ASPECTS CONCERNING WINTER WHEAT YIELD FORMATION UNDER TRANSYLVANIAN PLAIN CONDITIONS

Gheorghe Ionescu and Grigore Moldovan[1]

SUMMARY

This paper presents the experimental results obtained at the Turda Agricultural Research Station, in 1994-1997, regarding the influence of climatic, genetic and technological factors as well as of interactions between them on the formation of winter wheat yield (Transylvania, Turda 81 and Ariesan cultivars) under the ecological conditions of Transylvanian Plain. The comparative study on winter wheat yield during four years experiment showed that the causality relationships contributing to winter wheat yield are particularly complex, the genetical and technological factors being accompanied also by the action of natural factors. The trends of curves of yield variation according to the mathematical models prepared for each winter wheat cultivar every year (1995 and 1996) pointed out the non-linear character of the relationship between the yield and the studied technological factors. It was noticed that in 1995, both the optimum values of seeding density and nitrogen rates, although they determined high yields with all experimented winter wheat cultivars, were lower compared to the corresponding optimum values recorded in 1996. The Ariesan winter wheat cultivar manifested a better adaptability to the ecological conditions in the four experimental years and a better resistance to diseases as compared to the Transylvania and Turda 81 cultivars.

Key words: adaptability, cultivar, mathematical model, winter wheat

INTRODUCTION

It is known that any area is characterized by spatial and temporal variability of environmental conditions. Therefore, the definition of an ideotype supposes the quantitative forecast of the behaviour of different genotypes, under different conditions (Săulescu and Jinga, 1990).

The results regarding wheat growing under limited conditions of water supply (Debaeke et al., 1992) and the influence of different climatic modifications on the winter wheat development (Rajaram et al., 1990; Easterling et al., 1992; Semenov et Porter, 1993) represent a contribution to the definition of winter wheat ideotype depending on the growing area.

The development of plants in different phenological stages and the increase of the foliar area using interplant competition, temperature and momentary soil moisture content have been simulated in order to establish their response under the above mentioned stress conditions (Ahmad et al., 1989; Singels and Jager, 1991).

The wheat growing simulation according to precipitation and nitrogen fertilization (Engel, 1991) also represents the necessary premises to define the ideotype of the winter wheat plant.

The study of the complex process of the winter wheat yield formation under the ecological conditions specific to Transylvania Plain contributes to obtain new data on the role of the climatic factors, genetic materials and of some technological measures to achieve, intensify and stabilize the yield of this plant particularly important for mankind food security.

The emphasis of the main factors influence and their interactions as well as the quantification of their actions create the premises to model the formation processes of the winter wheat yield under specific Transylvanian Plain conditions and at the same time, to identify, among the studied cultivars, the winter wheat cultivar which presents a better adaptability and a higher ecological plasticity (Ionescu, 1998).

This four years experiment had also in view to know and establish the functional dependencies of the winter wheat yield in terms of the investigated technological and genetic factors. At the same time, the optimum levels of the technological factors which permit to obtain maximum yields under climatic conditions specific to the experimentation period, with direct implication in energetic and economic efficiency were determined.

MATERIALS AND METHODS

The study of the proposed objectives was carried out by organizing a multifactorial experiment of 4 x 4 x 3 x 3 type, with the following factors:

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- nitrogen fertilization: N_{50}, N_{100}, N_{150} and N_{200} (kg active ingredient /ha);

- seeding density: D_{250}, D_{450} and D_{650} (germinable grains/m^2 - g.g./m^2);

- genetic material: Transylvania, Turda 81 and Arieºan winter wheat cultivars.

The experiments were carried out on the vertic argillo-illuvial chernozem from Turda, a soil developed on clay marls, with groundwater table depth of 10-15 m. The soil is characterized by a low phosphorus content (15 ppm in topsoil), moderate nitrogen content (0.196%) and a high potassium content (249 ppm in topsoil). The humus content values range between 3.4 and 4 per cent, the soil reaction being neutral with pH values between 6.9 and 7.

The experiments were carried out in 1994-1997, years with different climatic conditions which influenced the yield levels.

The applied agrophytotechnical parameters were specific to the area, with nitrogen being applied by fractional dressings, on an uniform basic dressing with phosphorus (100 kg active ingredient /ha).

