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REGIONALISATION OF SPRING TRITICALE IN POMERANIA IN TERMS OF THERMIC AND PRECIPITATION CONDITIONS

Bożena Michalska, Eliza Kalbarczyk
Department of Agrometeorology and Land Reclamation, Agricultural University in Szczecin

ABSTRACT

The paper discusses the relations between spring triticale grain yield and weather factors: mean air temperature, total precipitation and insolation in the north-west of Poland. Boundary values were determined for the weather factors such that caused the decrease in grain yield by at least 10% against the many-years yield average. On the basis of weather data from the years 1971-2000, climate indices of spring triticale crop yield were estimated, which in turn provided a basis for the valuation, in terms of scores, of thermic and precipitation conditions in the north-west Poland. Crop yield of spring triticale is markedly restrained by the mean temperature exceeding 16°C in the stalk-shooting – coming into ear period, as well as by precipitation below 20 mm over the same period, and by the mean air temperature above 18.5°C in the coming into ear – dough stage. The most beneficial climate conditions for growing spring triticale are found in the central part of Pobrzeże Słowińskie, and the least beneficial in Pojezierze Myśliborskie and in Równina Gorzowska.

Key words: spring triticale, weather factors, boundary values, regionalisation in Pomerania

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INTRODUCTION

The spreading of spring triticale depends on the volume and stability of its yield, which in turn is related to the plants response to the environment conditions, including climate conditions. Spring triticale grown in Pomerania in field trials yields on average 57 $dt \cdot ha^{-1}$, but the variations in particular years may be as high as 40 $dt \cdot ha^{-1}$, which is attributable to differing patterns of weather conditions. Like rye, triticale withstands dry periods better than wheat does, but the lack of water always disrupts the growth process, which leads to poorer crop yields [7]. The time periods when triticale is the most sensitive to drought comprise the stalk shooting, coming into ear, and blooming stages, as well as the development and filling of kernels [10]. Beneficial to the triticale blooming and pollination processes are warm and sunny weather, the optimum temperature for its growing and cropping ranges from 15 to 25°C. High temperature during the maturation stage shortens the stage, leading to the poorer filling of kernels and usually lower crop yields [10]. Significant relations occurring between crop yields and meteorological factors provide a basis for developing countrywide or regional crop yields forecasts in stepwise temporal progression, which means that forecasts developed at the earliest time will be successively updated according to the incoming reports on conditions unfolding during the vegetation season. Crop yield forecasts have been prepared for winter wheat [8], winter barley [9], winter triticale [11], and spring wheat [12].

Weather conditions in Pomerania are subject to wide temporal and spatial variations [1]. One of the cheapest ways of utilizing biological capacities of plants and making them more productive is proper assignment of species and cultivars to regions, that is regionalisation according to the spatial differentiation of climate conditions. The aims of the present study were the following: defining a relation between spring triticale crop yield and meteorological factors, determining values of meteorological factors restraining crop yields, and regionalizing climate conditions for growing spring triticale in Pomerania.

MATERIALS AND METHODS

The study incorporated data on the commencements of developmental phases and on grain yields of spring triticale obtained by 7 COBORU stations: Białogard, Karżniczka, Lubań, Prusim, Przelewice, Rarwino and Wyczechy over 1984-1999. The meteorological material from 11 stations of IMiGW (Institute for Meteorology and Water Management) was derived from Agrometeorological Bulletins issued between 1971 and 2000 (Fig. 1). Mean air temperature, total precipitation, and insolation values (for each developmental phase) were read off the ten-day period charts included in Agrometeorological Bulletins [2]. Whenever the commencement or end of a particular developmental phase did not coincide with calendar-based dates, weighted mean was applied in order to calculate mean air temperatures. For estimating total precipitation and insolation values, a number of days with precipitation and dates of the largest precipitation were taken into account, following the descriptive part of Agrometeorological Bulletins (for days with precipitation, lesser values of insolation were assumed). Given the statistically demonstrated upward trend in crop yields, for further calculations, crop yield deviations from the trend line were employed. Correlations between spring triticale yield deviations and the above-mentioned meteorological factors at particular intermediate stages were determined using linear and curvilinear regression. Boundary values for temperature and precipitation were obtained, as such that contribute to at least 10% decrease of the crop yield achieved by the experimental stations against the many-years crop yield average. The probability of the occurrence of adverse air temperature and total precipitation values was calculated on the basis of the air temperature and total precipitation values gathered over the span of many years (1971-2000) from 11 meteorological stations in Pomerania. In order to determine a comprehensive impact of the meteorological conditions on spring triticale crop yield, multiple regression was applied using linear and parabolic function. Stepwise regression method was employed to isolate those meteorological factors that correlated with crop yields at different developmental stages at least at the level of significance $p = 0.01$.

