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IMPACT OF WEATHER CONDITIONS ON TRITICALE OVERWINTERING IN POLAND OVER 1988-1998

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ABSTRACT

The 1988-1998 study comprised analysis of statistical relation of degree of overwintering (in the 9-degree scale) and of winter damage (in percentages of sown area) of triticale, grown in field trials and in agricultural production to the air and soil thermic conditions and precipitation from December to March in the three distinguished overwintering zones. Also air minimum temperature at 5 cm above the ground, snow cover absent or less than 5cm thick as well as snow cover of different thickness and duration were analysed. It was found that triticale overwintering was determined mainly by air and soil temperature, especially in December and January, whose largest impact manifested itself in the central part of Poland.

Key words: overwintering degree, winter damage, analysis of regression, soil and air temperature, minimum temperature, precipitation, excessive snow cover

INTRODUCTION

Triticale overwintering in Poland is quite high and range from 8 to 8.5° (with the 1- to 9-degree scale). Winter damage is slight and by and usually does not exceed 3% of the total crop area [6,12]. However, in extremely unfavourable winter conditions, as over 1996/1997, the losses caused by adverse overwintering may be even ten times as much as the average [5,6]. In the past decade, triticale withstood winter stresses only slightly more badly than rye did, but better than wheat [7].
The overwintering of triticale, as that of other winter crops, is determined by air and soil thermic conditions combined with snow cover; winter damage occurs mainly as a result of frost killing and chilling-wind plant damage [2,4,11,13].

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Studies aiming to specify essential factors determining the overwintering of triticale rely mostly on results obtained from the field and laboratory methods, local or regional, and gathered from specific years, especially those that saw extremely unfavourable conditions or under provocative conditions that provide basis for plant-raising winter hardiness for breeders [8,9,10,15,13]. What is missing in the literature is a treatment of the question of weather conditions in triticale overwintering in Poland as a whole country from the perspective of many years. Few works that have been published in this area are devoted mainly to the least winter-hardy species – barley and rape.

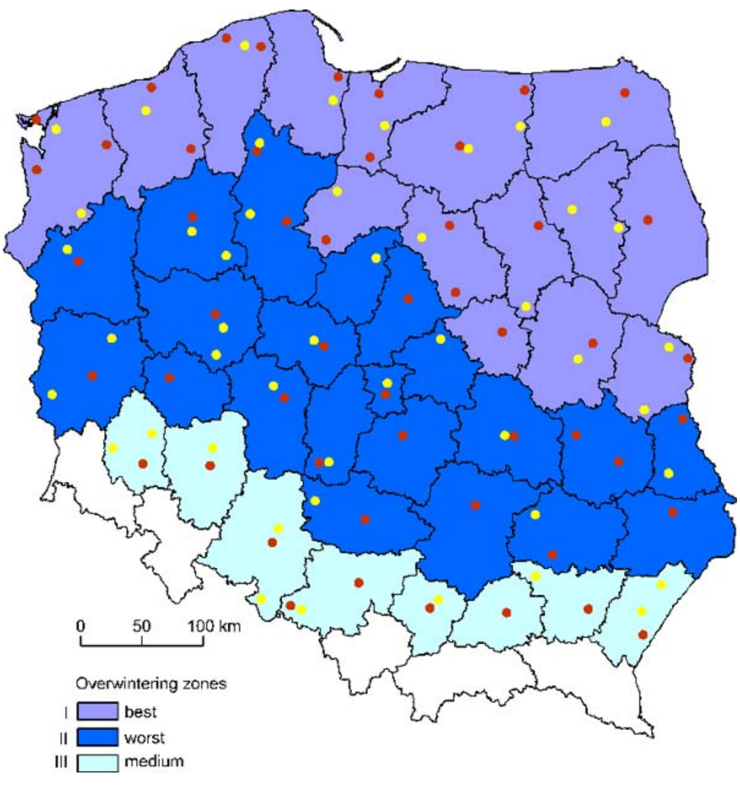
These considerations have affected the scope of the present study, whose aim was to evaluate the impact of basic weather conditions, and isolate a set of main weather factors determining the overwintering of triticale under experiment and field conditions. Taking into account other findings [1] that point to a clear spatial differentiation in the overwintering of triticale not only during adverse winters, but over the long-term perspective, analysis of climatic risk of the overwintering of triticale was carried out with respect to the three zones, distinguished and characterised in the earlier publication [7].

