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Wheat Production Obtaining Patterns according to the Aridity Index (AR), Soil Creditworthiness (CW_S) and Technological Processes Intensity (TPI)

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Abstract. The present study aims to present the effect of aridity index (AR) calculated by the UNEP version, of the quality of soil (CW_S), given by the official creditworthiness marks of the National Institute of Soil Science and of the agricultural intensity degree (TPI) at various levels of agricultural exploitation over the wheat yield in Romania. That creates the scientific basis for new technologies, which will be able to better exploit the water, so precious for the semiarid areas where wheat grows. A negative correlation between AR and the average wheat yield in the last 10 years and a positive one between soil quality and production were found.

Keywords. Aridity Index, soil quality (creditworthiness), wheat yield, production processes

INTRODUCTION

Romania has a complex continental climate, with an AR calculated, according to the UNEP method, between 0.31 and 3.25, so from semi-arid to wet areas (Berca, 2011).

The wheat crop occupies 2-3 million hectares (Berca *et al*., 2012), each year and has best results in semi-arid and arid areas (with AR from 0.31 to 0.65) from Southern, Eastern and Western Plains, but it is also cultivated towards the hills, in areas with enough moisture (AR = 0.65 - 1.00).

The driest part of the country is Eastern Baragan, as well as a large part of Dobrogea, where AR = 0.30 - 0.40 (Berca, 2008). Recently climate change also modifies the aridity placement on the map, indexes being calculated for a very long time.

Wheat yield can be realized at different levels throughout all the arid and semiarid region of the country because although the water consumption is high for an increased output (for 6000 kg/ha > 3000 m^3/ha only in May, June, July), the major part of the vegetation takes place at low temperatures (October - April).

The highest water consumption was in May - July, at Valu lui Traian (Dobrogea), 3200-3600 m^3/ha, and in Braila was of 2900-3300 m^3/ha in the same three months (May, June, July) (Bogdan, 1980; Dumitru *et al*., 2011; ***, 2011).

Our calculations show that with a poor technology, very present in technological processes, this water covers only 30% in Dobrogea and 40% in Braila of the plant consumption during this period.

In order to achieve higher yields, crops irrigation would be needed. As this became almost impossible, the only solution available to farmers is represented by the preservation of the water into the soil collected outside the period of crops excessive consumption through the elaboration and implementation of some technological processes based on recent research (Berca, 2011), as well as through a high management of the water consumption by the plants, in order to obtain a consumption index (CI) as small as possible (Rusu and Ritt).

$$CI\ (m^3/t) = \frac{\text{Water consumption } (m^3)}{\text{Yields (t)}}$$

The technological works system on wheat crop may be creditworthy with marks from 1 to 10 (also see the Poster on this subject), and we used this system to create the numerical models proposed (Berca, 2011). We also emphasize that there are many researches on how water is used by the plants and several indicators used.

The plant consumption is a function of two components (transported water and evaporated water). **The evapotranspiration** is the indicator used (Walter *et al*., 2002):

$$\text{Evapotranspiration} = PET \times K$$, where:

- ➔ PET = potential evapotranspiration determined on small crops (well organized pastures);
- ➔ K = a constant of the crop.

These methods, among others, are based on other climatic indicators. A direct method for the determination of plants' water consumption, but very expensive, is the one through **„the lysimeters method"** (Byun and Wilhite, 1999; NCL NCAR).

$$\mathbf{PC = P + I - D}$$, where:

- ➔ P = precipitation;
- ➔ I = irrigation (added water);
- ➔ D = drainage (lost water).

The condition for the above equation to be fulfilled is a good development of the plant. The Aridity Index (AR) used by us in our own researches has been the one recommended by FAO (UNEP). We used this one because it replaces De Martonne index (1926) more and more frequently, as a result of the Phare experts recommendations (ICPA, 2006; Walter et al., 2002; ***, 2011).

In this case the AR index was calculated using the formula: $AR = \frac{P}{PET}$, where:

- ➔ P = annual precipitation (mm);
- ➔ PET = potential evapotranspiration calculated by Penman-Monteith method, which is universally recognized as having the best estimates.