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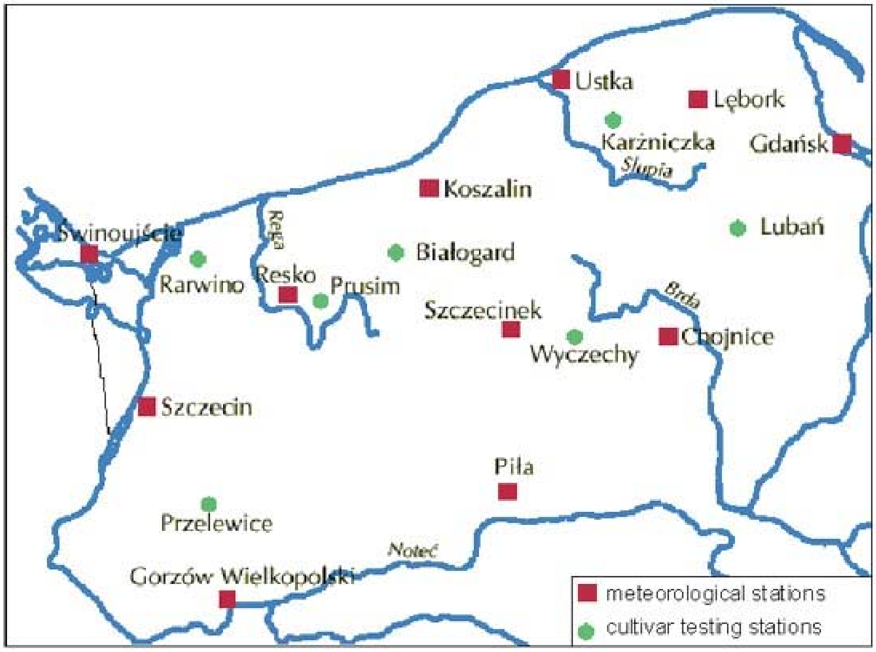
Fig. 1. Meteorological and cultivar testing stations location in Pomerania



Out of numerous multiple regression models illustrating the impact of meteorological elements on spring triticale crop yields, the one possessing the highest predictive value was finally adopted. All the considered factors were significant at the level of p = 99%, and they were not mutually statistically correlated, therefore total insolation values were disregarded. Taking into account the meteorological data over the years 1971-2000 on air temperatures during the following periods: sowing - seedlings, stalk shooting -coming into ear, coming into ear - dough stage, as well as total precipitation during the stalk shooting - coming into ear period, climate indices of spring triticale crop yields, expressed as deviations from the trend line, were estimated for 11 IMGW stations. In each case negative quantities were obtained, which were later converted into scores, where the highest score, 100 points, was assigned to the station for which the least negative deviation of crop yields from the trend line was calculated. Valuation of thermic and precipitation conditions in Pomerania with respect to spring triticale cropping was conducted on the basis of the graphic interpolation of the scores assigned to each meteorological station.

RESULTS

Field trials involving spring triticale have been carried out in Pomerania since 1984. The longest-lasting research was conducted at the Wyczechy station (for 13 years) in the central area of Pomerania and at the Rarwin station (12 years) situated in the north-west, whereas the shortest-lasting one in Białogard (3 years). The experiments were set up on a good rye soil complex (17), a very good rye complex (15), a poor rye complex (13), and a good wheat complex (12) (Table 1).

Table 1. The COBORU research station characteristics

Station	Research years	Spring triticale mean grain yield $dt \cdot ha^{-1}$	Soil agricultural suitability complex
Białogard	1994 - 1996	63.6	very good rye
Karżniczka	1989 - 1995	58.6	good wheat
Lubań	1984 - 1991	53.9	good rye
Prusim	1984 - 1992	55.4	good rye
Przelewice	1985 - 1989	50.8	good wheat
Rarwino	1988 - 1999	63.2	very good rye
Wyczechy	1987 - 1999	53.9	poor rye

The average crop yield of spring triticale grown in the experimental stations in Pomerania in 1984-1999 was 56.9 $dt \cdot ha^{-1}$ and showed a positive, significant trend (R^2 = 38.4%). Definitely the lowest crop yield was observed in 1992 – the average from 4 stations did not exceed 35 $dt \cdot ha^{-1}$ (Fig. 2), with the lowest yield ever in the whole

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time period 21 dt·ha^{-1}, reported at the Prusim station. This had been caused by the unfavourable weather conditions – high air temperature combined with low precipitations, which persisted from the tillering phase up to the harvest time. The pattern of precipitation and air temperature during the year of the extremely low triticale crop yield is presented in Fig. 3 in comparison with a not-so-distant year of relative high yields (1990), against the values observed in the analysed time span.