MATERIAL AND METHODS

The basic empirical data included the results obtained over the years from 1988 to 1998. The overwintering of triticale in field trials was graded on the scale from 1 to 9, by 47 COBORU (Research Centre for Cultivar Testing) experimental stations, where the species was represented by the mean from all the cultivars tested in a given year, whose number in the specified period of 11 years ranged from 14 to 29. Estimates provided by the Chief Statistical Office were accepted as the output of land production. They comprised the sizes of triticale cultivation areas that had been ploughed or designated for ploughing due to fall-winter and spring periods losses, expressed in percentages of sown areas, as well as grain yields in 44 provinces according to the administrative division in effect between 1975 and 1998. The mountainous regions, which cover the territory of the other five Polish provinces, had been excluded.

The weather data included daily minimum air temperature at 5 cm above the ground, decade mean air temperature at 2 m above the ground, decade mean soil temperature at 5 cm below the soil surface, daily thickness of snow cover and decade total precipitations reported by weather posts attached to COBORU experimental stations, and by weather stations established by the IMGiW (Institute for Meteorology and Water Management) (Fig. 1), published every ten days in Agro-weather Bulletins [3]. Then daily air temperature at 5 cm above the ground and snow cover thickness were selected as weather factors that are potentially threatening to winter crops as ones that induce frost killing, chilly-wind plant damage and smothering [4].

Fig. 1. Triticale overwintering zones in Poland over 1988-1998 and location of COBORU experimental stations (●) and IMiGW meteorological stations (●)



The minimum air temperature in the absence of snow cover or with snow cover less than 5 cm thick was analysed as follows:

- ≤ -5 °C, ≤ -10 °C, ≤ -15 °C – over the period from December 1st to March 31st;
- ≤ -5 °C, ≤ -10 °C – from February 1st to March 31st; marked respectively as t 11- t 15.

Excessive and long-lasting snow cover was represented by a number of days on which it exhibited the following characteristics:

- thickness ≥ 10 cm, ≥ 20 cm, and ≥ 5 cm, ≥ 10 cm, lasting uninterruptedly for at least 40 days; and thickness ≥ 20 cm lasting uninterruptedly for at least 30 days over the period between December 1st and March 31st,
- thickness ≥ 5 cm lasting uninterruptedly for at least 15 days and ≥ 10 cm lasting uninterruptedly for 10 days over the period from February 1st to March 31st, marked respectively as p11-p17.

For each specified weather factor, measured at COBORU and IMiGW stations, charts were drawn illustrating their spatial distribution for the consecutive decades and years. On the basis of the prepared charts, using the graphic interpolation method, values of the weather factors were determined for the particular provinces.
Analysis of the relation of the degree of overwintering and of winter damage to the weather factors was conducted within the boundaries of the three triticale overwintering zones, delineated in Fig.1. Out of the three zones, the best conditions for triticale overwintering were found in the zone I, the worst - in the zone II, whereas the zone III proved average winter triticale overwintering.

RESULTS AND DISCUSSION

The impact of the weather conditions on triticale overwintering was assessed on the basis of soil and air temperature as well as precipitations during the winter break over the triticale vegetation. The growth of triticale is stopped in fall usually in the third decade of November, and it is resumed in spring in the third decade of March [11], therefore the winter break in the vegetation was assumed to extend from December to March. The results of the relationship between triticale overwintering and thermic and precipitation conditions are included in Tables 1-3. Because the degree of overwintering and winter damage are opposite indicators of overwintering, therefore contrary signs (+ or -) emphasize the direction of influence exerted by the analysed weather factors on triticale overwintering under experiment and field conditions.

