EFFECTS OF DROUGHT ON YIELD OF WINTER WHEAT IN LONG-TERM FIELD TRIAL AND VOJVODINA PROVINCE

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Abstract: *In order to detect and quantifying drought (its frequency, duration and intensity), Palmer Drought Severity Index and Palmer Moisture Anomaly Z-Index were used in this paper. These indices were calculated by using monthly values of meteorological elements from meteorological station at Rimski Šančevi, Novi Sad, Serbia; for period 1965/66 to 2009/10. Also, yields of winter wheat from stationary long-term field trial, containing 20 different fertilization treatments with increasing doses of nitrogen, phosphorus and potassium were analyzed for the same region and period of time. For determining the most suitable index for quantifying effects of drought on wheat yield, correlation coefficients between two examined drought indexes and detrended wheat yields in long-term trial and Vojvodina province were calculated. Larger number of significant correlations was obtained between the wheat yields and Palmer's Z-index. On the basis of calculated r coefficients, it can be concluded that humidity/ drought conditions in October, December, March and April had the most important impact on grain yield. However, correlation coefficients in X and IV were positive, i.e. lower moisture conditions (drought) reduces yields, while in XII and III negative r coefficients indicated increase in yields at low moisture conditions. By observing the r values at different fertilizing variants in long-term experiment, it could be concluded that drought conditions in X and IV influenced all treatments more or less equally. Treatments with higher nitrogen doses were more sensitive to moisture conditions in XII, while in moisture conditions in III more sensitive were treatments without, or with small doses of nitrogen applied.*

Key words: *drought, drought indices, winter wheat, yield, mineral nutrition, correlations*

INTORUCTION

In Serbia wheat is grown on about 540.000 ha, with average yield of 3,7 t ha^{-1} and total annual production of about 2 million t. Area under wheat in Vojvodina Province is about 300.000 ha, with average yield about 4 t ha^{-1} and production near 1,2 mil. t. In comparison with other wheat producers in the world, Serbia is ranked as 32 out of 124 countries and 22/38 wheat producing countries in Europe, which is unsatisfactory considering favourable agro-ecological conditions (especially in Vojvodina) for wheat production. Beside lower yields, wheat production in Serbia is also characterized by high yield variation among years, which shows that our production is still very dependable from weather conditions during the vegetation (MALEŠEVIĆ et al., 2008; DENČIĆ et al., 2009). For a higher expression of wheat genetic potential, knowing of agro ecological characteristics and adaptation measures of production to such conditions is crucial for obtaining higher and stable yields (MALEŠEVIĆ et al., 2012).

Weather conditions during the life of the plant influences its growth, development and finally yield, which shows different sensibility in climatic terms and in variability between years (CHMIELEWSKI AND POTTS, 1995; ASSENG *et al.*, 2004). Variability of climatic elements directly influences phenology, photosynthesis and other physiological processes in plants. Indirect effects on plants are manifested by changing availability of nutrients, presence of weeds, pests and diseases etc. (SOUTHWORTH *et al.*, 2002).

Drought represents one of the most detrimental, the most complex but also the least understood out of all natural disasters, and it affects the great part of human population (HAGMAN, 1984; WILHITE, 2000). As a climatic occurrence, it actually represents the “usual” part of weather occurring in almost every region in the world, causing huge damage in all types of production with negative economic, social and environmental consequences (WILHITE, 2011). In our country, drought occurs almost every year in smaller or larger intensity, and represents the limiting factor for obtaining high yields (PEJIĆ *et al.*, 2011). During the vegetation season in Vojvodina, shorter or longer drought period are noticeable, meaning that the whole territory sometimes becomes arid area with pronounced water deficiency. Drought periods in Vojvodina are becoming more and more frequent, considerable lowering the yields of different crops, depending on its intensity and duration (STRIČEVIĆ *et al*., 2010).