Fig. 2. Mean spring tricale yielding in Pomerania over 1984-1999

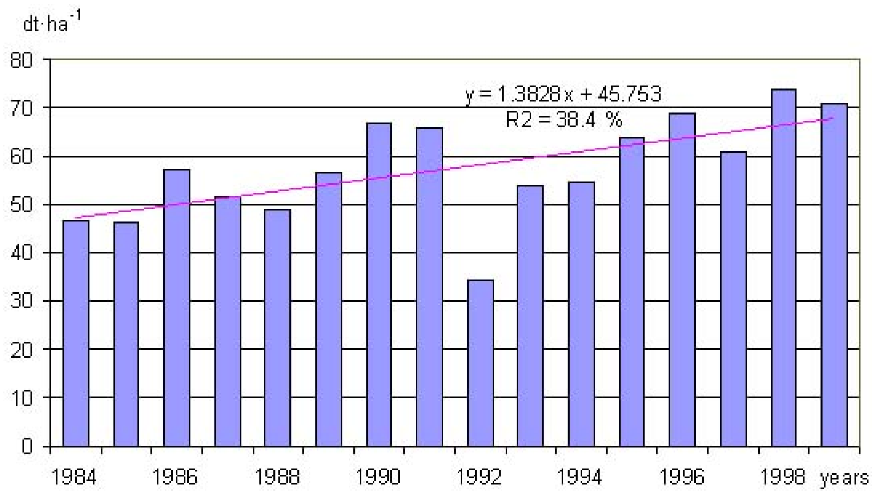
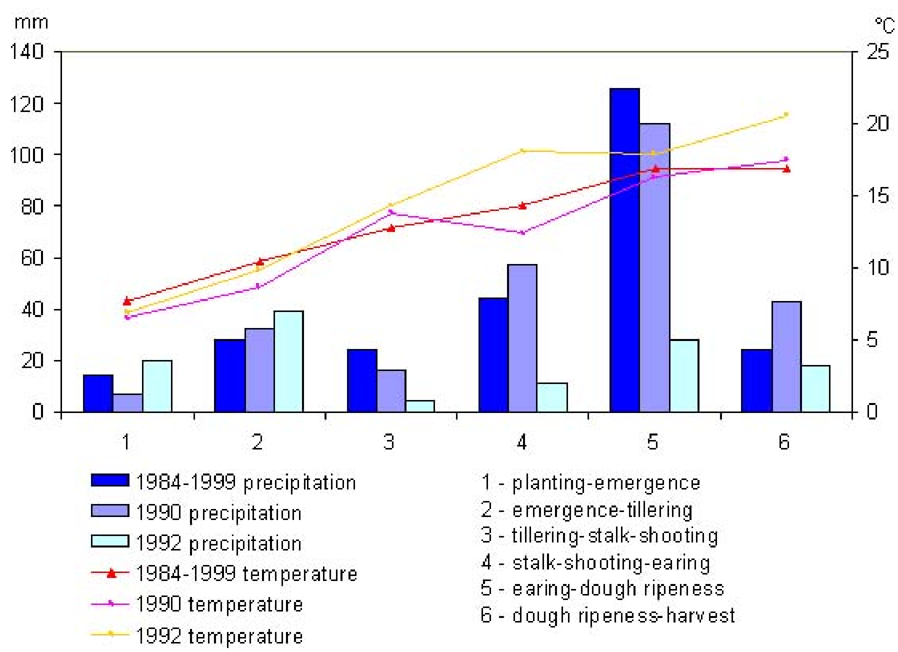


Fig. 3. Mean air temperature and sum of precipitations over successive spring triticale developmental phases in 1990 and 1992 on the background of 1994-1999



When investigating relations between the crucial meteorological factors in the successive intermediate developmental stages and the deviations of crop yields from the trend line (Table 2, Fig. 4 a-g), it was found that air temperature had the most significant impact in the period stalk shooting - coming into ear (R^2=23%), and it was a negative linear relation, while precipitation in the same period had a positive impact (R^2 = 23%). The significant impact of precipitation, graphed by a curvilinear function (like air temperatures and insolation) manifested itself in the next developmental phase coming into ear – dough stage. In the same intermediate phase also, the strongest relation (R^2 = 10.9%) between spring triticale crop yield variability and insolation was observed. In the other intermediate phases the impact of air temperature on triticale crop yield was found to be stronger than that of precipitation and insolation (Table 2).