With the help of AR, several types of areas can be delimitated for Romania:

➔ hyperarid	AR < 0,05
➔ arid	0.05 < AR < 0.20
➔ dry semiarid	0.20 < AR < 0.50
➔ underhumid	0.50 < AR < 0.65
➔ humid	0.65 < AR < 1.00

In the studied zones we have met all the values presented above, excepting the hyperarid and arid ones. Having the data calculated by the University of Bucharest (2011), the soil creditworthiness expressed by marks from 0 to 100, where 0 = no soil and 100 = excellent soil (Mihalache and Ilie, 2009; Teaci, 1980), but also our own creditworthiness system, we conducted research for 10 ± 2 years. They allowed us to establish the modal relations between the 3 indicators and the grain yields level in order to improve water management and to optimize the technological processes of the crops.

MATERIAL AND METHOD

Aim of the research: to establish the correlative models between the aridity index (AR), the soil quality (CW_S) by the number of creditworthiness points and the technological processes intensity (TPI) in wheat crop.

The research objective: to improve water management by using those technological processes (tillage, crops maintenance, crop nutrition) in a manner that will reduce the water specific consumption and will increase the yields level and quality.

For achieving the proposed models we randomly collected data from different wheat cultivation areas, each year approximately 60 - 70 surveys, out of each was selected a maximum of 45, eliminating the major deviations.

Each survey was a working variant, being harvested in 5 repetitions. So, the work has been made on the following 3 variants:

1. The aridity factor, with the following graduations in UNEP version, containing all the wheat growing area, from easy semiarid up to humid (Palosuo *et al*., 2011):
   - ➔ 0.30
   - ➔ 0.40
   - ➔ 0.55
   - ➔ 0.80.
2. The soil factor (creditworthiness marks), with the following values:
   - ➔ 40
   - ➔ 55
   - ➔ 64
   - ➔ 75
   - ➔ 86
   - ➔ 41, on hills area.

   Combinations were made: [AR] x [CW_S] ⇒ (0.30 * 40); (0.40 * 55); (0.55 * 64); (0.55 * 75); (0.55 * 86); (0.80 * 41).
3. The 3rd factor was graduated on 10 stept, but in the surveys only 9 were found, because the last graduation is too developed and not yet implemented in Romania.

In the end resulted **6 x 9 = 54 variants x 5 rehearsal = 270 annual surveys**.

For some surveys the study period was of 10 ± 2 years. The working areas were Dobrogea-Bărăgan, Moldova, South Plain, West Plain, Central Plain and the hills zone up to an altitude of about 400-500 m, where wheat was cultivated.

Processing of the data was performed by variance analysis (dispersional), all the data being placed in „t” distribution, graphically (curves and columns). Were also carried out analysis of multiple correlation.

The patterns allow the evaluation of yield based on the dynamic of the variable factors studied at any time. Knowledge of the evaluation result enable us to intervene with new technologies, brought by the research, and especially with the use of natural biological models for increasing yields without additional effort of capital. In other words, instead of financial capital we will use intellectual capital – the science.

RESULTS AND DISCUSSIONS

1. The influence of soil creditworthiness on wheat yield

The results are presented in Fig. 1. On a background defined by AR and an average of the technologies intensity dynamics by increasing the numbers which express the soil quality, the production index shows a rising trend. The 2 parameters, soil quality * yield, are positively correlated, but are polynomially expressed (Fig. 1) in a parabolic form.

Yield dynamics remains, however, within the confidence interval $\overline{m}$ ± DL5% = 12.28 → 47,78 q/ha, equally oscillating on both sides of the mean. It becomes clear that the other factors from the experiment have influenced a lot the individual behavior of soil quality.

Maximum yield obtained by canceling the Ist Order derivative of the function indicates, on average, an yield of 34.49 q/ha for the maximum number of creditworthiness (86) analyzed in the current research.