Nowadays, numerous quantitative drought indexes are being developed. These indices provide useful variables used for evaluation of intensity of negative drought effects on plants (GAMP, 2010). One of the most used indexes is PDSI - Palmer Drought Severity Index, developed by PALMER (1965), and based on concept of influx and losses of water, i.e. water balance. Another index developed by PALMER (1968) is CMI - Crop Moisture Index, originate by modification of PDSI in order to find severity of drought in agriculture.

PDSI is probably the most used and well known drought index worldwide (GREGORIČ, 2010). This index is based on concept of water balance with main goal to provide numerical, standardized and spatial comparable moisture conditions measurement (lasting and intensity of long-term meteorological drought). It is designed to analyze drought problems as an indicator of soil moisture in semi arid and semi humid conditions of North America. Soon, PDSI became widely known and accepted in agroclimatical analysis (ALLEY, 1984; KARL, 1986), but also useful indicator in investigation of climate changes (DUBROVSKY *et al*., 2005). Palmer’s model as a inter-step in calculation of PDSI also calculates Palmer’s Z-index (Palmer Moisture Anomaly Index; Z-index), which shows how monthly moisture conditions differ from normal climate conditions, i.e. indicates short term dry or excessive moisture conditions on monthly level. According to KARL (1986) and VASILIADES AND LOUKAS (2009) Z-index may properly identify agricultural drought, as well as fast reaction on changes in soil moisture.

As ecological factors influence on plants as well on soil, one of the main goals of this paper was to investigate mechanism of this process and to identify critical moments in wheat vegetation period in which yield is most affected by damaging weather conditions. Also, we wanted to quantify relationship between varying of meteorological elements and derived parameters (drought indexes) and wheat yield formation at different levels of mineral nutrition supply.

MATERIAL AND METHODS

The investigation was done on long-term field trial, founded in 1965/66 on experimental fields of Institute of Field and Vegetable Crops at Rimski Šančevi. The trial is based on four crop rotation (four fields) including sugar beet, maize, sunflower and wheat, as the most typical field crops in Vojvodina Province. In this paper results from 45 years of investigation (from 1965/66 to 2009/10) are shown. The trial was set up on a calcareous chernozem soil type, with slightly alkaline reaction, moderate content of humus and readily available phosphorus and with high content of readily available potassium.

The experiment is set up in 4 separate fields, where each year different crop is grown on different field. The size of each field is 1,84 ha (68 x 270 m) and is divided into 4 replication with 20 experimental plots in every replication, meaning that every field is divided into 80 plots with randomized treatments (different NPK doses), where every plot is further divided into more subplots, depending on the number of varieties examined.

The purpose of stationed plots in this trial was to investigate the effects of different nitrogen, phosphorus and potassium doses and ratios on wheat yield and grain quality over long period of time. Considering this, founders of the trial are chose 20 different combinations of amounts and ratios of N, P_2O_5 and K_2O, according to agro-ecological conditions and biological properties of the investigated species. Fertilization treatments were:

1. Control (unfertilized plot)
2. N_2
3. P_2
4. K_2
5. N_2P_2
6. N_2K_2
7. P_2K_2
8. $N_1P_1K_1$
9. $N_1P_2K_1$
10. $N_1P_2K_2$
11. $N_2P_1K_1$
12. $N_2P_2K_1$
13. $N_2P_2K_2$
14. $N_2P_3K_1$
15. $N_2P_3K_3$
16. $N_3P_1K_1$
17. $N_3P_2K_1$
18. $N_3P_2K_2$
19. $N_3P_3K_2$
20. $N_3P_3K_3$

where index number represents dose of pure active matter of each nutrient: 1=50, 2=100, 3=150 kg of N, P_2O_5 and K_2O per ha.

Each year standard cultivation practice for agro ecological conditions in Vojvodina is applied. The whole amount of P_2O_5 and K_2O and the half of the N dose were applied before tillage in autumn. Remaining amount of N fertilizers for wheat was given in spring at topdressing and before seeding for other species in the trial. Wheat straw and harvest residues of other crops are ploughed under after harvest. Sowing was done in optimal sowing date for conditions of Vojvodina (in October) with sowing densities from 500-700 viable seeds per m^2, according to each variety requirements, and spacing between rows of 12,5 cm. Application of pesticides was done sporadically, only if it was necessary.

