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Grain yield response of facultative and winter triticale for late autumn sowing in different weather conditions

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Abstract. Climate change is affecting the growing conditions of winter cereals. Peculiarities of organogenesis and their impact in grain yield of facultative triticale depend on different nitrogen fertilization can help to avoid adverse effects of unfavorable conditions. Field experiment was conducted in zone of the Right-Bank Forest-Steppe of Ukraine. The experiment included 2 late autumns sowing periods and fertilization system with few variants of nitrogen fertilization applied in spring. Features of organogenesis of two winter varieties and facultative triticale Pidzimok kharkivskiy were determined by apical meristem microscopy from emergence till heading. Was established process of apical meristem differentiation in facultative triticale has non-linear relation between temperature and number of spikelets. The efficiency of apical meristem differentiation reaches its maximum at 12 °C. Grain yield of triticale varieties depend on studied factors but main impact had weather conditions. Grain yield of facultative triticale significantly exceeds winter varieties and had a lesser difference between sowing period than winter cultivars. Crops in the first sowing period were more productive than in the second. Facultative triticale has great productivity potential in late autumn sowing and can realize it in various conditions. Reduced yields in late sowing are lower than in winter cultivars.

Key words: apical meristem, nitrogen fertilization, organogenesis, sowing period.

INTRODUCTION

Sustainable grain production depends on growing technologies. Sowing time is the key to successful wintering and ensures efficient use of resources. Autumn climatic conditions do not allow sowing in optimal terms in recent years. Cereals germinate later and vegetative period in the fall is shrinking. Winter varieties accumulate less sugars what reduce their winter hardiness. On the other hand, winter hardiness depends on conditions before winter and may difference in same variety.

Low temperature tolerance (LT) depends on daylight length and exposure of period (Limin & Fowler, 2006). Late autumn is preceded by shortening day length that positive affected on LT-tolerance genetic potential. Triticale and wheat get half of their cold resistance in 2 weeks and full in 6–7 weeks. Expression of VRN-A1 allele is a major cause of delayed plant development on early vegetative stages in the autumn. Late autumn sowing can be effective when cereals wintering in BBCH 05–09.

VRN-1 gene expression occurs in plant after germination at low temperature (Humphreys et al., 2006). Increase in temperature could result in a failed or insufficient vernalization of winter wheat. This imperfection is manifested in varieties with high vernalization requirement and sensitivity to day length. Spring and facultative triticale have not such disadvantages.

Productivity of winter crops decreases when sowing is delayed (Yildirim et al., 2013). The main reasons of low efficiency are decrease in the number of productive stems and grains in the ear. The weight of grain in spike depends on the grain size and its filling in the later stages of ripening. This allows to increase yields, when the number of spikes per m^2 and grains in the spike has been determined.

The experience of spring triticale growing (Grocholski et al., 2007) with late autumn sowing showed that their winter hardiness is sufficient by the typical winter conditions with snow cover.

Facultative crops in late autumn sowing have many advantages because their development may occur by winter or spring types depending on environmental conditions. Triticale seeds can sprout at 1–3 °C.

Germinated seeds stay viable at low temperature and they vernalization are continuously. When vegetation continues for a long time the plants do not switch to 'double ridge' stage in the autumn. They increase in root system mass and accumulate solute carbohydrates. Grain and biomass yield of facultative triticale had a less dependence on sowing periods than in winter varieties.

MATERIALS AND METHODS

Field experiments were conducted in 2016–2019 (3 vegetative seasons for winter cereals). Triticale was cultivated in the Right-bank Forrest-Steppe of Ukraine (49°46′ N, 30°44′ E). The soil is typical low-humic black, the arable layer of which is characterized by the following agrochemical and agro-physical indices: humus content – 4.31–4.63%; pH – 7.2, easily hydrolyzed nitrogen (according to Kornfeld) – 152.3–167.0 mg; P_2O_5 in acetic acid extract (according to Chirikov) – 109.0–142.0 mg; exchangeable potassium (according to Chirikov) – 127.0–132.0 mg per 1 kg of soil.

Climate conditions

Meteorological indicators were obtained from the meteorological station #33466(Mironivka). The calculation of monthly average temperature and summary of precipitations was carried out during vegetative period (October–June).