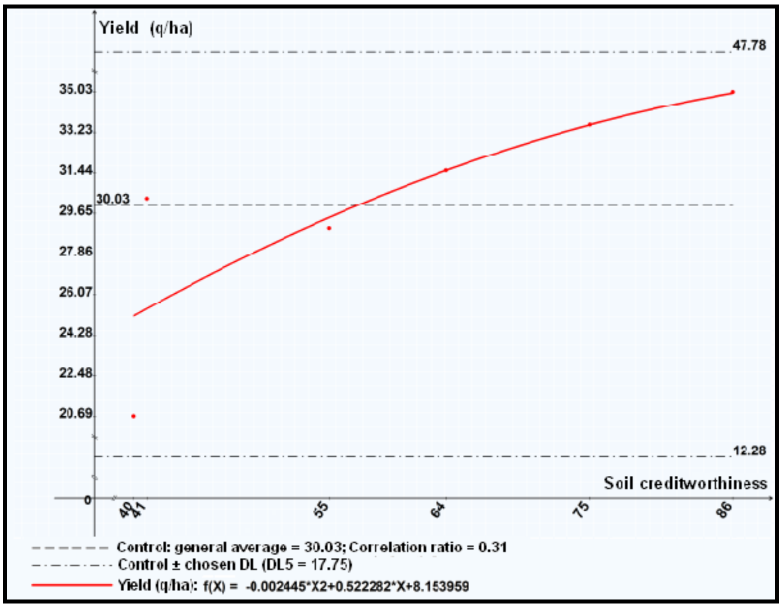

Fig. 1. Soil's creditworthiness influence on wheat yield – graphical presentation for 2002-2012 (original)

2. The influence of aridity index (AR) on wheat yield

The results of the calculations for this indicator are shown in Fig. 2. On the AR route between the limits of 0.30 - 0.80 the yield level increases visible, but insignificant between AR 0.30 and AR 0.40 and decreases slightly to AR 0.80. ±

Although 0.80 indicates a humid area, the other factors and especially the soil quality, with some areas of acid reaction, are slightly reducing the wheat yield (insignificant).

The maximum yield obtained by the average dynamics of this factor is of 33 q/ha, achieved at AR = 0.55. Precipitation increase and PET reduction, given by a higher AR, don't have a positive impact on the yield for the reasons mentioned above – less fertile soils and poorer technologies.

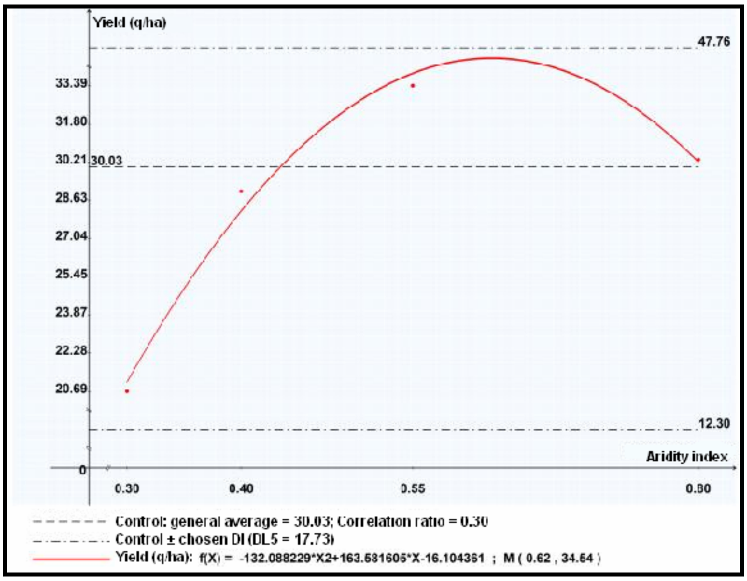

Fig. 2. Aridity indes influence on wheat yield – graphics presentation for the period 2002-2012 (original)

3. The influence of technological processes intensity on wheat yield

The production processes represent the quantity and the quality of the inputs applied to the crop on the technological chain. One can say that equals, partially, with the crop management.