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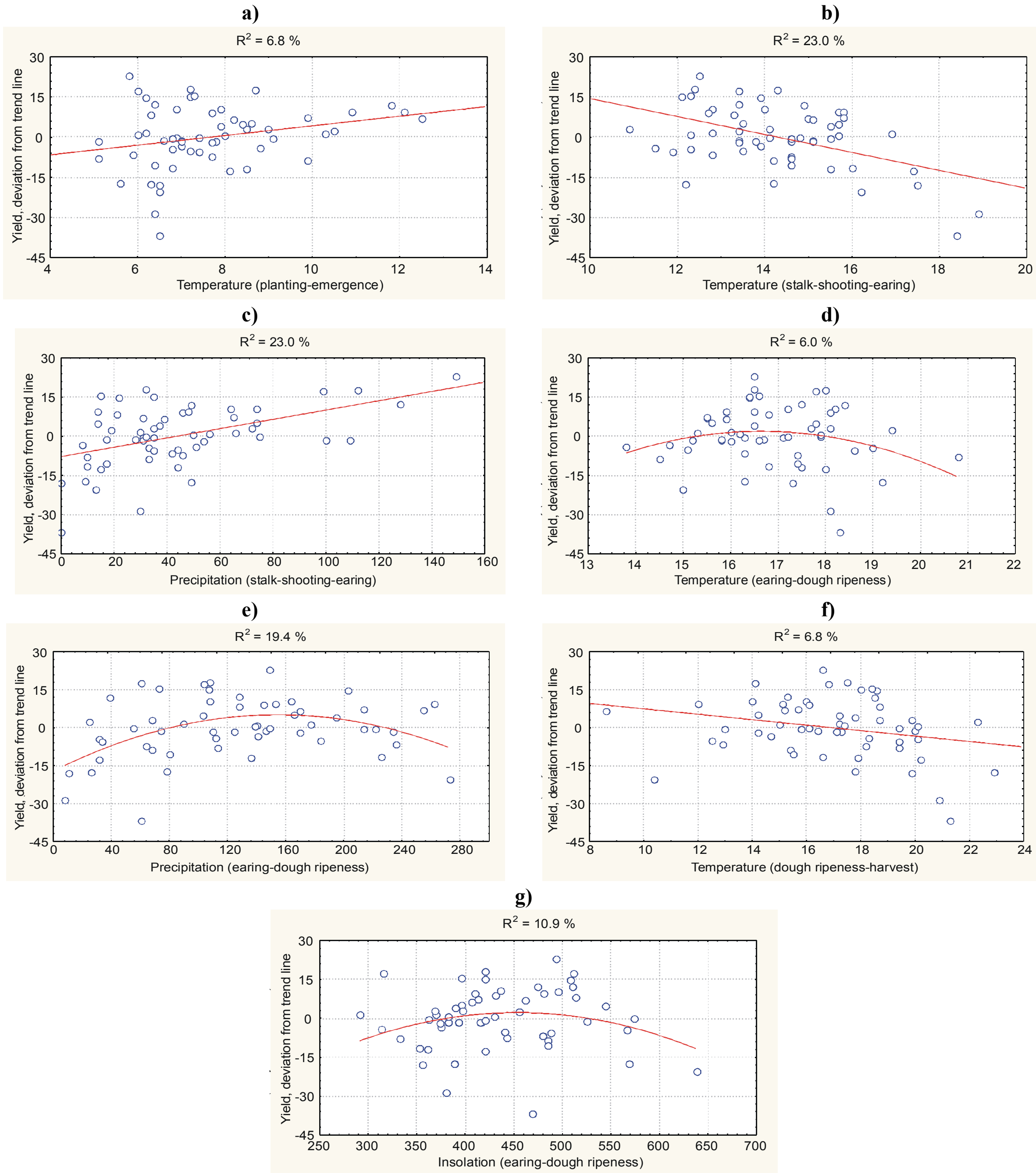
Table 2. Determination coefficients (%) for grain yield expressed as deviation form trend line and weather conditions over successive spring triticale developmental periods (mean for 1984-1999)

Developmental period	Mean air temperature	Sum of precipitations	Sum of insolation
Seed planting – plant emergence	6.8*	3.6	0.8
Plant emergence - tillering	1.7	0.6	2.0
Tillering – stalk-shooting	4.4	5.3	1.4
Stalk-shooting – earing	23.0***	23.0***	1.2
Earing – dough ripeness	6.0*	19.4***	10.9*
Dough ripeness – harvest	6.8*	2.0	3.6

***** – significant at $p \leq 0.01$; ** – significant at $p \leq 0.05$; * – significant at $p \leq 0.1$;**
positive / negative relation

Fig. 4. Spring triticale grain yield expressed as a deviation from trend line related to:
a - seed planting - emergence temperature, b - stalk-shooting - earing air temperature, c - stalk-shooting sum of precipitations, d - earing - dough ripeness sum of precipitations, e - earing - dough ripeness sum of precipitations f - dough ripeness - harvest sum of precipitations, g - earing - dough ripeness insolation



The final multiple regression model, presenting the impact of the meteorological conditions at the various developmental phases on spring triticale crop yield (expressed as deviations), included air temperature and precipitation.