Establishment of weather condition deviation was conducted by equation:

$$K_{sdw} = \frac{X_i - \bar{X}}{S} \quad (1)$$

where K_{sdw} – coefficient of weather conditions deviation; X_i – multi-annual average parameter; $\bar{X}$ – average/summary parameter in year; S – standard deviation in observed period.

$|K_{sdw}| < 1$ – typical condition, $|K_{sdw}|$ from 1 to 2 – conditions differences from typical, > 2 – rarely or abnormally condition.

Result of weather condition analysis and their typicality by the e.g. (1) are showed in Table 1.

Table 1. Monthly average temperature[1] (°C) and precipitations during triticale vegetation in 2016–2019

Month	Temperature, °C				
	2016/2017	2017/2018	2018/2019	Average	Average multi-annual
X	6.7	8.6	10.5[a]	8.6	7.9
XI	1.4	3.5	0.1[a]	1.7	2.0
XII	-1.8	2.2[b]	-1.9	-0.5	-2.5
I	-5.3	-3.0[b]	-4.9	-4.4	-5.6
II	-2.6	-3.6	0.4[b]	-2.0	-4.5
III	6.1[a]	-1.8	4.7[a]	3.0	0.4
IV	10.5[a]	13.3[b]	10.4[a]	11.4	8.6
V	15.4	18.4[b]	17.3[a]	17.0	15
VI	20.6[a]	20.2[a]	22.6[b]	21.1	18
Average per season	5.7	6.4	6.6	6.2	4.4
	Precipitations, mm				
X	118.9[a]	115[a]	36.6	90.2	27
XI	45.9	86.2[a]	32.2	54.8	39
XII	46.2	161.1[b]	108.3[a]	105.2	44
I	39.8	104.3[b]	53.6	65.9	34
II	48.5[a]	54.1[b]	37	46.5	32
III	19.2	114.3[a]	44.4	59.3	33
IV	55.7	23.1	68.1	49	45
V	38.0	42.1	66.5[a]	48.9	44
VI	27.7	162.6[a]	156.9[a]	115.7	77
Sum per season	439.9	862.8	603.6	635.4	375.0

[1]Data from meteorological station #33466 (Mironivka); [a] – conditions differences from typical; [b] – rarely or abnormally conditions.

Spring vegetation was restored in 3rd decade of March in 2017 and 2019, but 2018 (restoration on 2nd decade of April) had a significant difference from them. Temperature conditions in this month had deviations from ordinary conditions. They were more warm than multi-annual parameter. This month has been typical by precipitations in both years, but their quantity was increased in 2018. Temperature conditions of April are important because there is a transition from vegetative to generative development. The temperature conditions were not typical and exceeded multi-annual parameter by 1.8 °C in 2017 and 2019. Weather conditions in 2018 were rarely and the average monthly temperature exceeded the multi-annual by 4.7 °C.

Sampling and methods

Features of facultative triticale development and affect of factors on grain yield were obvserved in the field experiment by 3-factorial scheme (Table 2). The experiment was established in 4 replications. The size of elementary plots was 32 m^2 (25.2 m^2 to harvesting). Each year, 36 kg P ha^{-1} (superphosphate, 18% P) and 72 kg K ha^{-1} (potassium chloride, 60% K) were applied before sowing on all plots. Nitrogen fertilizer applied on subplots depending of research programme. Tillage system included only one plowing after preceding crop harvesting (soybean). Was conducted cultivation on sowing depth (2–4 cm) before sowing. Triticale was sown with 15-cm inter-row spacing with rate 450 grains per square meter. Weren't applied pesticides during research. Plots were harvested in July. Yield per hectare was calculated to 14% moisture.

Table 2. Scheme of field experiment

Variety Factor A	Fertilization system Factor B	Code FS^2	Sowing date Factor C
A1. Pidzimok kharkivskiy	B1. $P_{36}K_{72}$	N_0	C1. 2nd decade of October
A2. Amur	B2. $P_{36}K_{72} + N_{25(11\text{-}13)}{}^1$	N_{25}	
A3. Obrii Myronivs`kyi	B3. $P_{36}K_{72} + N_{25(11\text{-}13)} + N_{55(23)}$	N_{80}	C2. 3rd decade of October
	B4. $P_{36}K_{72} + N_{25(11\text{-}13)} + N_{55(25)} + N_{20(49)}$	N_{100}	

[1]BBCH scale; [2]Code FS(fertilizing system) uses in text.