Over 1988-1998, the impact of the considered weather features on triticale overwintering in most decades between December and March was statistically significant all over the country. However, more influential for triticale overwintering were the thermic conditions, while the precipitation in successive decades, proved to be less influential. Statistically significant impact of the thermic conditions was observed in most decades of the winter break in triticale vegetation, in all the distinguished overwintering zones. The largest number of statistically significant coefficients of correlation between overwintering and soil temperature at 5 cm below the surface and air temperature at 2 m above the ground, for the consecutive decades in the period from December to March, was found in the northern part of Poland (zone I). The impact of soil and air thermic conditions on triticale overwintering manifests itself especially in the first half of the winter break that is in December and January. The period marked by the strongest influence of the thermic conditions begins in the second decade of December, and lasts well into the first decade of February, while the period of the strongest impact of air temperature is a bit shorter and comes to an end of the second decade of January. The essential part of air thermic conditions in December and January in accounting for triticale overwintering variability had been demonstrated by Raszka [11] and for rye, wheat, and barley – by Szymczyk [14].

The data included in Tables 1 and 2 suggest also that in the whole country, triticale overwintering is determined by the thermic conditions prevailing at the end of the winter break in the vegetation season. Statistically significant coefficients of the degree correlation between overwintering and winter damage with soil and air temperature were found in the three analysed zones for the third decade of March, and the impact of air temperature, for most of the country, proved to be significant also in the second decade of March. These findings corroborate opinions quoted in agricultural science handbooks, known also from the agricultural practice, that in the climatic conditions prevailing in Poland, whether or not plants are in good shape after the winter vegetation break is determined by the weather features, and especially their variability around the time of the advent of spring. Recurring spells of cold weather can be more harmful than winter freezes, which is due to the extensive de-hardening of plants, whose hardiness in March as a rule matches their hardiness during fall. The data presented in Tables 1 and 2 proved that in the eleven years, from 1988 to 1998, rise in the soil and air temperature in March affected beneficially the triticale overwintering, which was most pronounced in the northern territories of Poland.

Table 1. Triticale overwintering (a) and winter damage (b) determination coefficients (R^2 in %) in relation to soil temperature at 5 cm below the soil surface (1988-1998)

Month	Decade	Overwintering zone							
		I		II		III		Poland	
		a	b	a	b	a	b	a	b
December	1	•	-* 1.7	+** 2.9	•	•	•	+** 1.7	-* 0.7
	2	+* 2.7	-*** 11.5	+*** 6.2	-*** 6.4	+** 5.0	-*** 8.4	+*** 4.5	-*** 5.3
	3	+*** 6.5	-*** 7.0	+*** 44.1	-*** 53.0	+*** 38.2	-*** 39.8	+*** 27.1	-*** 38.7
January	1	•	- 1.2	+*** 31.6	-*** 39.6	+*** 19.8	-*** 18.5	+*** 17.8	-*** 24.8
	2	+** 3.8	-*** 9.8	+*** 23.8	-*** 26.9	+*** 27.8	-*** 29.6	+*** 15.5	-*** 20.1
	3	+*** 9.7	-*** 14.6	+*** 16.9	-*** 7.6	+*** 11.3	-*** 12.1	+*** 13.1	-*** 7.2
February	1	+*** 10.6	-*** 7.8	+*** 13.0	-*** 4.7	+** 7.1	-** 5.8	+*** 10.6	-*** 4.2
	2	+* 2.7	•	+*** 7.8	•	+* 4.1	•	+*** 5.0	-* 0.7
	3	+** 4.4	•	•	•	•	•	+** 1.6	•
March	1	+** 5.0	•	•	+** 2.4	•	•	•	+* 1.3
	2	+*** 10.4	-*** 11.7	•	•	•	•	+*** 2.7	•
	3	+*** 15.2	-*** 22.6	+*** 12.3	-*** 12.3	+*** 10.5	-*** 10.6	+*** 12.1	-*** 8.7

+/- relation positive/negative; ***significant relation at $\alpha \le 0.01$; **significant relation at $\alpha \le 0.05$; *significant relation at $\alpha \le 0.1$; • non-significant relation

Table 2. Triticale overwintering (a) and winter damage (b) determination coefficients (R^2 in %) in relation to air temperature at 2 m above the ground (1988-1998)