Climate conditions. Rimski Šančevi are situated in the southern part of province of Vojvodina, in area of continental climate. The whole region is located in semiarid area where variations in amount of precipitation, air temperature and other important climatic elements among years are substantial. During the vegetation period of winter wheat, shorter or longer periods of drought are common, although occurrences of excessive water are not rare. Average precipitation on Rimski Šančevi site for period of 1965-2010 was 634 mm with average temperature of 11,3 °C. Cold period of the year lasts from October till Mart. Average air temperature during this period was 4,5 °C, with average precipitation of 258 mm. Hot period of vegetation season starts in April and ends in July (for wheat) with average air temperature of 16,2 °C and precipitation of 198 mm, or about 31% from total amount of precipitation during winter wheat vegetation period. In order to detect and quantify drought (its frequency, duration and intensity), and for analysis of drought influence on variability of wheat yield in trial and in Vojvodina, PDSI (Palmer Drought Severity Index) and Palmer Moisture Anomaly Z-Index (Palmer Z-index) were used.

PDSI is based on concept of water balance for a specific period of time. Variables for calculating PDSI are potential evapotranspiration (*Thornthwaite* method), precipitation, amount of water needed for reaching field water capacity and amount of water for evapotranspiration. Detailed description of this index is given in PALMER (1965), ALLEY (1984) and KARL (1986). As can be seen from table 1, PDSI values can significantly vary, where values $\leq$ -4,0 and $\geq$ 4,0 represent extreme (dry or wet) conditions, while values close to zero represent normal conditions of wetness.

Palmer Moisture Anomaly Index (Palmer Z-index) show how monthly moisture conditions deviate from climatic normal for given month, thus, describing short term droughts or excessive moisture levels on monthly basis.

Calculations of PDSI and Z-index are done by using software developed by USDA Risk Management Agency (RMA), the National Drought Mitigation Centre (NDMC) and University of Nebraska (Lincoln Department of Computer Science and Engineering), downloaded from the website of joint "*GreenLeaf*" project: http://greenleaf.unl.edu/.

Table 1.

Classification of moisture conditions based on PDSI

PDSI	**Moisture condition**
≥ 4,00	Extremely wet
3,00 to 3,99	Very wet
2,00 to 2,99	Moderately wet
1,00 to 1,99	Slightly wet
0,50 to 0,99	Incipient wet spell
-0,49 to 0,49	**Normal**
-0,99 to -0,50	Incipient dry spell
-1,99 to -1,00	Mild drought
-2,99 to -2,00	Moderate drought
-3,99 to -3,00	Severe drought
≤ -4,00	Extreme drought

During the writing of this paper, statistically significant long-term *trends* of wheat yields in trial were noticed. They are partly a consequence of long-term changes in natural soil fertility caused by different fertilization treatments, as well as the factors of technological improvement in production. If influences of this factors are quantified by trends and extracted from yield series, the residuals of such trends represents remaining influence of other factors, mostly climatic conditions (GOMMES, 2001; WANG et al., 2000). Such detrended variations of yield among different years could be in great extent explained by meteorogicaly induced factors, i.e. weather variations to which crops are susceptible. Detrending (trend elimination) was applied on all yield series (to all treatments of mineral nutrition), according to PHILLIPS et al., (1999) and ALEXANDROV AND HOOGENBOOM, (2001).

RESULTS AND DISCUSSIONS

For analyzing yields of winter wheat obtained on 20 different fertilization treatments, method of analysis of variance for long-term field trial was used. Trial was treated as a specific 2-way factorial design, where effects of varieties were excluded. F-test of ANOVA for 45 years long period (table 2) showed that wheat yield was significantly affected (p<0,001) by treatments, i.e. doses and ratios of nutrients applied, weather conditions, as well as their interactions.

Table 2.