All researched varieties have good winter and cold resistance (Table 3). They are able to form high grain yield in diffirent conditions (drought and salt resistance).

Table 3. Variety characteristic

Variety	Type	Thousand kernel weight, g	Protein content, %	Grain yield potential, t ha^{-1}	Freezing injurious temperature, °C
Pidzimok kharkivskiy	facultative	40–45	13–16	9.2	-16.5
Amur	winter	50–60	13–15	9.6	-18.5
Obrii Myronivs`kyi	winter	45–50	12–15	9.7	-18.0

The date of organogenesis stage beginning was the moment when 10% of plants entered in the stage. Were analyzed 10 plants from each variant to establish organogenesis stage by apical meristem microscopy. Organogenesis stages was established by Kuperman scale (Kuperman, 1969). For establishing average number of spikelets on spike was analyzed 30 plants in ripening stage, sampled from each experimental plot.

Statistical analysis

Relation between parameter was determined by linear and polylinear correlation. Evaluation of regression coefficient significance was derived by means of *t-test*, adopting zero hypothesis and 0.05 confidence level. *ANOVA* (confident interval Fisher`s LSD) and cluster analysis were conducted by Statistica 13.3.

RESULTS AND DISCUSSION

Influence of weather conditions on spike elements formation

Peculiarity of triticale organogenesis in non-traditional sowing dates is that it germinates in autumn and spike organs are formed in the spring. Restoration of spring vegetation occurs at daily temperature more 5 °C. At initial stages, development of plants is most affected by temperature regime. The date of spring restoration and temperature regime is a key factor, influencing on apical meristem differentiation. Average monthly air temperatures over the years was increased in compared to multi-annual average parameter. This influenced on apical meristem differentiation, especially in 2018. The linear size of the apical meristem increased more rapidly in 2018 than in other years, but the number of double ridges did not increased (Fig. 1).

Development of apical meristem in crops of the second period was slower but under abnormal conditions was accelerated in compare with 1st sowing date (C1). Differentiation occurred differently depending on variety and temperature from germination to double ridge formation. The highest duration of double ridge formation and more favorable temperature conditions in variants with first sowing period. This stage occurred at higher average daily temperatures in crops of 2nd sowing date (C2) that affected on differentiation and potential spike structure. Differentiation in facultative triticale at this stage was similar to the winter variety Amur.

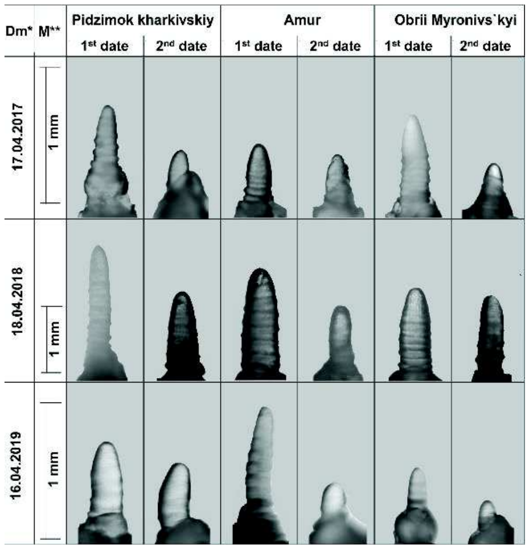

Figure 1. Apical meristem development (main shoot) in BBCH 25, *Dm – date of microscopy, m** – measurement.

Decrease in some phases of development duration was observed in crops during the late autumn sowing (Hall et al., 2013). Reduction in duration of double ridge is occurs in decrease of spikelets and grains number, but an increase in weight of thousand kernels. Self-regulatory ability of the plant increases flow of dry matter to the grain, which in turn realizes photosynthetic potential in grain yield.

The main difference in the process of apical meristem differentiation between winter and facultative triticale was relationship between formation of double ridges and average daily temperature during this process (Fig. 2). Double ridges develop to spikelets in future.