Month	Decade	Overwintering zone							
		I		II		III		Poland	
		a	b	a	b	a	b	a	b
December	1	•	-* 1.9	•	•	•	•	•	•
	2	•	-*** 27.2	+* 2.1	-*** 7.3	+* 4.0	-** 5.1	+** 1.8	-*** 6.2
	3	+*** 8.1	-*** 14.4	+*** 22.3	-*** 43.4	+*** 28.6	-*** 37.7	+*** 18.3	-*** 28.0
January	1	+* 2.9	-*** 4.1	+*** 16.9	-*** 31.9	+*** 20.1	-*** 20.7	+*** 11.9	-*** 19.5
	2	+*** 7.8	-*** 7.8	+*** 4.0	-*** 11.8	+*** 16.9	-*** 15.6	+*** 6.1	-*** 8.8
	3	+*** 5.7	-*** 14.3	+** 3.3	•	+** 6.5	•	+*** 4.1	-** 1.1
February	1	+*** 6.3	-** 3.9	+** 4.8	•	+** 4.2	•	+*** 4.6	•
	2	•	•	•	•	•	•	+** 1.4	•
	3	+* 2.9	•	•	+*** 5.7	•	•	•	+*** 3.0
March	1	+*** 7.9	•	•	+*** 5.3	•	•	•	+*** 2.6
	2	+*** 11.8	-*** 20.8	+* 2.4	-* 1.3	+* 3.6	•	+*** 4.2	-*** 1.7
	3	+*** 12.8	-*** 21.6	+** 3.6	-*** 12.7	+*** 14.3	-*** 11.5	+*** 5.6	-*** 9.0

For details – see Table 1

The determination coefficients between triticale overwintering and the soil temperature at 5 cm below the surface were mostly higher and to the air temperature at 2 m above the ground, slightly lower. Over 1988-1998 the importance of the thermic conditions for triticale overwintering was all evident in the central part (zone II), and also in the southern part (III) of Poland. In the both zones, the highest correlation coefficients (38 to 53%), both under experiment and field conditions were obtained for the soil temperature at 5 cm below the surface in the third decade of December, and then in the first and second decades of January. In the northern part of Poland, at this time, the effect of the thermic conditions on triticale overwintering was considerably lower.

The data included in Table 3 demonstrate that the impact of decade total precipitations on triticale overwintering over 1988-1998 was statistically significant, mainly in the zone II. In this region, high total precipitations in winter, mainly in the second and third decade of December, were favourable for triticale overwintering, whereas the only negative effect on triticale overwintering was due to precipitation in the second decade of February. The statistically significant role of precipitation in determining triticale overwintering in the analysed period of time, but only under agricultural practice conditions, manifested itself in the northern region, the zone I.

Table 3. Triticale overwintering (a) and winter damage (b) determination coefficients (R^2 in %) in relation to sum of precipitations (1988-1998)

Month	Decade	Overwintering zone							
		I		II		III		Poland	
		a	b	a	b	a	b	a	b
December	1	•	-*** 4.7	+*** 7.2	-*** 9.3	+* 3.0	-** 5.2	+** 1.7	-*** 6.0
	2	•	-*** 8.6	+*** 12.6	-*** 13.2	•	•	+*** 1.9	-*** 7.3
	3	•	•	+*** 5.1	-*** 11.6	•	•	+** 1.4	-*** 6.6
January	1	•	•	+** 3.6	-*** 5.1	•	•	•	-*** 2.1
	2	•	-*** 8.0	+** 4.1	-*** 4.8	•	•	+*** 1.8	-*** 3.8
	3	•	-*** 4.4	•	-*** 4.9	+** 5.6	-** 6.7	•	-*** 3.8
February	1	•	-** 3.9	+** 3.3	-** 2.7	•	-* 3.2	-** 1.4	-*** 2.3
	2	•	+* 1.8	-*** 7.4	+** 2.7	•	•	-*** 1.9	+** 1.3
	3	•	•	•	•	•	•	•	•
March	1	•	•	+*** 7.3	-*** 4.8	•	•	+** 1.7	-*** 2.6
	2	•	•	•	•	•	•	+** 1.2	•
	3	•	•	•	•	•	-* 3.6	•	-** 1.0