The regression equation:

$$y = -753.862 + 3.188 \cdot T_1 - 3.753 \cdot T_4 + 0.125 \cdot O_4 - 2.793 \cdot T_5^2 + 93.443 \cdot T_5$$

$t = 5.2$	$t = -6.0$	$t = 3.9$	$t = -5.0$	$t = 5.0$
$R^2 = 65.3\%$	$t_{0.01} = 2.68$	$F = 18.8$	$p_{0.01} = 3.36$	$n = 57$

y – crop yield – deviation from the trend line ($dt \cdot ha^{-1}$)
T – mean air temperature over:
1 - sowing – emergence,
4 – stalk-shooting – coming into ear,
5 – coming into ear – dough stage,
O_4 – total precipitation in the stalk-shooting – coming into ear period,
t – test of significance of a given variable in the regression,
R^2 – coefficient of determination in %,
$t_{0.01}$ – test of significance of the regression equation,
F – test of significance of the regression equation,
$p_{0.01}$ – critical value of F,
n – number of observations in a trial.

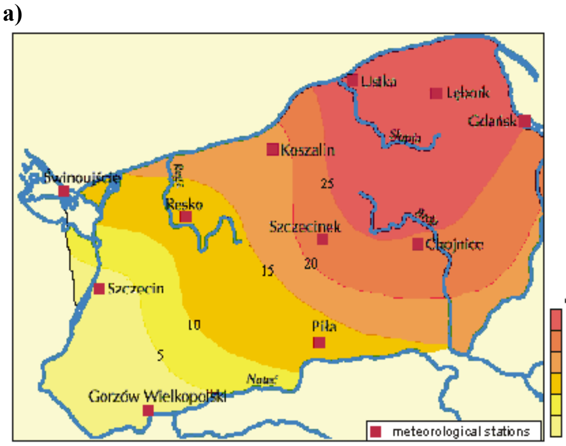
From the regression equations, boundary values were derived, that is such values of the included meteorological elements exceeding or falling short of which, at any of the developmental stages, resulted in decreasing crop yield of spring triticale by at least 10% against the many-years average (Table 3). The probability of the occurrence of the mean air temperature lower than 4.5°C throughout the whole sowing – sprouting period, which tends to coincide with the first and second ten-day period of April, in Pomerania ranges from 5 to 25% (Fig. 5a), and is the lowest in the south-west of the examined territory. On the other hand, in the north-east of Pomerania, the mean air temperature in the first two decades of April is lower than 4.5°C in 4 years out of 10.

Table 3. Values of weather conditions decreases spring triticale grain yield by more than 10%

Developmental period	Weather factor	Boundary value
Seed planting – plant emergence	Mean air temperature	≤ 4.5 °C
Stalk-shooting - tillering	Mean air temperature Sum of precipitations	= 6.0 °C ≤ 20 mm
Earing – dough ripeness	Mean air temperature	≤ 14.5 °C and ≥18.5°sC

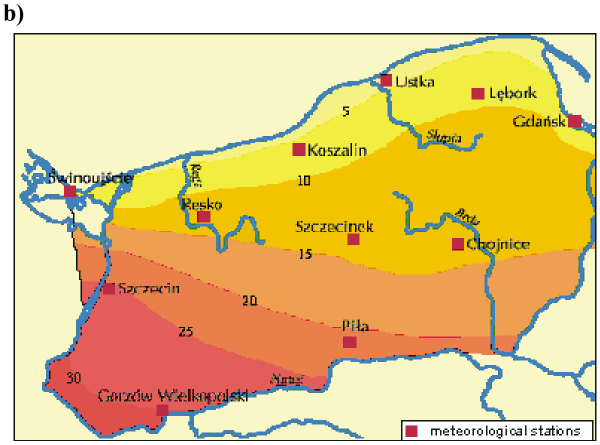
Fig. 5. Probability (%) of:
a - mean air temperature less than 4.5°C over 1st and 2nd decade of April
b - mean air temperature over 16°C from 3rd decade of May to 2nd decade of June
c - sum of precipitation lower than 20 mm from 3rd decade May till 2nd decade of June
d - mean air temperature over 18.5°C from 3rd decade of May till 1st decade of August
e - mean air temperature lower than 14.5°C from 3rd decade of June till 1st decade of August

a)



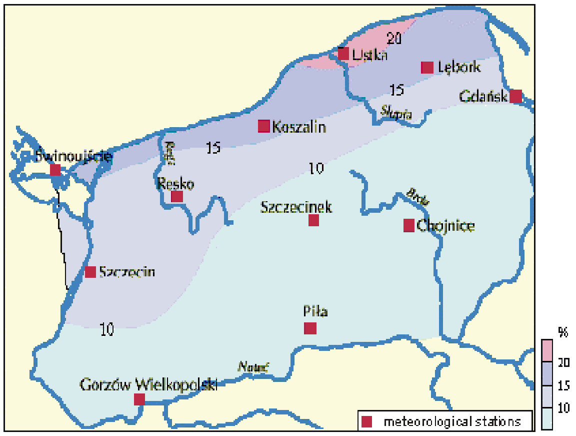
≤ 4.5

b)