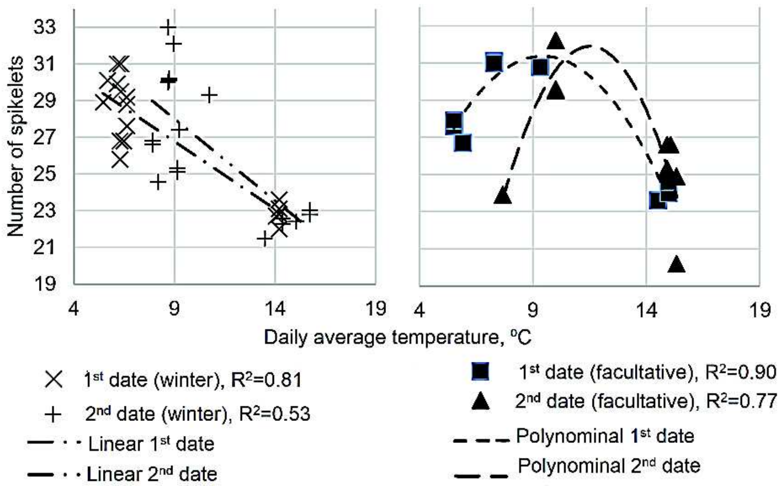

Figure 2. Correlation between spikelets number (at the ripening phase) and the average daily temperature during double ridge formation.

The total number of spikelets after apical meristem differentiation depended on the average daily temperature in winter and facultative triticale. The nature of this relationship was different. In winter varieties with average daily temperature increasing was a linear decrease in the number of spikelets. But a nonlinear relation was observed in facultative triticale for both sowing periods. This relationship was described by a quadratic function (inverted parabola) with focus in the range 9–12 °C. After spring vegetation restoration, increasing of average daily temperature to the focus point caused increase in number of spikelets per spike. If temperature during differentiation is more than 12 °C the total number of spikelets in the spike decreases.

Impact of weather condition on productive shoots number per m^2 and grain yield

Main factor affecting the yield of triticale is productive shoots number per m^2 (Fig. 3). Gustavo et al. (2013) founds the main impact on grain yield has a number of grains per m^2, what correlate with number of shoots per m^2. Quantity of grain and weight of thousand kernels reflect on weather conditions and nutrition. Shoots density depends on these factors too. Precipitations affect the number of shoots with enough nutrients. If autumn vegetation is shorter than ordinary condition there is a decrease in the number of spikes per m^2, the number of grains per spike is similar, but thousand kernels and grain weight per spike can increase (Santiveri et al., 2004; Slafer et al., 2014; Wenda-Piesik et al., 2016).

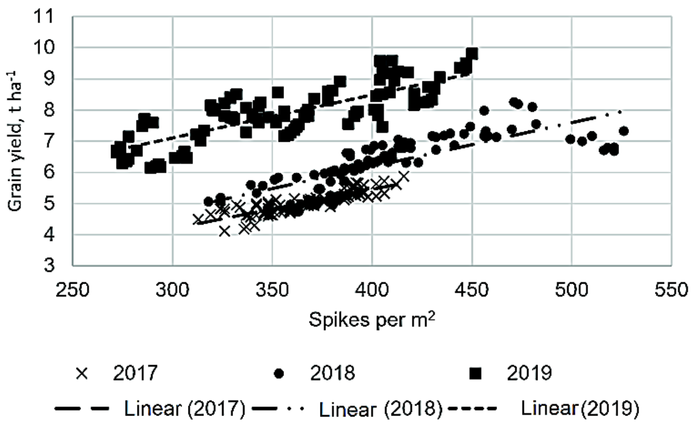

Figure 3. Regression analysis between grain yield and density per m^2 for 3 triticale varieties in every year of research.

Relation between grain yield and number of productive shoots per m^2 had a similar point but variate depend on year conditions (Table 4).