For details – see Table 1

The essential impact of the thermic conditions on the triticale overwintering over 1988-1998 is confirmed by the data presented in Tables 4 and 5 which show that in the analysed period, all over Poland, the main adverse weather factors, detrimental to triticale overwintering, was the recurrent dropping of the minimum air temperature at the ground level, with snow cover either absent or not sufficiently thick, while less damage was induced by excessive and long-lasting snow cover. The above-mentioned temperature and snow cover factors are also disadvantageous for other crops, but over the years 1976-1990, overwintering of rye, wheat, barley and rape was far more determined by excessive length and thickness of snow cover [Czarnecka 1998]. For the whole territory of Poland, coefficients of determination between degree of triticale overwintering and the number of days when the minimum temperature was ≤ -5°C, ≤ -10°C, ≤ -15 °C were approximate, while the amount of plant losses in agricultural production was primarily determined by the number of days with the minimum temperature lower than 5 °C (Table 4). The dropping minimum temperature frustrated triticale overwintering mostly in the central and southern regions (zones I and II). The negative role of snow cover, both under experiment and field conditions, was visible above all in the northern region, and its effect, rendered in determination coefficient, was equivalent to or even stronger than that of the minimum air temperature. The statistically significant influence of excessive and long-lasting snow cover was also proved for the southern region (zone III) of Poland, but only under experiment conditions.

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Table 4. Impact of minimum air temperature at 5 cm above the ground, with snow cover absent or less than 5 cm thick, on degree of overwintering (a) and winter damage (b) of triticale (1988-1998)

Minimum temperature	Overwintering zone							
	I		II		III		Poland	
	a	b	a	b	a	b	a	b
t 11	-*** 4.7	+*** 7.5	-*** 29.5	+*** 26.3	-*** 8.1	+*** 26.2	-*** 13.7	+*** 20.1
t 12	-*** 5.4	+*** 4.8	-*** 26.4	+*** 16.9	-*** 11.4	+*** 21.8	-*** 14.1	+*** 13.2
t 13	-*** 6.9	+** 3.7	-*** 22.7	+*** 9.9	-** 6.6	+*** 13.7	-*** 12.5	+*** 8.3
t 14	-* 2.0	+*** 6.4	-*** 14.1	+*** 16.4	-** 4.6	+*** 14.7	-*** 6.0	+*** 11.3
t 15	-** 2.7	•	-*** 6.1	+* 1.3	-* 4.0	•	-*** 4.3	+** 1.2

t – number of days with minimum air temperature, in the absence of snow cover or with snow cover less than 5 cm thick; t 11 ≤ -5°C ; t 12 ≤ -10°C ; t 13 ≤ -15°C - during the winter break in the vegetation; t 14 ≤ -5°C; t 15 ≤ -10°C - from February 1st to the resumed vegetation in spring

Table 5. Impact of snow cover on degree of overwintering (a) and winter damage (b) of triticale (1988-1998)

Snow cover	Overwintering zone							
	I		II		III		Poland	
	a	b	a	b	a	b	a	b
p 11	-*** 6.2	+*** 4.3	•	-* 1.4	-*** 7.8	•	-*** 3.1	•
p 12	-*** 6.6	+** 3.2	•	•	-** 5.9	•	-*** 3.0	•
p 13	-*** 5.1	+*** 6.7	-** 3.0	•	-*** 8.5	•	-*** 4.7	•
p 14	-** 3.3	+*** 6.3	•	•	-*** 10.0	•	-*** 3.5	•
p 15	-*** 7.1	+*** 4.7	•	•	-** 6.2	•	-*** 3.0	•
p 16	-*** 6.8	+** 3.1	•	-* 1.2	-** 4.6	•	-*** 3.5	•
p 17	-*** 6.1	+** 2.7	•	•	-** 6.2	•	-*** 2.7	•

p – number of days with snow cover during the winter break in the vegetation: p 11 - thickness ≥ 10cm; p 12 - thickness ≥ 20 cm, and p 13 - thickness ≥ 5 cm; p 14 - thickness ≥10 cm, lasting uninterruptedly for at least 40 days from February 1st to the resumed vegetation in spring: p 16 - thickness: ≥ 5 cm lasting uninterruptedly for at least 15 days; p 17 - thickness ≥ 10 cm lasting uninterruptedly for 10 days

Excessive thick and long-lasting snow cover turned out to be the weather factor that more than any other differentiated correlation results calculated for degree of overwintering and for triticale winter damage. This certainly does not mean that the role of excessive thick and long-lasting snow cover in triticale overwintering differs under experiment and agricultural production conditions. This may have resulted, it seems, from the method adopted for establishing parameters characterising the occurrence of snow cover in the particular provinces. Although it was identical for all the factors analysed in the present study, it probably entailed too much generalisation with reference to the factor subject to the largest temporal and spatial variability of all. Over 1966-1990, the random variability coefficient of the occurrence of excessive and long-lasting snow cover in Poland exceeded 2 or 3 times that of the occurrence of the minimum air temperature with snow cover absent or less than 5 cm thick, and for some thickness and uninterrupted sequences of days during which it persisted, the coefficient amounted to as much as 350% [4]. A more complete characterisation of snow cover in the province scale would require taking into account measurements taken by the whole network of active IMiGW weather stations and precipitation observation posts.