Analyze of variance for grain yield in the trial (for period 1966 – 2010)

Source of variation	**Degrees of freedom**	**Sum of square**	**Portion in sum of square (%)**	**Mean of square**	**F-test**	**p**
Blocks (replications)	90	213,64	2,78	2,37	98,07	
Fertilizer	19	3899,66	50,74	205,25	8479,13**	<,001
Year	44	2767,02	36,00	62,89	26,49**	<,001
Fertilizer x Year	836	764,11	9,94	0,91	37,76**	<,001
Error	1710	41,39	0,54	0,02		
Total	2699	7685,82	100			

Based on the sharing of individual sources of variation in the total sum of squares, it can be concluded that on the overall variability of wheat yields in the trial dominant effect (51%) had fertilization, i.e. different amounts and ratios of N, P and K, while the effect of years was somewhat lower (36%), but also highly statistically significant. In addition, the presence of highly significant interactions between fertilization and years in the experiment (nearly 10% of total yield variability) has provided a basis for a more detailed analysis of this interaction (FxY).

Average wheat yield for all 20 fertilizing variants for every year examined (Fig. 1) showed great variation between years. As 20 fertilizing treatments are very different, average yield obtained under influence of all treatments combinations can show a real situation of interactions of ecological factors and grain yield. Thus, yield varied significantly depending upon weather conditions in specific year and ranged in average for all mineral nutrition treatments from 3,00 t ha^{-1} in 2003 to 7,01 t ha^{-1} in 1995 and 2000, or 133% relatively.

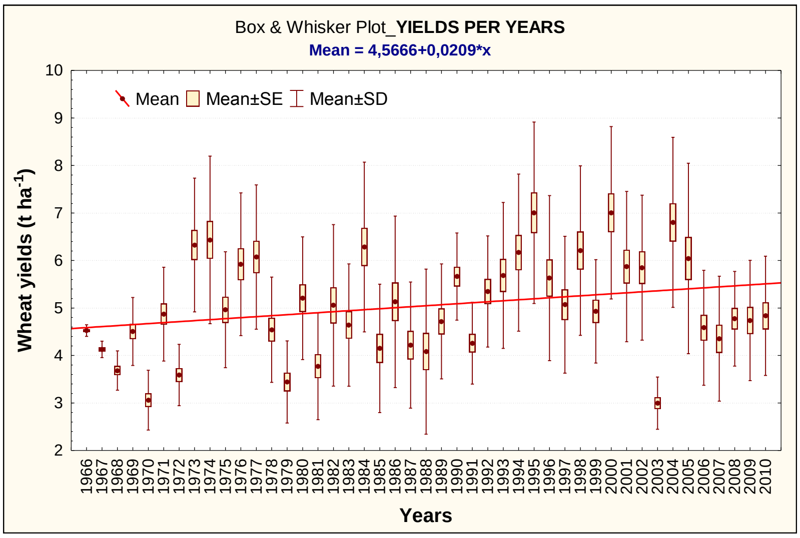

Figure 1. Yield of winter wheat in each of the years examined
(average for 20 treatments of mineral nutrition)

On the basis of monthly PDSI values calculated for vegetation period of winter wheat at Rimski Šančevi (Fig. 2a), in 45 year period analyzed there were 16 dry years (PDSI$\leq$-2). Extremely severe drought occurred just in 2001 (PDSI$\leq$-4) (in two months, X and XI), very dry periods (PDSI from -4 to -3) of short duration (1 month) were registered in the following years 1968, 1987, 1990, 1994 and 2003, and severe long lasting drought occurred in 1972 (9 months of dry period, from X to VI, thus entire vegetation period of wheat) and 1989 (7 months, from X-IV).

From the figure 2a, occurrence of significant number of dry years (11 years in period 1966-1990) can be noticed, while in the last 20 years (from 1991-2010), 5 dry years occurred. Obtained results showed that in the analyzed period of 45 years, frequency of occurrence of wet years was similar to the frequency of dry years. However, out of 17 years with PSDI$\geq$2, in some months during wheat vegetation in the first 25 years of the trial (1966-1990) there were only 5, while in the second period (after 1991) number of very wet years was higher (12), and with extremely high PDSI values in four years examined (2000, 2001, 2006 and 2010).