Table 4. Regression between grain yield and number of shoots per m^2

Year	Regression equation	R^2	R
2017	y = 0.0127x + 0.3922	0.74	0.86
2018	y = 0.0142x + 0.5173	0.61	0.78
2019	y = 0.0139x + 2.9403	0.64	0.80

Grain yield deviation from the regression equation was the smallest in 2017. Correlation coefficients between grain yield and number of grains per m^2 was 0.86. High accuracy of the model is due to the low variation of spike grain weight, thousand kernels weight and number of grains in different varieties in 2017. May and June were more warm than multi-annual condition (has a deviation from ordinary condition), but precipitations were lower (in normal range) what impacted on filling the grain in ripening phase. Precipitations before anthesis has a significant effect on formation processes but high temperatures after anthesis can limit the yield (Kalenska et al., 2018).

Weather conditions were similar in May and June on two next years. Temperature condition was rarely by average monthly parameter. They exceeded the multi-annual by 3.4 °C and impacted on triticale development from jointing (stem elongation) to anthesis. Temperature conditions had a deviation in June, but intensive rainfalls reduced the negative effects of high temperatures in this period. Decrease in yield compared to 2019 (similar to June) due to the number of spikelet's formed in double ridge. High temperature in period apical meristem differentiation decreased formation processes.

The higher yield triticale formed in 2019 than in two previously years. Main reason is increased rainfalls from spring restoration to ripening which impacted on efficiency of dry matter synthesis and grain filling. Correlation between grain yield and number spikes per m^2 was like in the previous year. More favorable conditions in double ridge formation period and enough precipitation in anthesis-ripening allowed to form higher yield due to the bigger mass of grain from the spike.

Increasing rainfalls leads to increased grain yield. Difference in grain yield between varieties was reduced at high precipitations rates (Linina & Ruza, 2018).

Response to fertilization system and sowing dates varied by variety depend on the weather condition during vegetation. Variety Pidzimok kharkivskyi (Table 5) had a low difference between variants in 2016/17 vegetation period but some variants of second sowing period decreased in grain yield when nitrogen dose was increased. Increase in the nitrogen dose leads to increased yields on all variants of first sowing date in 2017/18. Significant difference in sowings of 2nd sowing date was observed at variant N_{80} in that year. There was no significant difference between N_{80} and N_{100} variants for different sowing dates, but facultative triticale of 1st sowing date had a bigger grain yield than 2nd.

Table 5. Grain yield (t ha^{-1}) of winter and facultative triticale Pidzimok kharkivskyi

Sowing date	Fertilizing system	Year		
		2016/17	2017/18	2018/19
C1	B1	5.31 ± 0.11^{a}	6.42 ± 0.10	8.25 ± 0.03^{a}
	B2	5.22 ± 0.04^{ab}	7.15 ± 0.10^{b}	8.51 ± 0.02^{ab}
	B3	5.35 ± 0.11^{abc}	7.31 ± 0.10^{bc}	8.75 ± 0.11^{bc}
	B4	5.54 ± 0.03^{cd}	8.14 ± 0.06	9.51 ± 0.10^{d}
C2	B1	5.51 ± 0.07^{acdg}	6.67 ± 0.03^{d}	7.72 ± 0.13^{e}
	B2	5.70 ± 0.08^{dg}	6.83 ± 0.11^{de}	7.81 ± 0.09^{e}
	B3	5.26 ± 0.04^{abce}	7.15 ± 0.07^{bc}	8.61 ± 0.12^{bc}
	B4	5.30 ± 0.02^{abce}	6.75 ± 0.03^{de}	9.24 ± 0.13^{d}
Average		5.40 ± 0.04	7.05 ± 0.09	8.56 ± 0.011

Means in columns with the different letter are highly significantly different according to the Fisher's test ($P \leq 0.05$) Value with ± represent the standard errors. Without letter has significant difference from other variants.

Nitrogen fertilization increased the yield in variety Amur (Table 6) every year, but the lower impact was observed in 2016/17. Dose of nitrogen had a significant difference on triticale of first sowing period, but in crops of second period almost did not change the yield level. Situation in 2017/18 was changed because first fertilization by 25 kg ha^{-1} N increased yield more than the next fertilization. Level of yield had insignificant difference in the adjacent variants of nitrogen fertilization. In 2018/19 the situation was similar to the previous year, but nitrogen fertilization significantly increased yield only by high doses of nitrogen (N_{80} and N_{100}) compare with N_0 and N_{25} variants of first sowing period. There was no significant difference between the variants of nitrogen fertilization, but they had a significant difference compare to variant without fertilizing. Application of nitrogen fertilizers may be a determining factor for productivity by the short autumn vegetation, but grain yield has not a significant difference because of the nitrogen dose (Petunenko et al., 2016).

