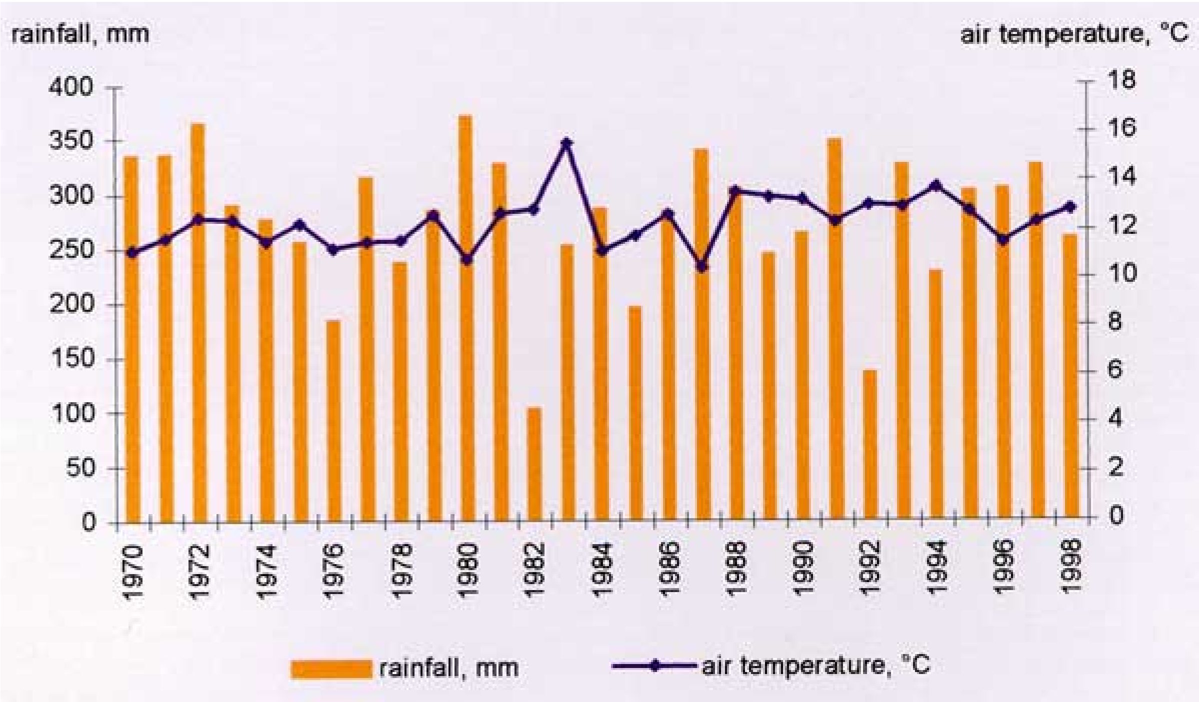
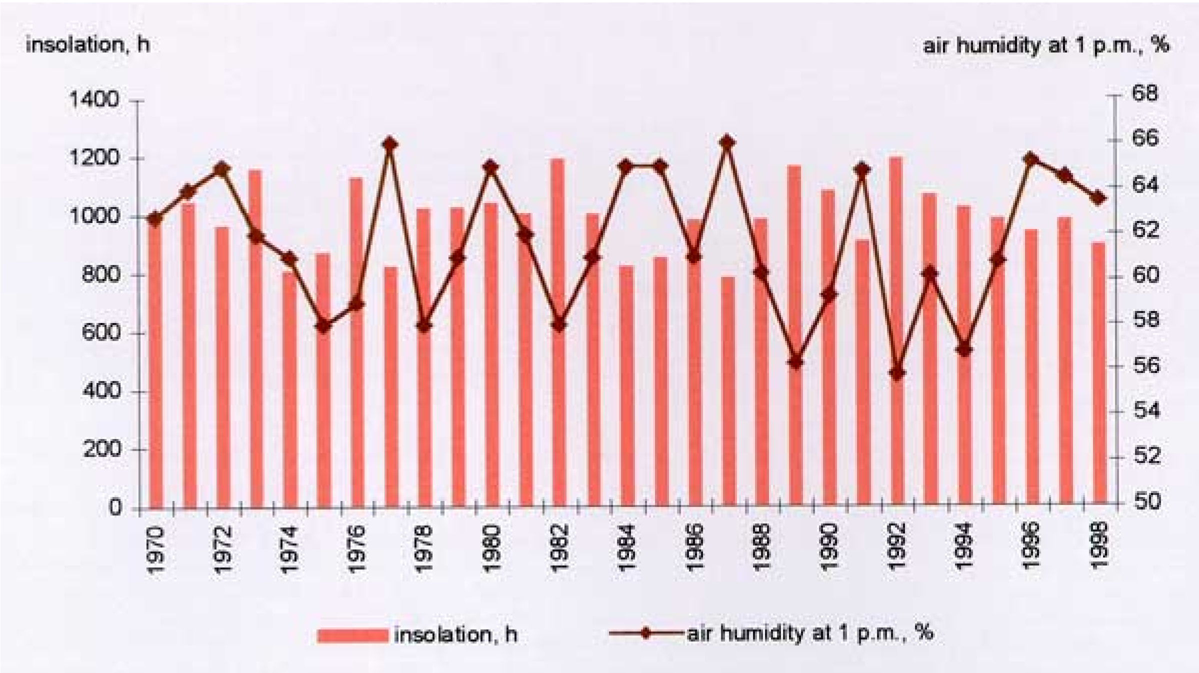