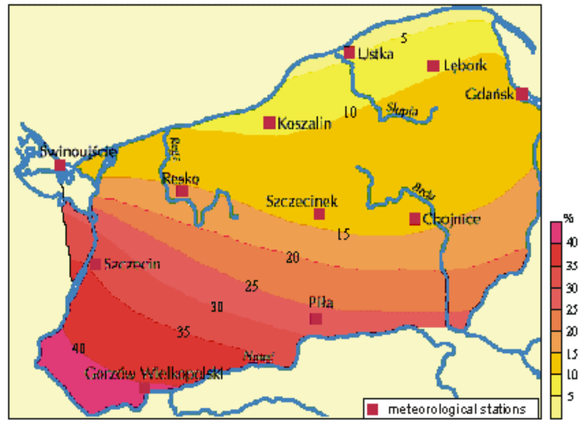
≥ 16.0

c)



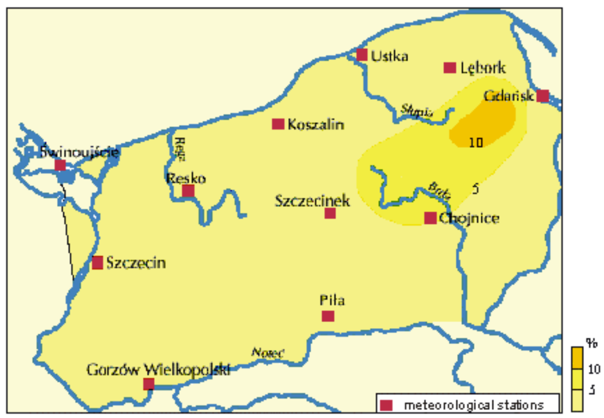
≤ 20 mm

d)



≥ 18.5

e)



≤ 14.5

In the stalk shooting – coming into ear period, that is from the third ten-day period of May to the second ten-day period of June, an disadvantageous effect is derived from the mean temperature in the period exceeding 16 °C and precipitation below 20 mm (Fig. 5b and 5c). The probability of the occurrence of temperature higher than the boundary value rises while proceeding from the north (less than 5%) toward the south-west (more than 30%), whereas the likelihood of precipitation falling short of the required amount is the largest in Wybrzeże Słowińskie (more than 20%).

In the coming into ear – dough stage, crop yield of spring triticale is restrained by the mean air temperature above 18.5°C and below 14.5°C. The temperature of 18.5°C is most frequently (more than 40%) exceeded in the western part of Pojezierze Myśliborskie and in Równina Gorzowska, and least frequently (less than 5%) in Pobrzeże Słowińskie (Fig. 5d). The probability of the mean temperature falling short of 14.5°C from the third ten-day period of June to the first ten-day period of August is slight in Pomerania, and only in the uplands of Pojezierze Kaszubskie goes beyond 10% (Fig. 5e).

Climate indices of spring triticale crop yields, derived from the multiple regression equation (for each IMGW station) (Table 4), provided the basis for the valuation of Pomerania in terms of thermic and precipitation conditions conducive to growing the plant in question (Fig. 6). The most favourable conditions exist in Pobrzeże Słowińskie, especially its central part, therefore this region was awarded the highest score, 100 points. Toward the south of Pomerania, the climate conditions for cropping spring triticale deteriorate, mainly due to high air temperatures. The lowest values of the climate indices (translated into 90 points) were obtained for the western part of Pojezierze Myśliborskie and for Równina Gorzowska.

Table 4. Spring triticale climate yielding index and point classification for meteorological stations in Pomerania

Meteorological station	Climate yielding index, deviation from trend line, $dt \cdot ha^{-1}$	Point classification
Chojnice	-5.4	95.8
Gdańsk	-6.1	95.1
Gorzów	- 11.2	90.0
Koszalin	- 1.2	100.0
Lębork	- 3.9	97.3
Piła	- 10.4	90.8
Resko	- 3.6	97.6
Szczecin	- 9.9	91.3
Szczecinek	- 4.8	96.4
Świnoujście	- 3.4	97.8
Ustka	- 1.5	99.7

Fig. 6. 100-point thermic and precipitation spring triticale regionalisation in Pomerania