At the next stage of the analysis an attempt has been made to isolate main weather factors that conditioned triticale overwintering in the years 1988-1998. The results of performed stepwise regressions are presented in Table 6. The singled out weather factors accounted for 15 to 51% of the variability of degree of triticale overwintering, and for 33 to 67% of the winter damage losses. The weather conditions exerted the largest impact on triticale overwintering in the central region, zone II, and the least – in the northern region, zone I. In the northern part of Poland (I), the influence of the weather factors on the overwintering of triticale grown in agricultural production was twice as high as in field trials, whereas for the other regions it was much alike. In the years 1988-1998, triticale overwintering was determined chiefly by the thermic conditions in December. Out of the isolated weather factors crucial for triticale overwintering, the most common one in the three zones was decade soil temperature 5 cm below the surface in the second and third decade of December, and additionally, in the third decade of March. However, as indicated by the percentages of squared partial correlation coefficients, in the central part of Poland the most decisive factor in determining the variability of triticale overwintering was air temperature in the third decade of December which accounted for as much as 60% of the winter damage variability, and about 43% of the overwintering degree variability. Decade total precipitations significantly complemented the picture of triticale overwintering variability in the zones II and III, but their contribution, estimated on the basis of partial correlation, was small, amounting to less than 10%. Out of the adverse temperature and snow factors, excessive thick and long-lasting snow cover was found to be influential in triticale overwintering, but only in the zone II. However, contrary to what single regression yielded, in the set of isolated weather factors, under experiment conditions, the essential role was played by snow cover ≥ 20 cm thick, lasting uninterruptedly for at least 30 days between December 1st and March 31st, while under production conditions, the prominent contribution came from the number of days when snow cover was ≥ 5 cm thick and lasted uninterruptedly for at least 15 days at a time, but in the second half of the winter break, from February 1st to March 31st. On the other hand, the absence, in the set of singled out weather factors, of the minimum temperature, combined with insufficient snow cover, obviously results from the fact its influence is subsumed under the mean decade air temperature.

Table 6. Weather factors determining variability of triticale degree of overwintering (a) and winter damage (b) (1988-1998)

Overwintering zone	Overvintering feature	Weather factors	R^2	Sy	S
I	A	$TG_{3\ March}^{***}$	15.2	0.7	0.8
	B	$TP_{2\ December}$ $TG_{3\ March}$ (13.6**)(8.4***)	33.2	1.5	1.8
II	A	$TP_{3\ December}$ $OP_{1\ January}$ p15 (43.4***) (1.3***) (1.5***)	51.3	0.7	1.0
	B	$TG_{2\ December}$ $TP_{3\ December}$ $OP_{2\ January}$ p16 (7.6***)(60.2***)(9.3***) (39.3***)	66.8	4.3	7.3
III	A	$TG_{3\ December}$ $TP_{2\ January}$ $OP_{2\ February}$ (26.6***) (15.4***) (5.3**)	47.8	0.7	0.9
	B	$TG_{3\ December}$ $TG_{2\ January}$ $OP_{1\ February}$ (21.1***) (12.8***) (5.9**)	49.0	2.5	3.5
Poland	A	$TG_{3\ December}$ $TP_{2\ January}$ (20.0***) (4.0***)	30.1	0.8	0.9
	B	$OP_{1\ December}$ $TG_{3\ December}$ $OP_{2\ January}$ (1.2**) (35.7***) (1.9***)	41.0	4.2	5.4

TG - mean soil temperature at 5 cm below the surface; TP - mean air temperature at 2 m above the ground; OP - total rainfall; 1, 2, 3 in lowered index - consecutive decades; p15, p16 – as in Table 5; in brackets - r^2 - squared partial correlation coefficient in %; R^2 – determination coefficient in %; Sy – regression equation error S – standard deviation; relation positive/negative