In similar conditions on climate and soil the processes intensity (TPI) plays the main role. This phenomenon is also demonstrated historically. In 1800 Germany's yield of wheat was situated, on average, at 1000 kg/ha and it reached 2000 kg/ha only in 1930. In 130 years the yield increased with only 1,000 kg/ha due to slow development of technologies. In 1950 it reached 3000 kg/ha (in just 20 years), and until 2005 it climbed to 7500 kg/ha (Farack, 2010).

This fantastic growth is the exclusively result of the production processes intensification, starting from varieties becoming more and more performant and going from step to step on the entire technological chain.

In Romania, at the moment, we find technologies from horse + plow (Note 1) to the most modern machines of high productivity, with which we reach Note 9 (Poster). We can't have yet the last mark, Note 10, because the ecological phenomena of the land practically exist only in experimental locations. Romania practices conventional, with slight beginnings toward conservation agriculture.

The water is hardly retained in conventional agriculture, but increasingly better in the conservation and no-tillage one. The costs are decreasing correlative with this vector and so is the efficiency.

Average yields in Romania start from 11.63 q/ha for the primitive technologies (Note 1) and reach to 51.34 q/ha for the most modern technologies that we have. If we had had the technology of Note 10, the yield would have been with at least 200 kg/ha higher, acording to the functions estimation (Fig. 3).

The graph presented in Fig. 3 shows a more than polynomial increase, which tends toward exponential logarithmic.

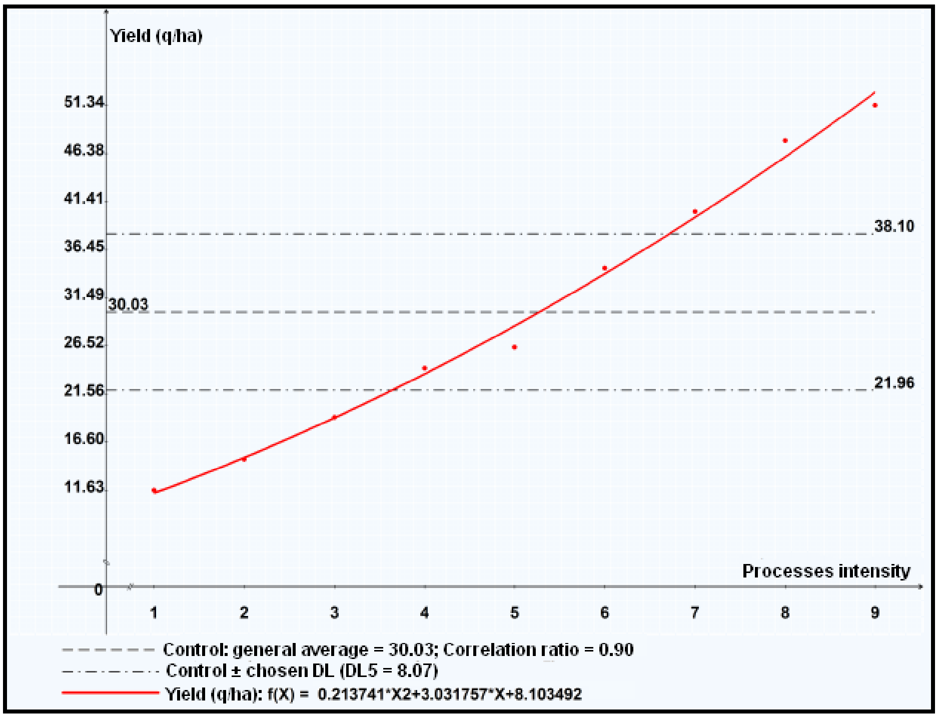

Fig. 3. Influence of production processes intensity on wheat yield – graphical presentation (original)

Nowadays, the average yields in Romania is done with processes intensities of 4-5. However, on about 700.000 ha are also practiced intensive technological processes, that raise the production, in average for the other factors, to more than 51 q/ha (Note 9). It can be even better, but with other efforts of research and technical implementation.

The main restraining factors on the known soils, in the current ecological state are:

- ➔ the water;
- ➔ the technology;
- ➔ the knowledge.