On the basis of PDSI values it can be stressed that the last 20 years period is characterized by lower frequency of dry (5) and higher frequency of wet years (12). At the same time, Fig. 2 shows that period 1991-2010 was characterized by more extreme values of PDSI (higher deviation from 0), and longer duration of extreme conditions (specially wet).

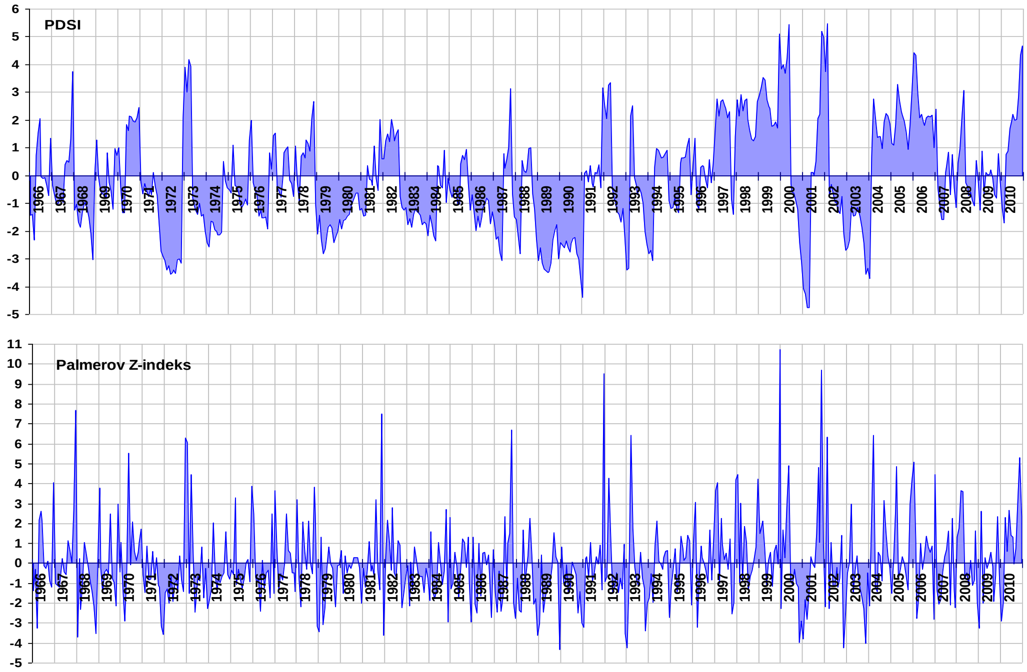

Figure 2 (a, b): Classification of moisture conditions in years examined
(from VII of previous to VI of the year when wheat was harvested) based on PDSI (a) and ZIND (b)

Extreme conditions of humidity / drought in the last 20-year period could be also identified on the basis of Palmer's Z-index (Fig. 2b). This index shows how monthly moisture conditions deviate from the normal and describes short-term dry or wet conditions on monthly basis.

In difference to PDSI, by this index for both sub-periods (1966-1990 and 1991-2010) equal number of short-term periods of drought events can be noticed (8 extreme values of ZIND $\leq$-3) and substantially larger number (16) of extremely wet periods (ZIND $\geq$4) in the last 20 years. Hence, according to this index, by calculating in the monthly intervals, equal number of occurrence of extreme droughts of shorter duration in both sub-periods can be noticed. Having in mind their length (25 and 20 years, respectively), this indicates a slightly higher frequency of shorter droughts in the last 20 years than in the previous period analyzed.

In order to find the most reliable index for quantifying effects of drought on yield of wheat, coefficient of correlation between Palmer’s drought indexes and detrended yields in the trial and Vojvodina were calculated (Table 3). Significantly higher number of significant correlative relationship was obtained between the yield of wheat and Palmer's Z-index, while the PDSI managed to register only the effects of moisture conditions in October and November, and only in a smaller number of fertilization variants in the experiment.