In the analysed time span, extremely unfavourable conditions for triticale overwintering occurred in 1987/88, 1995/96, and 1996/97, the latter being the most adverse winter of the three [3,7]. During each of these winters, the isolated factors: mean decade soil temperature at 5cm below the surface, mean decade air temperature at 2 m above the ground, and as frequently, decade total precipitations, exerted a varied impact on the overwintering of triticale grown under experiment and field conditions (Table 7). In the winter of 1987/88, the influence of the analysed weather factors on winter damage of triticale grown under production conditions was twice as much as on the degree of overwintering in field trials, whereas in 1995/96, on the contrary, a definitely larger, even 2.5 times as much, role of the weather factors was proved for experiment conditions. On the other hand, during the most adverse winter of 1996/97, the contribution of the weather features to the variability of both overwintering degree and winter plant damage was approximate for the whole country. Furthermore, the data presented in Table 7 point to a widely varied, often contrary, impact of the isolated weather factors on triticale overwintering, in relation to the other weather features in a given winter as well as to the winter break in the vegetation. For instance, snow cover ≥ 5 cm thick lasting uninterruptedly for at least 40 days at a time during the severe winter of 1996/97 enhanced triticale overwintering, while during the milder winter of 1987/88 – the effect was negative.

A contrary influence exerted by the same weather factor during the same winter, but at different stages of the winter vegetation break, and in consequence, with respect to different degree of plants hardening, was revealed by the correlation between overwintering degree and soil temperature over the winter of 1995/96, or the correlation between overwintering (in field trials and in production) degree and precipitation over the 1987/88 winter, and also 1995/96. It must be emphasized, however, that a contrary effect of the same weather factor, displayed in the course of the same winter for the whole country, may result from the diversity of weather causes and their regional or even local influence. However, the statistical evaluation of such a typically random phenomenon for the three overwintering zones was not sufficiently reliable, because of inadequate basic data.

Table 7. Weather factors determining variability of triticale degree of overwintering (a) and winter damage (b) in the years 1988, 1996 and 1997

Years	Overvintering feature	Weather factors	R^2	Sy	S
1988	a	p12 OP_{3III} (22.4***) (17.3***)	33.4***	0.3	0.4
	b	$TG_{2\,XII}$ $OP_{2\,I}$ $TP_{2\,II}$ (16.2***) (40.2***) (37.6***)	65.0***	0.8	1.3
1996	a	OP_{1XII} TG_{3XII} TG_{3I} OP_{2III} (37.2***) (16.1**) (15.5**) (16.7**)	50.5***	0.9	1.3
	b	$TP_{3\,XII}$ $OP_{3\,XII}$ (13.5**) (12.5**)	20.3***	1.3	1.4
1997	a	p13 TP_{3II} OP_{2III} (27.5***) (36.9***) (28.4***)	53.4***	1.1	1.6
	b	$TP_{1\,XII}$ $TG_{1\,I}$ (17.3***) (48.5***)	54.7***	8.4	12.2

CONCLUSIONS

1. Over 1988-1998, the overwintering of triticale was determined chiefly by the thermic conditions of the soil and air in the period from the second decade of December to the first decade of February, with the largest effect exerted by the soil temperature at 5 cm below the surface in the third decade of December, which in the central and southern parts of Poland accounted from 38 to 44% of the overwintering variability degree in field trials, and for 40 to 53% of the variability of winter plant damage under agricultural production conditions.
2. In the second half of the winter vegetation break, the impact of the thermic conditions on triticale overwintering occurred in the third decade of March all over Poland, being the most pronounced in the northern part of Poland.
3. In the years 1988 – 1998 the main adverse weather factor frustrating triticale overwintering in the whole country was the dropping of minimum air temperature at 5 cm above the ground below – 5 °C or – 10 °C, with snow cover either absent or insufficient in thick, whereas the unfavourable effect of excessive and long-lasting snow cover manifested itself mainly in the northern Poland.
4. The thermic and precipitation conditions accounted for 15 to 51% of the degree variability of overwintering of triticale grown in field trials, and for 33 to 67% of the winter damage of plants under agricultural production conditions; the least effect was visible in the northern part, the most - in the central part of Poland.

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