4. Bilateral interactions and the yield

4.1. The influence of the aridity index (AR) and of the production processes intensity on wheat yield

The production average variation in this interaction is between 9.7 q/ha (at AR = 0.30, with TPI = 1) and 56.10 q/ha (at AR = 080, with TPI = 9). A ratio of approximately 5.8 to 1. Under conditions of dry area, no matter how good the technology would be, the yield stops just under 3 tons/ha and remains in slight increase, insignificant compared with the average.

In relation to the general average of the experiment, all differences are negative and, until Note 6, distinct or very significantly negative. In case of AR = 0.40 there is a very significant increase in production, especially in high TPI creditworthiness marks. It is the area where those who are doing technologies are rewarded mainly due to accumulation, in properly prepared soil, of the water from autumn-winter.

A similar situation is at AR = 0.55 and AR = 0.80, with the specification that AR = 0.55 seems to be the most favorable for the wheat crop, which is also due to the really good soils from this area. In Fig. 4 is composed the bifactorial model of the interaction, that demonstrates us the following:

a) The increase, the improving technologies and the working capital use are represented best at AR = 0.55 – well above other areals;
b) The lowest yield dynamics is found at AR = 0.30, regardless of TPI.

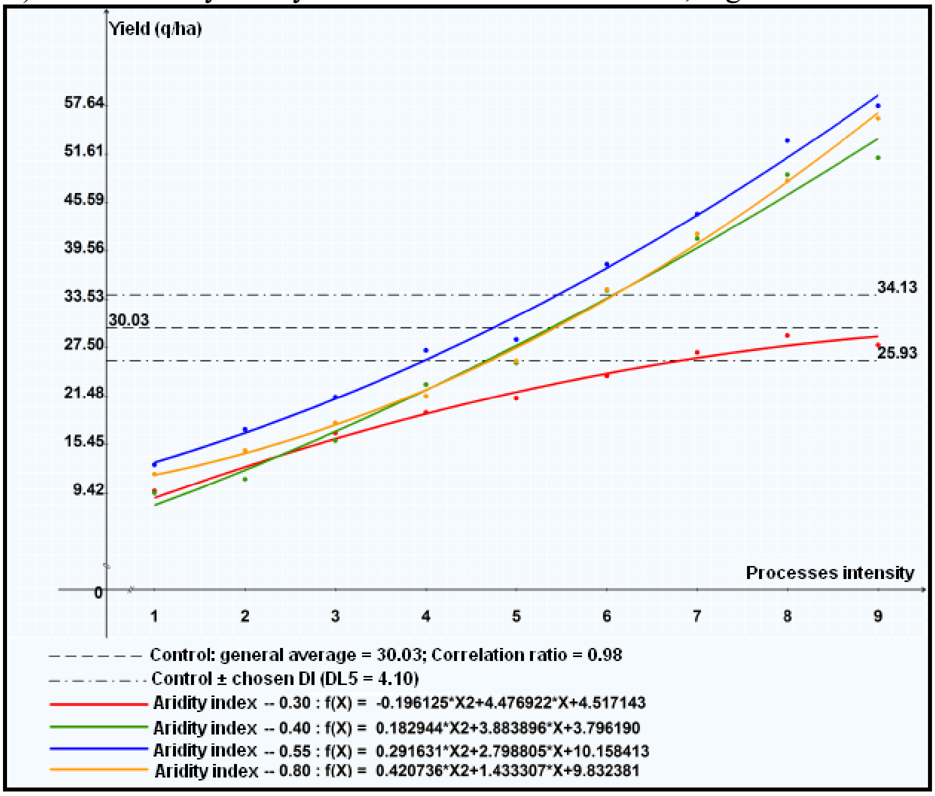

Fig. 4. AR and TPI intensity on wheat yield – graphic bifactorial model

The rest of the AR areas are getting closer of 0.55 and distance themselves of 0.30, particularly at high notes of TPI. The model can be used for yields calculation for any technological system and areal. For example, for a process noted with 4.5 and an AR = 0.55 the yield is slightly above 30 q/ha, while for a process noted with 8.5 and an AR = 0.30 the yield is about 26 q/ha. Practitioners can use this model to optimize the technological processes in their climatic areas.