Fig. 2. Relative air humidity of 1 p.m. and insolation from March 11 to August 20 in the Zachodnie Pomorze Province over 1970-1998.



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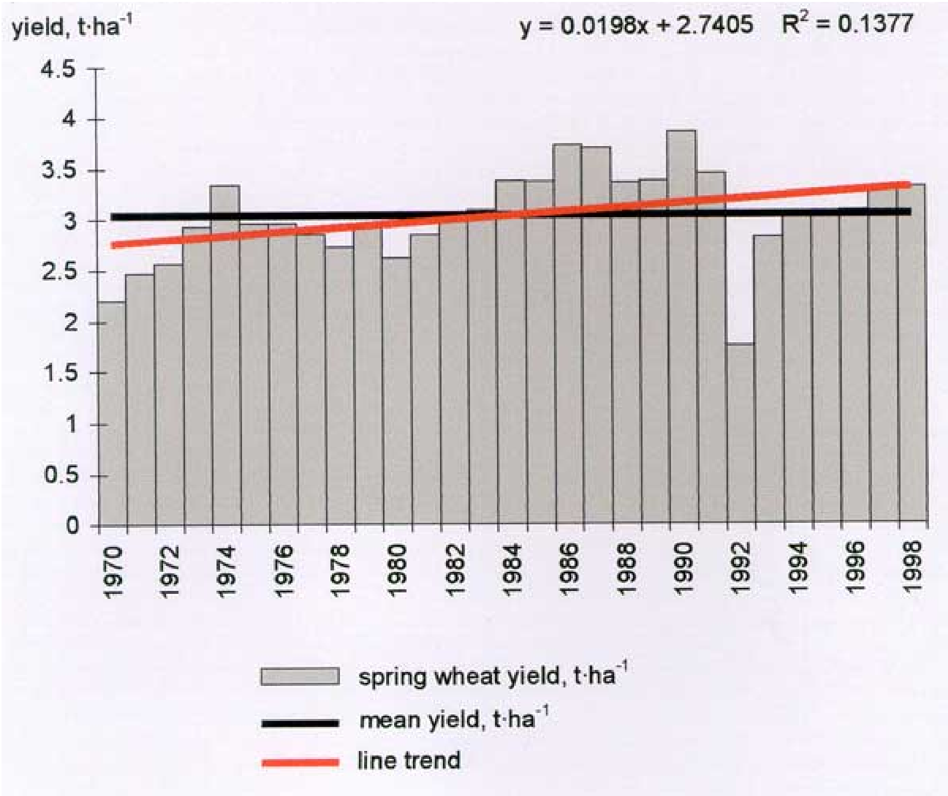
RESULTS