Table 6. Grain yield (t ha^{-1}) of winter variety Amur

Sowing period	Fertilizing system	Year		
		2016/17	2017/18	2018/19
C1	B1	4.61 ± 0.01^{a}	6.00 ± 0.06^{a}	7.59 ± 0.12^{a}
	B2	4.88 ± 0.03	6.80 ± 0.13^{b}	7.54 ± 0.09^{ab}
	B3	5.02 ± 0.03	6.99 ± 0.13^{bc}	8.03 ± 0.12^{c}
	B4	5.12 ± 0.02	7.13 ± 0.14^{c}	9.24 ± 0.13
C2	B1	4.22 ± 0.04	5.17 ± 0.06	7.77 ± 0.02^{abc}
	B2	4.64 ± 0.02^{ab}	5.70 ± 0.07	8.26 ± 0.11^{cd}
	B3	4.74 ± 0.04^{c}	6.17 ± 0.05^{ab}	8.04 ± 0.04^{cd}
	B4	4.71 ± 0.02^{bc}	6.20 ± 0.10^{ab}	8.38 ± 0.06^{d}
Average		4.74 ± 0.05	6.27 ± 0.12	8.10 ± 0.10

Means in columns with the different letter are highly significantly different according to the Fisher's test ($P \leq 0.05$) Value with ± represent the standard errors. Without letter has significant difference from other variants.

Table 7. Grain yield (t ha^{-1}) of winter variety Obrii Myronivs`kyi

Sowing period	Fertilizing system	Year		
		2016/17	2017/18	2018/19
C1	B1	4.65 ± 0.06^{a}	5.60 ± 0.08	6.54 ± 0.04^{a}
	B2	4.87 ± 0.03^{b}	6.04 ± 0.05	7.20 ± 0.07^{b}
	B3	4.87 ± 0.13^{b}	6.36 ± 0.09^{a}	7.28 ± 0.07^{b}
	B4	5.03 ± 0.07^{bc}	6.52 ± 0.09^{a}	7.82 ± 0.05
C2	B1	4.99 ± 0.02^{bcd}	4.88 ± 0.07^{b}	6.20 ± 0.02
	B2	5.05 ± 0.05^{abcde}	4.96 ± 0.07^{bc}	6.45 ± 0.09^{a}
	B3	4.83 ± 0.06^{bd}	4.93 ± 0.07^{bc}	6.83 ± 0.11
	B4	5.06 ± 0.02^{cde}	5.24 ± 0.02	7.60 ± 0.05
Average		4.92 ± 0.03	5.57 ± 0.11	6.99 ± 0.10

Means in columns with the different letter are highly significantly different according to the Fisher's test ($P \leq 0.05$) Value with ± represent the standard errors. Without letter has significant difference from other variants.

Variety Obrii Myronivs`kyi (Table 7) had not significant difference in grain yield between many variants of first sowing period but yield was changing unsystematic depending of nitrogen dose in 2016/17. There was a significant decrease in yield at second sowing period compare to the first in 2017/18. Nitrogen fertilizers significantly increased the yield in N_{25} and N_{80} variants of second sowing period but had not difference between N_{80} and N_{100}. Only variant N_{100} had a significant difference compare to other sowings of second sowing period in that year. Fertilization significantly increased the yield of crops first and second sowing period in 2018/19 but yield of the second sowing period was lower. Gibson et al. (2007) showed that some varieties had not significant difference in grain yield depend on nitrogen dose, but the number of productive shoots was increased and, accordingly, grain mass per spike was decreased.

Grain yield varied in different years depending on precipitations. Precipitations contributed to the tillers formation, but this process depended on available nitrogen. Estrada-Campuzano et al. (2012) in their studies indicated that grain mass from the main shoot under different nitrogen doses has not significant impact, but nitrogen fertilizers increased grain yield from the tiller. The main role of additional nitrogen nutrition was manifested in increase of thousand kernels weight at the tillers and increase in the grains number. The application of high rates of nitrogen fertilizers has lesser impact on grain yield. Efficiency of high nitrogen norm depends on weather condition more than low one (Litke et al., 2018).