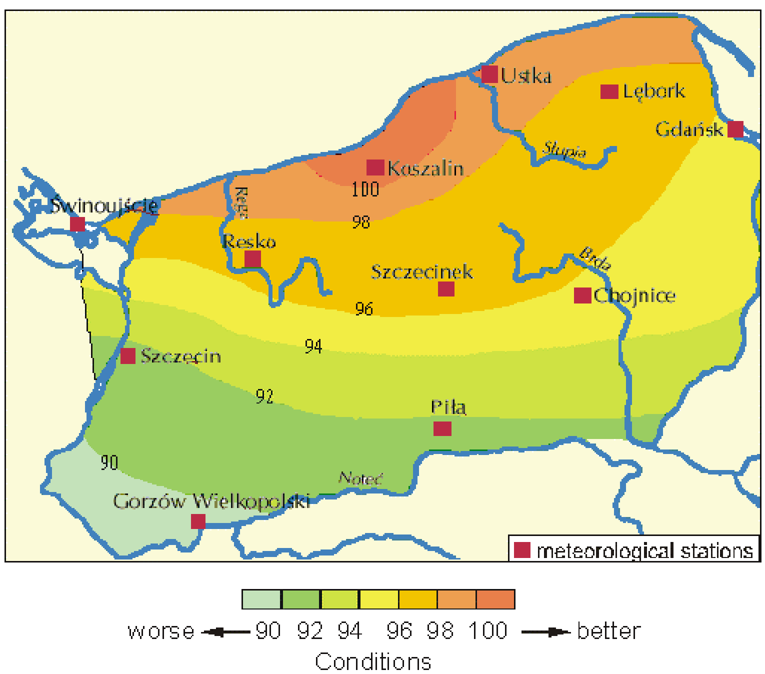


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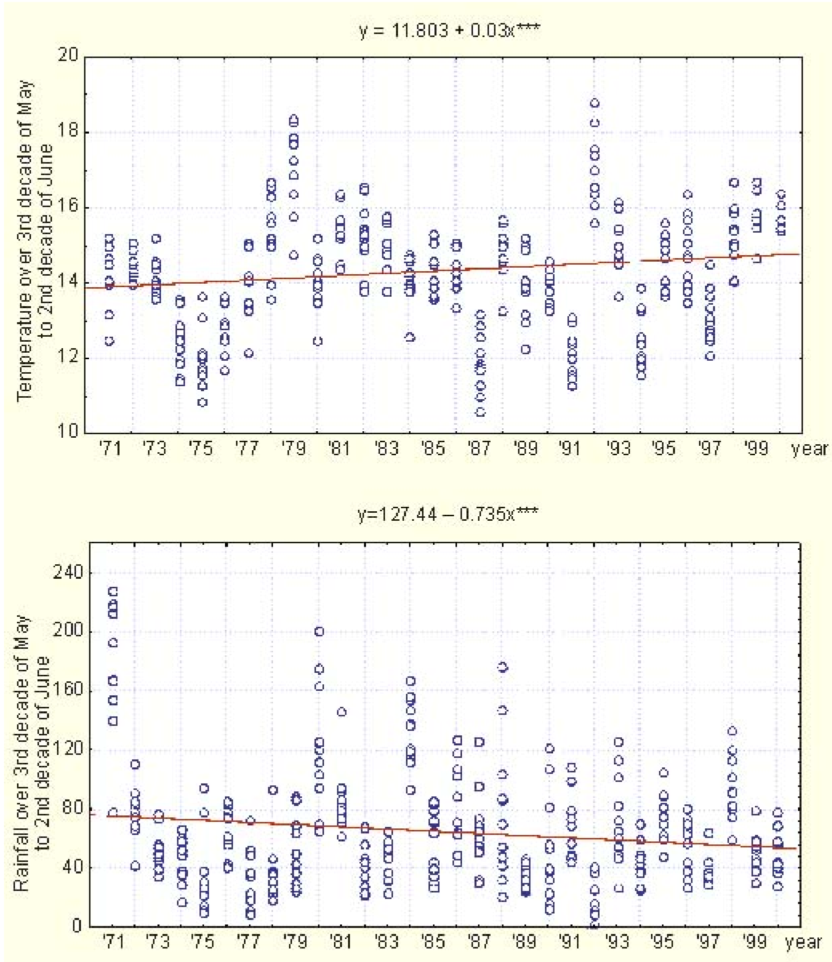
Fig. 7. Temperature and precipitation trends from 3rd decade of May till 2nd decade of June in Pomerania (mean for 1971-2000)



Derived from the regression equation, the many-years average values of climate indices (as deviations from the trend line) were negative for all the analysed meteorological stations (Table 4, Fig. 7). It was found that the relation between the mean air temperature and the years (1971-2000) in the stalk-shooting – coming into ear period is linear, positive, significant at the level of $p = 0.01$; whereas for the precipitation in the same period – linear, negative, significant at the level of $p = 0.01$. This could indicate that the thermic and precipitation conditions for growing spring triticale in Pomerania are deteriorating.