The 1970-1998 average spring wheat yield in the Zachodnie Pomorze Province amounted to 3.04 t·ha^{-1}. The yield in the former Szczecin Province (3.28 t·ha^{-1}) contributed mostly; in the other three provinces the yields were lower, respectively, from 2.84 t·ha^{-1} in the Koszalin to 2.92 t·ha^{-1} in the Gorzów Provinces. As shown in Fig. 3, the highest yields, each year exceeding the average, were recorded over 1984 to 1991. In early 90s there was observed a slump in yielding due to poorer agronomic practices, and in 1992 – also due to a long semi-drought. Despite seasonal yielding fluctuations over 1970-1998, there was observed a positive trend in yielding (r = 0.32); hence the years, just like weather conditions, represented as the independent variable, have been covered by the regression equations to define the relationships between weather and yielding.

Fig. 3. Spring wheat yielding in the Zachodnie Pomorze Province over 1970-1998.



An average spring wheat sowing date coincided with mid of the first decade of April; the earliest sowing was recorded at Rarwino and in Białogard (April 3), and the latest at Przelewice (April 6). On average wheat emerged after 20 days and ear formation started in the second decade of June - the earliest ear formation was reported in Białogard (June 13), and the latest - at Rarwino (June 20). The period from ear formation to wax maturity (June 18 – August 13) lasted 58 days and from maturity to harvest – 8 days, on average. The difference between the harvest dates amounted to 10 days, in Białogard harvest took place on August 17, while at Rarwino on August 27.

Table 1 presents regression equations which show the relationship between spring wheat yields and weather conditions late in April, May, June and July which do not coincide with the beginnings of plant development phases, yet due to the availability of decadal weather components, the equations developed can be widely applied to future spring wheat yielding estimates. The values of determination coefficient R^2 calculated for different yielding forecast dates increased steadily from 67.8% of April 30 to 90.5% of July 31, which decreases the forecast error. The spring wheat yield standard deviation amounted to 0.45 t·ha^{-1}, which accounted for about 15% of the average yield. The regression equation error developed late June amounted to 0.170 t·ha^{-1}, and at the end of July – to 0.166 t·ha^{-1}, which was over 2.5 times lower than the natural yielding variability.

Table 1. Yielding trend - related relationship between spring wheat yield (t·ha-1) in the Zachodnie Pomorze Province and weather components over 1970-1998

Regression equations	R^2	S_y	S
Till April 30 $y = 1.40129 + 0.2396x_1{}^{***} - 0.0448x_2{}^{***} + 0.130222x_3{}^{***} - 0.002306x_4{}^{**}$	67.84	0.28	0.46
Till May 31 $y = 2.25358 + 0,2837x_1{}^{***} - 0.01490x_2{}^{***} + 0.15782x_3{}^{***} - 0.01039x_5{}^{*} - 0.020279x_6{}^{***}$	79.31	0.23	
Till June 30 $y = 3.77033 + 0.2557x_1{}^{***} - 0.01218x_2{}^{***} + 0.13753x_3{}^{***} - 0.01265x_5{}^{**} - 0.0235x_7{}^{**} - 0,00273x_8{}^{***}$	88.85	0.17	
Till July 31 $y = 3.61260 + 0.02643x_1{}^{***} - 0.01126x_2{}^{***} + 0.13129x_3{}^{***} - 0.01291x_5{}^{***} - 0.02982x_7{}^{**} + 0.03687x_9{}^{*} - 0.00215x_{10}{}^{***} + 0.03107x_{11}{}^{*}$	90.5	0.17	

Explanations
R^2 - determination coefficient
S_y - regression error
S - standard deviation
y - grain yields
x_1 - yield trend for successive years of 70....98
x_2 - March rainfall
x_3 – mean air temperature of the third decade of March
x_4 – insolation from March 10 to April
x_5 - relative air humidity of 1p.m. of the first decade of May
x_6 – insolation from March 10 to May
x_7 – maximum air temperature of the first decade of June
x_8 - insolation from March 10 to June
x_9 – May minimum air temperature
x_{10} – insolation from March 10 to July
x_{11} – mean air temperature of the second decade of July