Peculiarities of the varieties in relation to the sowing periods and fertilization system in interaction of 'grain yield – the number of productive shoots' were identified with using cluster analysis (Fig. 4).

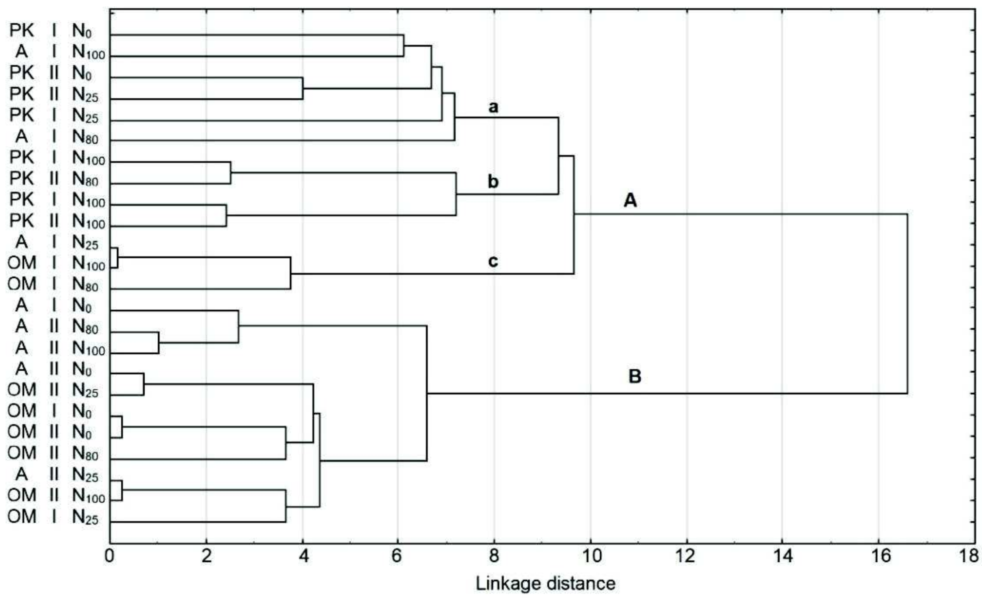

Figure 4. Cluster analysis of studied variants by relation 'grain yield – productive shoots per m^2'; PK – Pidzimok kharkivskyi; A – Amur; OM – Obrii mironivs'kyi; I – 2nd decade of October; II – 3rd decade of October; N_0, N_{25}, N_{80}, N_{100} – nitrogen fertilizing (B1 – B4).

All variants are grouped into two groups at the 10tn linkage distance: high performance (**A**) and low performance (**B**). High-performance crops divided on 3 groups on 8th linkage distance.

First group (**a**) include variants of Pidzimok kharkivskiy with application 25 kg ha^{-1} N and without nitrogen fertilizers by the two sowing dates. Variety Amur of first sowing date with application 80 and 100 kg ha^{-1} N was included too. The unifying feature of this group was the high number of productive shoots and relative yield level, which did not reach the maximum.

Second group (**b**) included variety Pidzimok kharkivskyi with high level of nitrogen nutrition. On 3rd linkage distance this group divided on 2 lesser in depend on dose of nitrogen. Sowing date has not effect on this group.

Third group (**c**) had intermedium level of yield and number of productive shoots. There were included winter varieties Amur and Obrii Myronivs`kyi of first sowing period with high level of nitrogen fertilizing.

Large group of low-performance variants (**B**) include Obrii Myronivs`kyi with low nitrogen doses and Amur by 2nd sowing date. These variants characterized by lowest number of productive shoots and accordingly yield level. Grain yield may vary insignificantly because of the different nitrogen doses (Lestingi et al., 2010) in different condition, but can change chemical content of grain.

CONCLUSIONS

Weather conditions significantly affected the process of triticale organogenesis at the early stages and yield. Increasing of nitrogen fertilization doses leads to linear increase in yield due to the increase of productive shoots number. The sowing period affected the yield of winter triticale much greater extent than facultative variety. Facultative triticale has a greater yield potential than variety and can realize it in different weather condition.

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