4.2. The influence of the interaction between CW_S and TPI on wheat yield

We find that, at small values of soil quality (40 points), the yields level remains low, ranging between 9.7 and 27.9 q/ha, ie a ratio of 1 : 2.9.

Concrete, this increase of 2.9 times of the yield is mainly caused by the improvement, intensification of the production processes. Compared to the average of the experience, all differences are negative, statistically assured at very and distinctly significant level.

Between old technologies (Notes 1-3) and modern technologies there is a plus 14-19 q/ha, also statistically assured.

Increasing soil quality doesn't improve the yield at low levels of the technological processes, but allow a very favorable interaction to high notes of them intensification. The diferences between large and small yields reach ratios of 1 : 5.4-6 to soils with 55, 64, 75 and 86 points.

Our data confirm the results obtained by other authors, among which we quote Farack (2010). Our yield intensification model resembles with the one from Germany, in the years 1950-1970. Of about 50 years the average wheat yield of the country is at the level of 2500 kg/ha ± 20%, the cause being placed on the technological chain, as well as on the lack of conservation of soil and water resources.

The request that appears from the nomogram (Fig. 5) lies in finding solutions to increase production in conjunction with processes intensification, including on poor soils. Only in this way we can get to a good exploitation of investments and of working capital.

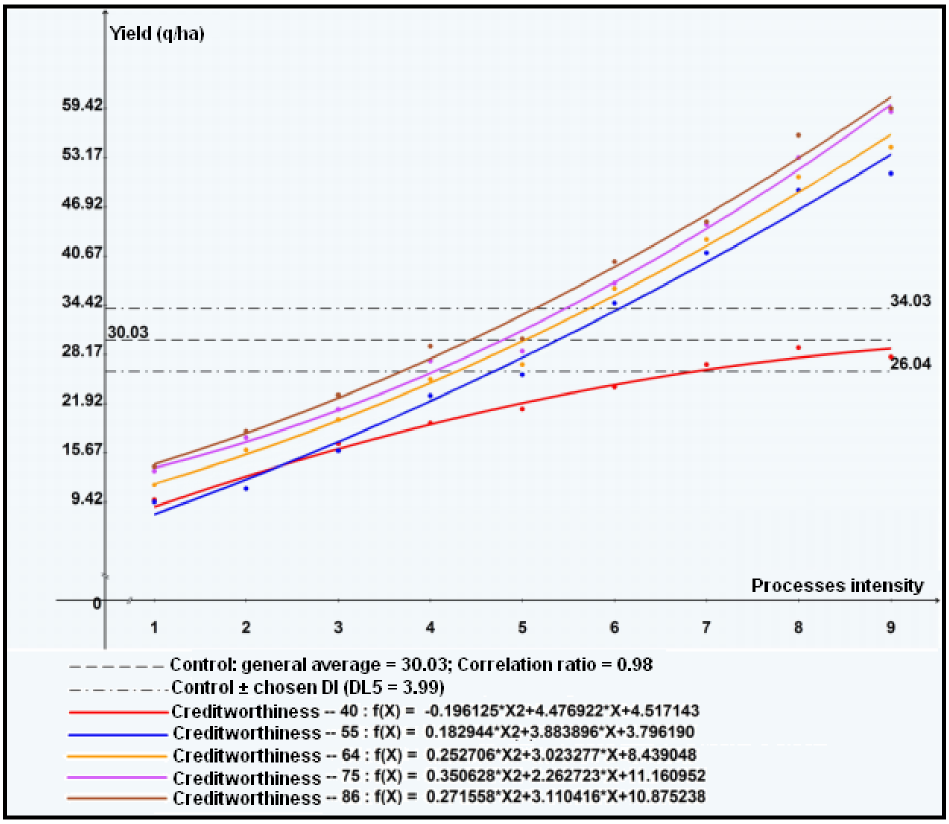

Fig. 5. CW_S and TPI influence on wheat yield – the nomographic version

From 55 to 86 point the curves are concentrated, the differences between them in dynamic being insignificant. Actually, significant secondments of the yields occur in technologies from 8 points, on all soils starting with 50-55 points (quality).