By analyzing correlation coefficients of Z-index and wheat yield, it can be seen that for the grain yield the most important are condition of dry/wetness in the month of sowing – October, then in the December, Mart and April. However, correlation coefficients in X and IV were positive, i.e. lower moisture conditions (drought) reduces yields, while in XII and III negative r coefficients indicated increase in yields at low moisture conditions. Also, by observing the r values at different fertilizing variants in long-term experiment, it is evident that humidity/drought conditions in X and IV affect all treatments more or less equally. Treatments with higher nitrogen doses were more sensitive to moisture conditions in XII, while to moisture conditions in III more sensitive were treatments without nitrogen, or with smaller doses of N applied.

Table 3.

Table 3: Correlation coefficients between Palmer drought indexes and detrended yields of winter wheat in different fertilizing treatments in the trial and Vojvodina*

Fertilizing treatment	**PDSI -** ***Palmer Drought Severity Index***									**ZIND –** ***Palmer Moisture Anomaly Z-Index***								
	oct	**nov**	**dec**	**jan**	**feb**	**mar**	**apr**	**may**	**jun**	**oct**	**nov**	**dec**	**jan**	**feb**	**mar**	**apr**	**may**	**jun**
Ø	0,26	-	-	-	-	-	-	-	-	0,27	-	-	-	-	-0,34	-	-	-
N_2	0,26	-	-	-	-	-	-	-	-	0,33	-	-0,31	-	-	-	0,26	-	-
P_2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-0,38	-	-	-
K_2	0,25	0,25	-	-	-	-	-	-	-	0,26	-	-	-	-	-0,39	-	-	-
N_2P_2	-	-	-	-	-	-	-	-	-	0,26	-	-0,29	-	-	-	0,29	-	-
N_2K_2	0,28	-	-	-	-	-	-	-	-	0,40	-	-0,26	-	-	-0,31	-	-	-
P_2K_2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-0,41	-	-	-
$N_1P_1K_1$	-	-	-	-	-	-	-	-	-	0,27	-	-	-	-	-0,36	0,25	-	-
$N_1P_2K_1$	-	-	-	-	-	-	-	-	-	0,26	-	-	-	-	-0,32	-	-	-
$N_1P_2K_2$	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-0,33	0,25	-	-
$N_2P_1K_1$	-	-	-	-	-	-	-	-	-	0,27	-	-0,31	-	-	-	0,31	-	-
$N_2P_2K_1$	-	-	-	-	-	-	-	-	-	-	-	-0,27	-	-	-	0,27	-	-
$N_2P_2K_2$	-	-	-	-	-	-	-	-	-	0,27	-	-0,26	-	-	-	0,25	-	-
$N_2P_3K_1$	-	-	-	-	-	-	-	-	-	0,28	-	-	-	-	-	-	-	-
$N_2P_3K_3$	-	-	-	-	-	-	-	-	-	0,28	-	-	-	-	-	-	-	-
$N_3P_1K_1$	-	-	-	-	-	-	-	-	-	0,26	-	-0,28	-	-	-	0,32	-	-
$N_3P_2K_1$	-	-	-	-	-	-	-	-	-	-	-	-0,29	-	-	-	0,28	-	-
$N_3P_2K_2$	-	-	-	-	-	-	-	-	-	0,27	-	-0,28	-	-	-	-	-	-
$N_3P_3K_2$	-	-	-	-	-	-	-	-	-	0,26	-	-0,31	-	-	-	-	-	-
$N_3P_3K_3$	-	-	-	-	-	-	-	-	-	0,25	-	-0,29	-	-	-	0,26	-	-
Trial	-	-	-	-	-	-	-	-	-	0,29	-	-0,27	-	-	-0,26	0,26	-	-
Vojvodina	-	-	-	-	-	-	-	-	-	-	-	-0,40	-	-	0,29	-	-	-

*(only significant r values on the level α=10% are shown)