DISCUSSION

In their studies of the cereals response to weather conditions during the vegetation season, many researchers have concluded that precipitation has a stronger impact on the growth and yield of the plants than the temperature [3,5,7,14,15]. This is explained by referring to a larger variation in precipitation than in air temperature, and by pointing to the quantity of water available in the soil as a factor restraining cereal crop yields. That precipitation is one of the crucial climate factors in determining crop yield is unquestionable, however, what seems to pose difficulty is an attempt to quantify the relation of precipitation to yield. Manipulating mean values does not adequately represent the impact of precipitation on crop yield, as its relation with crop yield is non-monotonic [4]. Another difficulty raised by the above-mentioned authors is all kinds of soil-climate interactions or errors resulting from projecting point precipitation on larger crop areas. The quantity of water optimum for crop yield varies as the vegetation progresses. Sufficient precipitation in April and May is conducive to the sprouting and tillering of plants, and ample precipitation in June enables them to shoot stalks and develop kernels [16]. The time when spring cereal crops are the most sensitive to the shortage of water, according to Doroszewski et al. [4], is the period of 30 days preceding their coming into ear. This is corroborated by the findings of the present authors, since the thirty-days period before coming into ear is in fact an intermediate stage, from stalk-shooting to coming into ear, which lasts through the third decade of May and the first two decades of June. Obtained for this period, the linear, positive relation between crop yield and precipitation (R^2 = 23%) is not sufficient for determining the optimum level of precipitation, but it can be assumed that for precipitation exceeding 60mm, deviations of crop yield from the trend line were not observed. Koziara [7] calculated the optimum precipitation for spring triticale grown in Wielkopolska, which from sowing to maturation should reach 200mm, while in the period from coming into ear to maturation – 137 mm. The present study indicates that the highest yield of spring triticale grown in Pomerania was achieved when the precipitation in the period from coming into ear to dough stage ranged from 140 to 170 mm.

Air temperature is generally negatively correlated with crop yield, as spring cereal crops are more vulnerable to low temperatures in the first period – from sowing to sprouting. In the research carried out by the present authors, spring triticale yield was found to be positively correlated with the temperature in the intermediate stage in question; a similar relation was obtained by Nowicka [13] for spring wheat and spring barley grown on rye soil complexes, and Michalska and Witos [12] for spring wheat cultivated in Pomerania.

Spring triticale is the most sensitive to high temperature in the period from stalk-shooting to coming into ear. The value of determination coefficient (R^2 = 23%), obtained in the present study, was the highest for this developmental stage. Similar results were achieved for spring triticale Koziara [7]. The study of Wang and Connor [17] revealed that an increase in the temperature by 3 C° in the period proceeding blooming led to a decrease in spring wheat grain yield by as much as 50%. On the other hand, Fisher and Mauer [6] in their research on spring wheat found that the plants response to changes in the temperature is the most acute in the period from coming into ear to dough stage; air temperatures in this period below the many-years average contribute to good crop yield.

The multiple regression equation, obtained for determining the volume of spring triticale crop yield in Pomerania by taking into account the crucial meteorological factors, captures this relation in 65%. How strictly crop yields are connected with weather patterns depends on the accuracy and quantity of empirical data, the number of considered factors significantly affecting the yield, the degree of fitting of a function capturing relations between weather and crop yield, and the degree of dependence of crop yield on extra-meteorological factors for which the model does not account for.

CONCLUSIONS

1. It was found that air temperature had the most significant impact on spring triticale crop yield in the period stalk shooting - coming into ear, while precipitation - in the same period and in the next developmental phase coming into ear – dough stage
2. Crop yield of spring triticale is markedly restrained by the mean air temperature above 18.5°C in the coming into ear – dough stage, and by the mean temperature exceeding 16°C in the stalk shooting – coming into ear period, as well as by precipitation below 20 mm in the same period.
3. The risk of the occurrence of temperature higher than the boundary value rises in Pomerania while proceeding from the north toward the south-west.
4. The most beneficial climate conditions for growing spring triticale are found in Pobrzeże Słowińskie, and the least beneficial in Pojezierze Myśliborskie and in Równina Gorzowska.
5. Thermic and precipitation resources in Pomerania enable potential average spring triticale grain yield from 57 to 67 $dt \cdot ha^{-1}$; however, the observed positive trends in air temperature and the negative trend in precipitation occurring in the periods of the highest sensitivity of triticale to these factors suggest that the thermic and precipitation conditions for growing the plant in Pomerania are deteriorating

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Bożena Michalska, Eliza Kalbarczyk
Department of Agrometeorology and Land Reclamation
Agricultural University
Papieża Pawła VI 3, 71-469 Szczecin, Poland
e–mail: bmichalska@agro.ar.szczecin.pl

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