Technologies, the well-valorised capital, raise the wheat yields level on any qualitative type of soil.

4.3. The effect of the interaction between the AR and CW_S indexes and the winter wheat yields level

The synthesis of this interaction is presented in Fig. 6. The combinations between the aridity (AR) and soil quality indices shows that the best yields are achieved at AR = 0.55 and CW_S = 86. AR = 0.55 indicates a transition area from semi-humid to humid on the inner side, toward the Carpathians Curvature, but permanently on good soils, chernozems, with 3.5 – 4.5% humus (harvest level + 16% above the experience average, within the random variation limit for the 95% probability – „t” distribution).

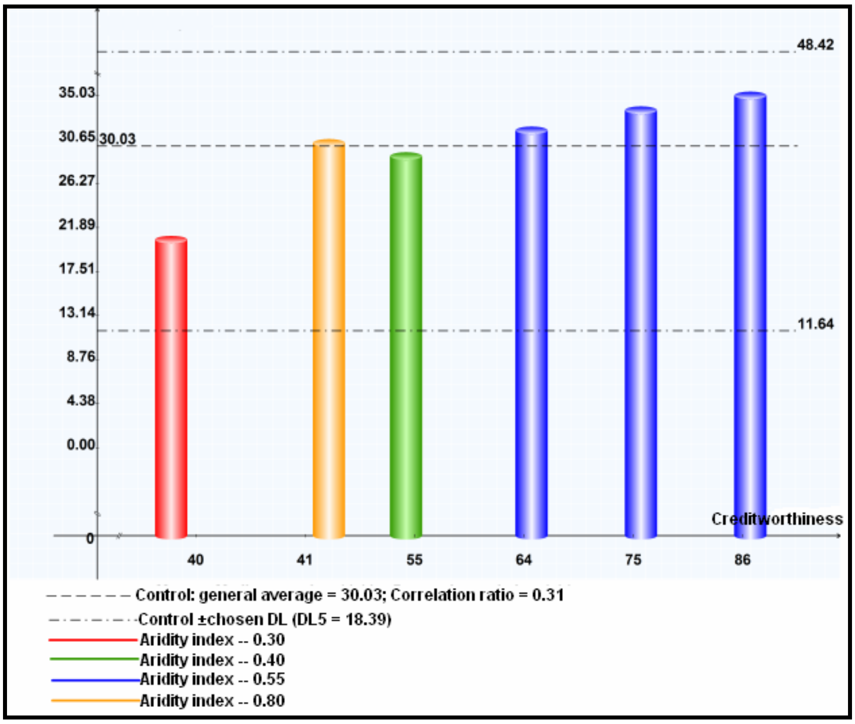

Fig. 6. Bifactorial analysis between AR and CWS factors on winter wheat yield – graphic presentation

From Fig. 6 is obvious the small variation of the yield parameters, but also the fact that the 3 combinations (AR = 0.55 with CW_S 64, 75 and 86) remain the best.

Quite good results can also be obtained from AR = 0.80, which indicates a humid climate. In this case the yields were reduced by the poor quality of the soil: CW_S = 41 points ⇒ physical and chemical (acidity) degradation, that haven't been the subject of any improvement (treatments).

5. The interactive influence of AR, CW_S and TPI factors on wheat yield in Romania (2002-2012)

It was emphasized that 6 areal combinations (clime * soil, AR * CW_S) and 9 TPI steps (variants) were studied, a total of 54 variants.

The lowest yields are encountered in the combinations AR = 0.30 * CW_S = 40 * TPI = 1 and AR = 0.40 * CW_S = 55 * TPI = 1, yields under 1000 kg/ha (10-year average), equivalent to what was obtained in Germany 180 years ago.

The highest yields are obtained on AR = 0.55 in combination with CW_S = 75 or CW_S = 86 and TPI = 9. The difference between maximum and minimum average yields is at the level of 59.4 – 9.4 = 50 q/ha.

Such a difference on decadal averages is especially generated by the great technological variability and by the capital, and only then by the soil quality and aridity. At the end of the paper we will also present the separation of the analyzed factors influence on wheat yield variation.