Table 2 shows real spring wheat yields over 1981-1990 and yields calculated with regression equations developed at the end of June and at the end of July. The period of 1981-1990 was selected due to its highly diversified weather (Fig. 1 and Fig. 2). In 1982 there were recorded low rainfall and high insolation, in 1983 - temperature scored highest, while in 1987 - high rainfall and relative air humidity were accompanied by the lowest air temperature and insolation. An average difference between the real yield and the one obtained from equation on the day of June 30 amounted to 4.4% whenever each year being verified was excluded, while 3.7% - without excluding. The respective values on July 31 amounted to 3.6% and 2.9%. The difference calculated for the total period (without excluding successive years from the research) was slightly higher, at the end of June it amounted to 4.2%, and at the end of July to 3.6%.

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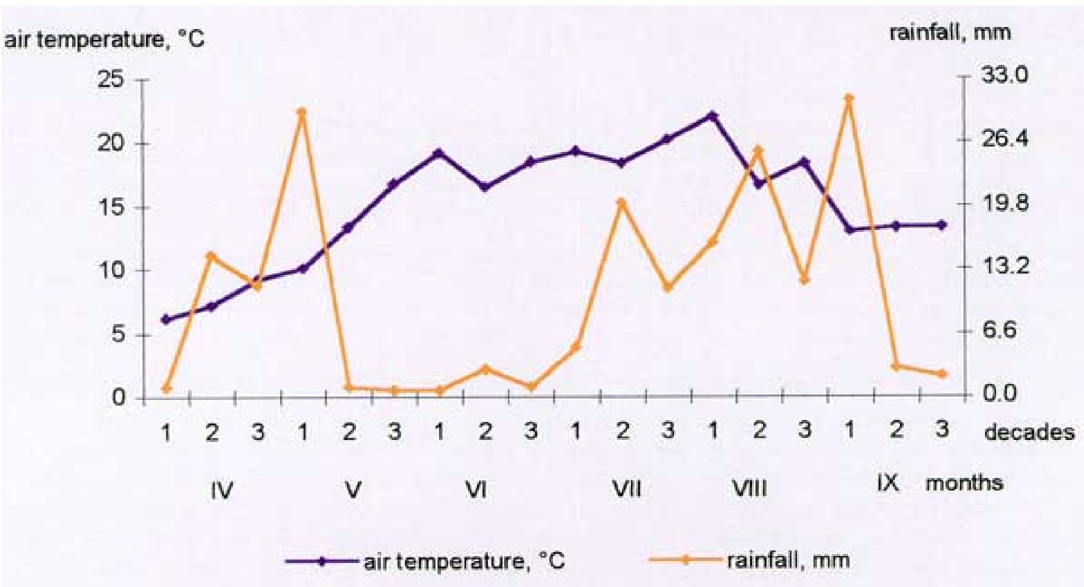
Table 2. Percentage differences between spring wheat yields calculated on June 30 and July 31 and real yields obtained in the Zachodnie Pomorze Province over respective years of 1981-1990

Years	Real yield	Yields calculated till June 30			Years	Real yield	Yields calculated till July 31		
		Calculated yield	Error %	Mean error			Calculated yield	Error %	Mean error
81	2.85	2.90	1.7	4.4	81	2.85	2.98	4.6	3.6
82	3.02	2.73	9.6		82	3.02	3.00	0.7	
83	3.09	3.36	8.7		83	3.09	3.29	6.5	
84	3.38	3.47	2.7		84	3.38	3.62	7.1	
85	3.37	3.28	2.7		85	3.37	3.41	1.2	
86	3.73	3.54	5.1		86	3.73	3.85	3.2	
87	3.70	3.52	4.7		87	3.70	3.55	4.1	
88	3.36	3.12	7.1		88	3.36	3.32	1.2	
89	3.38	3.37	0.3		89	3.38	3.51	3.8	
90	3.85	3.78	1.8		90	3.85	3.99	3.6	

Out of all the years analysed, the greatest difference (16.7%) between the calculated and the real yield was observed in 1992, which must have been due to an agricultural breakdown (changes in production means, first of all a decrease in fertilisation, which started as early as in 1991), as well as very unfavourable extreme weather conditions.