On the basis of both drought indexes analyzed and correlation coefficients, it can be stressed that the strength of this relationships was relatively weak or moderate, thus, by this indexes only the low percentage of variance of wheat yield could be explained. Partly this could be explained by the fact that on the basis of specific drought index for a different time periods the certain year can be characterized as both wet and dry. Moreover, nature of these relationships is not linear, because too low or too high values of drought indexes lead to the yield decline. Furthermore, numerous other factors in relation with conditions of drought/wetness indirectly influence on decrease of the yield, i.e. floods, disease and pests occurrence (LI et al., 2009) as well as the efficiency of nutrients applied, nitrogen cycle disorder etc. Also, yield is very often influenced by short lasting but extremely severe weather conditions, i.e. extreme weather events (LALIĆ et al., 2011).

SABAU et al. (2002) investigated relationship between climatic indexes and yields of maize, wheat and cabbage in Romania. Highly significant correlations were found by applying indexes on maize and lower with cabbage and wheat, where the examined coefficients were the weakest. De Martone drought index had the most significant correlation with wheat yield (R^2=0,72), but calculated only for the warm period of the year (IV-IX). As an explanation of the low correlations between climate indices and yield of wheat authors suggest a high variation in the yield potential of varieties during the analysed period, and the ability of wheat that in different ways may compensate yield losses. According to KUNZOVA AND HEJCMAN (2009), in years characterized as unfavourable for wheat production in Czech Republic, yields of wheat were reduced due difficulties in germination influenced by water deficiency in autumn, bad wintering due low temperatures and deficiency of snow cover, slower development of plants due to high temperatures in spring and low precipitation in May and/or poor grain filling, as well as high temperatures and lack of precipitation in June.

MALEŠEVIĆ et al. (2009) stressed that average yield loss in dry years ranged in interval from 90 to 1770 kg ha^{-1}, depending on amount of fertilizers applied. The strongest influence on yield decrease in dry years had the nitrogen nutrition; highest yield loss in average were in treatments with highest nitrogen doses and lowest on unfertilized treatment and treatments with low amounts of nitrogen applied.

Amount of precipitation in period before sowing and the month of sowing (September and October) are often crucial for yield formation of wheat. Lack or insufficient precipitation during this period complicates soil tillage, seedbed preparation and sowing, which longer the germination and root growth, making the plants less resistant to low temperature in winter (DENČIĆ et al., 2000; MALEŠEVIĆ et al., 2008). The highest yields in Vojvodina are obtained in years with abundant precipitation in April and moderate precipitation during May and Jun (JEVTIĆ AND LABAT, 1985).

Dry soil due to lower availability of water and water uptake, influences low uptake and translocation of mineral nutrients. Increased temperature and lower water availability decreases plant yields and also their reaction on the nitrogen applied (BOGDANOVIĆ AND MALEŠEVIĆ, 2009). Balanced NPK nutrition can mitigate negative effects of drought by lowering transpiration coefficient (BOGDANOVIĆ et al., 2001), and plant susceptibility to abiotic and biotic stress (FINCK, 1982).

CONCLUSIONS

By analyzing wheat yield in long-term stationary field trial, it can be concluded that the most significant effects on grain yield had the amounts and ratios of NPK and then weather conditions during the year.

From two indexes used for detection and quantification of drought influence, more significant correlations were obtained by comparing wheat yield with Palmer Z-index, while PDSI managed do detect moisture effects on a smaller number of fertilized treatments.

Large number of significant correlations with yields shows that drought indexes can help in estimation of wheat yield decrease due to occurrence of drought or excessive soil wetness. Indexes analyzed can be successfully used for monitoring drought effects, estimation of influence on yield as well as for adjustment of cultivation practice in order to mitigate negative drought effects. They represent good base for creating a models which could be used for more precise yield estimation on the basis of the meteorological elements forecasted.

With appropriate system of mineral nutrition (amounts, ratios and time of application), negative effects of climatic conditions on crops could be mitigated. This measure could increase stability of the yield, lower its variations among years, and decrease eventual nutrient loss due excessive application.

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