We point out that high technology and superior capitalization of inputs, of working capital, is best accomplished on AR = 0.55, irrespective of soil quality, from Note 6 upward offering crop increases from significant the very significant .

A proper technology and the scientific application of inputs may lead to yields increases of up to 56 q/ha even on soils with less than 50 points, if a humid climate is ensured.

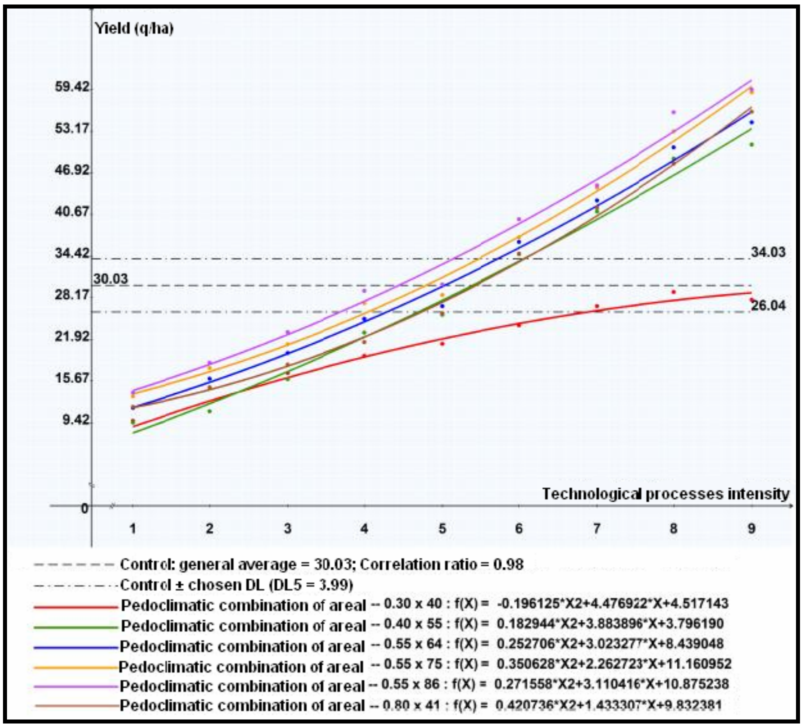

Fig. 7. Wheat yield model based on AR, CW_S and TPI in România, after a survey of 10 years

In Fig. 7 is presented the achievement model of wheat yield accordint to all 3 analyzed factors. The nomogram indicates crop values situated very significant for all AR * CW_S combinations, except the first (0.30 * 40), which remains significant in the negative area.

The nomogram allows the yields precise determination for all 54 studied combinations, proving to be a useful pattern for farmers and researchers. From here starts the improved elaboration of wheat crop management.

The model, in its lower part, require the improvement of the water regime, and this requires irrigation, but a modern one, allowing a superior capitalization of water.

CONCLUSION

The influence analysis of the AR (aridity index), soil quality (CW_S) and technological processes intensity (TPI) indicators on the wheat crop led us to the following conclusions:

1. The average aridity index, calculated as yield, gives it a variability of 12 q/ha ⇒ 24% of the total variability of the experiment.
2. The average yields, calculated according to the soil quality (CW_S) on the interval of 40-86 points, indicate a yield variation of 30% of the total average variability of the experiment.
3. The average yields calculated according to TPI (technological processes intensity) indicate the highest variability in system ⇒ 80% of the total average variability. Because the gathered percentages are much higher than 100%, results that the effect of factors interaction it is necessary to be calculated separately for each crop area, the national data of yield variation not showing significant differences, unless in the TPI case.

4. The intensity, the technologiea quality, the knowledge and the scientific use of working capital are reducing a part of the negative effects of yields stagnation at aridity indexes of 20 - 30, but also on soils with creditworthiness under 50 points.
5. The calculated models have a 95% probability of credibility. However, they clearly show with what intensity of the yield processes can be worked, on different soils and climatic conditions. Since the pedoclimatic parameters vary over short periods of time, a dynamic adaptation of TPI by the farmers becomes a basic condition of maintaining the high level of production.

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