The Waltera-Lietha climate graphic presentation, modified by Gregorczyk [5], developed for 1992 (Fig. 4) shows that a rainfall shortage started in the second decade of May and lasted till the second decade of August, while an insufficient soil moisture was observed in the Pomorze Region at the beginning of June, which remained in the western part of the Province till the end of August. [6].

Fig. 4. Climate graphic presentation of the 1992 vegetation period



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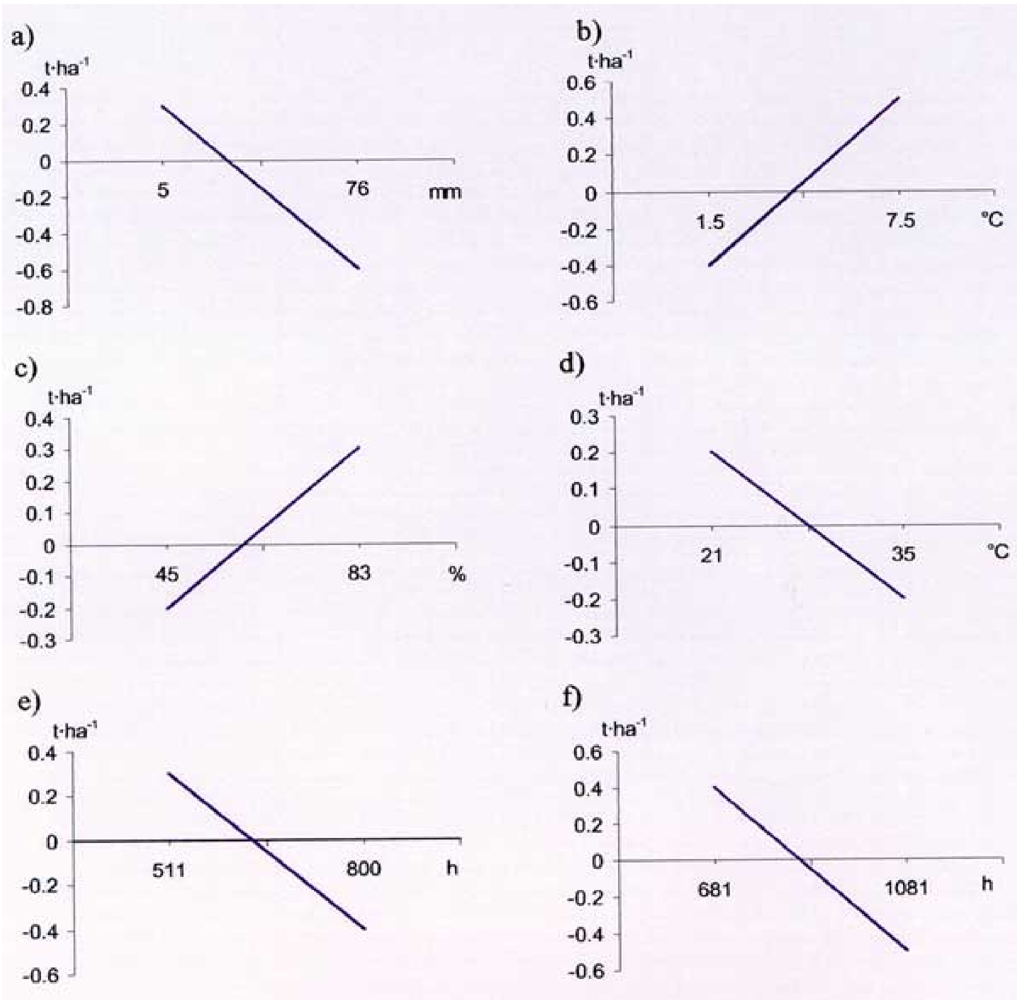
With the regression equations developed there were calculated spring wheat yields in the Zachodnie Pomorze Province in 1999 which was not analysed. The calculated yield of the end of June amounted to 3.23 t·ha^{-1}, of the end of July – 3.59 t·ha^{-1}. The difference between the real yield (3.36 t·ha^{-1}) in the first case amounted to 4.2%, while in the second – to 7.1%. The model verification results obtained showed that as early as the end of June one can, with high probability, forecast spring wheat yields based on rainfall, average and maximum air temperature, air humidity and insolation. Additional weather data in July do decrease the mean forecast error by 0.6%, however, over the years analysed there were recorded end-of-July forecast errors higher than the June-forecast error, which shows that the relationship between the yield and the weather components researched in July was not as strict as in earlier months.