To quantify the action of the studied factors regarding the winter wheat yield formation, mathematical models were used to calculate their optimum values in order to obtain the maximum yield.

To determine the optimum values of the factors leading to maximum yield and permitting at the same time, to obtain also the response under other non-experimental conditions, the canonic transformation of the model was carried out that allows the winter wheat yield (y) determination in terms of nitrogen fertilization factors (x_1) and seeding density (x_2), for each wheat cultivar and each growing year.

The general form of the mathematical model to determine the yield is:

$$y = b_o + \sum_{j=1}^{k} b_j x_j + \sum_{j=1}^{k-1} \cdot \sum_{q=j+1}^{k} b_{qj} x_q x_j + \sum_{j=1}^{k} b_{jj} x_j^2$$

In order to determine the regression coefficients of this mathematical model, the Œbîºev orthogonal polynomial method, which satisfies the method of the smallest squares, was used. Thus, the wanted function $y = f(x_1, x_2)$ is developed using the formula:

$$y = A_0 \psi_0(x) + A_1 \psi_1(x) + A_2 \psi_2(x),$$

and for the polynom determination the recurrence formula is used:

$$\psi_m(x) = (\alpha_m x + \beta_m) \psi_{m-1}(x) - \alpha_m \psi_{m-2}(x)$$

so that: $\psi_0(x) = 1$, $\psi_1(x) = x_1 - T_{10}(\psi_0)$ ...

In virtue of the polynomial orthogonality: $\sum [\psi_m(x) \psi_k(x)] = 0$, for $m \neq k$

the needed formulae for computing the Œbîºev polynomial coefficients and then the regression coefficients may be determined in a relatively simple way.

The area described by this mathematical model (from the geometric viewpoint), the extreme points of this area or at least the knowledge of area form in the domain close to the extreme present an economic, technical, etc. interest, offering at the same time, the direction towards which the next research should be performed.

The previously mentioned desiderata can be reached by the transformation of the mathematical model in a standard form, called canonic form, which may be considered also as a method for optimization.

The center of the response area in the new system of $x_1 o x_2$ co-ordinates, representing, in fact, the co-ordinates of the extreme point in the old co-ordinate system, is determined using the following matricial formulae:

$$x_e = (-1/2) \cdot b_{11}^{-1} \cdot b_1 T$$
$$y_e = b_0 + b_1 \cdot x_e + x_e \cdot T \cdot b_{11} \cdot x_e$$

RESULTS AND DISCUSSIONS

In the context of the general form of the mathematical model, the following form of the objective function was chosen for expressing the functional dependencies between the yields of the tested cultivars and the studied technological factors:

$$p = b_0 + b_1 N + b_{11} N^2 + b_2 D + b_{22} D^2 + b_{12} ND \ (q/ha)$$

were: bi, i = 0, 1, 2, ... , k: = regression coefficients of the equation;

k: = number of factors.

GHEORGHE IONESCU AND GRIGORE MOLDOVAN: ASPECTS CONCERNING WINTER WHEAT YIELD FORMATION UNDER TRANSYLVANIAN PLAIN CONDITIONS

79

Having the experimental results for each variant and using the Cebî°ev polynomial method, the values of the regression coefficients of the above mentioned mathematical model were determined (Table 1).

Using the determined regression coefficients, the final form of the mathematical model for any experimented cultivar and any cropping year can be elaborated.

Also it should be specified that, after checking the relation $b_i > t \cdot S(b_i)$, it has been noticed that all the regression coefficients are significant, and the mathematical model obtained in the complete form represents, from the geometric viewpoint, the response areas.

In the previous relation, the t coefficient is taken from tables depending on the selected significance level (5%) and degrees of freedom of error, and $s(b_i)$ is the average error of the regression coefficients.

The functional dependencies of the experimented cultivar yields, in terms of the nitrogen fertilization and seeding densities, were established in the extreme cases as concerns their level during the four years experiment, namely, for 1995 (the year with the highest yields) and 1996 (the year with the lowest yields). Thus, using the determined coefficients, in this case, six non-linear regression equations can be formed.

The extreme of the response areas of these regression equations, considered as optimum for the tested cultivars as well as the maximum yields determined by the levels of the optimum values are presented in table 2.