Fig. 5 (a-f) show yielding effect of weather components of the regression equation developed for the end of July; i.e. March rainfall (Fig. 5a), higher than 55 mm decreased the yield by at least 0.3 t·ha^{-1}, as compared with the mean spring wheat yield (3.04 t·ha^{-1}), while rainfall lower than 20 mm increased the spring wheat yield by about 0.1 t·ha^{-1}, as compared with the mean value. A decrease in yield by about 0.3 t·ha^{-1} is to be expected whenever insolation from March to July (Fig. 5e) exceeds 990 hours.

Fig. 5. Effect of regression equation weather components recorded to the end of July on spring wheat yield forecasting. a) March rainfall, b) Mean air temperature of the third decade of March, c) Relative air humidity of the first decade of May, d) Maximum air temperature of the first decade of June, e) Insolation from March 10 to July, f) May minimum air temperature, g) Mean air temperature of the second decade of July.



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DISCUSSION

The factors which heavily affect the future spring yield were March rainfall and an average temperature over the last decade of the month. According to Panek [11,12], very frequently it is rainfall which determined plant yielding. However the yield quality is mostly determined, in most parts of the country, by rainfall over the pre-sowing period; its deviation by 1 mm per decade from the multi-year mean increased or decreased the spring wheat yield from 44 to 157 $kg \cdot ha^{-1}$ on wheat-complex soils and from 72 to 146 $kg \cdot ha^{-1}$ on rye-complex soils [11]. Too excessive rainfall and a low temperature make the soil moisture too excessive, which can delay soil cultivation and sowing. The research by Koźmiński and Michalska [8] show that a 15-day delay in sowing decreases the spring wheat yielding in the north-western part of the country by 10-15%.

According to Rachoń [13], a significantly negative effect of delayed sowing is observed over tillering, in grain weight per ear and per plant as well as in the weight of 1000 grains. Those parameters, according to Bac and Chrzanowska-Drożdż [3], determine a grain production potential. Nowicka [10] recorded a highly significantly positive relationship between wheat grain yield and mean air temperature taken a decade before sowing. Insolation showed a significant or highly significant impact on wheat yielding in the Zachodnie Pomorze Province over each research period, which is also reported by Makowieckiego [9].

Other factors, including soil moisture, evaporation or those of climatic water balance, could increase yield forecasts yet limit the application of the model due to a scarcity of relevant data in Bulletins of Agricultural Meteorology.

CONCLUSIONS

1. The most essential weather components affecting spring wheat yielding included March rainfall and mean air temperature of the third decade of March as well as insolation over the second decade of March to the end of June and over the second decade of March to the end of July. The other model weather components, which covered the period to the end of June and to the end of July, were significantly correlated with yielding, yet did not show any such considerable effect on yield variability.
2. March rainfall over 30 mm decreased spring wheat yielding by about 0.1 $t \cdot ha^{-1}$ per each 10 mm of rainfall.
3. Mean air temperature over the third decade of March lower than 4.5°C limited the grain yield; a decrease in temperature by 1°C decreased grain yield by 0.13 $t \cdot ha^{-1}$.
4. An increase in the total insolation by 50 h (over 650 h) from the second decade of March to the end of June decreased the spring wheat grain yield by about 0.15 $t \cdot ha^{-1}$.
5. In the Zachodnie Pomorze Province the data available on weather components enhance spring wheat yielding forecasts; preliminary forecasts are available late in May, whereas precise forecasts late in June.

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Submited:

Bożena Michalska, Agnieszka Witos
Department of Agricultural Meteorology
Agricultural University in Szczecin
Papieża Pawła 3, VI, Szczecin, Poland
Phone: (48 91) 42-50-280, 42-50-277
e-mail: agro@agro.ar.szczecin.pl, aga125@go2.pl