The variation of the winter wheat cultivar yields, at the optimum nitrogen fertilization level of each cultivar, in terms of the tested seeding densities is presented in figure 1.
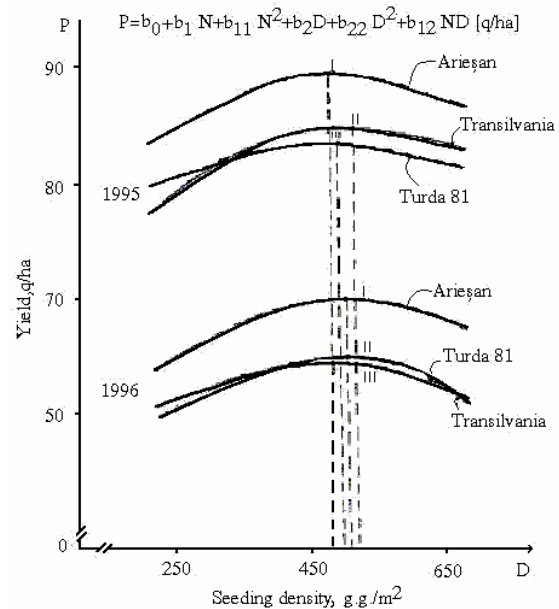

$$P=b_0+b_1\,N+b_{11}\,N^2+b_2D+b_{22}\,D^2+b_{12}\,ND\;[q/ha]$$

Figure 1. Winter wheat yield determined at optimum fertilization level in terms of seeding densities under climatic conditions of 1995 and 1996 years at Turda Agricultural Research Station

Under climatic conditions of 1995, a year considered as very suitable for winter wheat growing due to the good precipitation in the

Table 1. Values of regression coefficients

Year	Cultivar	b_0	b_1	$b_{11} \times 10^2$	$b_2 \times 10^1$	$b_{22} \times 10^4$	$b_{12} \times 10^3$
1995	Arie°an	33.370	0.518	0.180	0.965	0.830	0.130
	Turda 81	39.180	0.370	0.110	0.810	0.610	0.160
	Transylvania	32.411	0.441	0.140	0.970	0.720	0.180
1996	Arie°an	24.680	0.275	0.080	0.980	0.860	0.073
	Turda 81	33.520	0.201	0.054	0.560	0.450	0.056
	Transylvania	36.760	0.116	0.030	0.740	0.700	0.031

Table 2. Maximum yield of experimented winter wheat cultivars determined by optimum nitrogen rates and seeding density in 1995 and 1996

Year	Cultivar	Maximum yield (q/ha)	Optimum nitrogen (kg a.i./ha)	Optimum density (germinative grains/m²)
1995	Transylvania (II)	85.0	124.0	518
	Turda 81 (III)	83.4	132.0	499
	Arie°an (I)	89.4	126.0	482
1996	Transylvania (II')	65.0	168.0	506
	Turda 81 (III')	64.1	159.0	523
	Arie°an (I')	69.9	148.3	510

period preceding the seeding, and during the grain formation and filling ranked the first as concerns the productive potential, at all levels of the experimented densities.
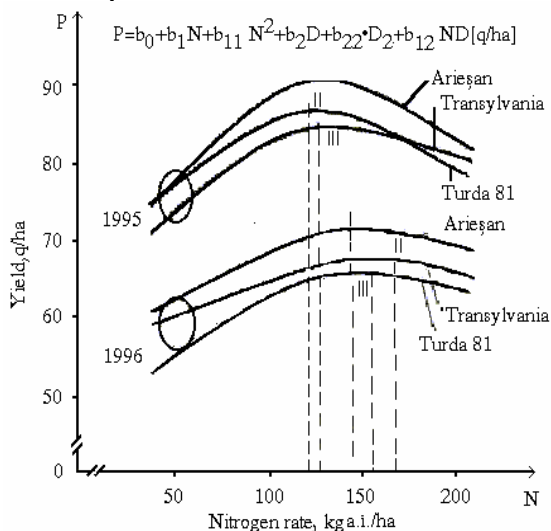

$$P=b_0+b_1N+b_{11} N^2+b_2D+b_{22} \cdot D_2+b_{12} ND[q/ha]$$

Figure 2. Winter wheat yield determined at optimum density level in terms of nitrogen fertilization under climatic conditions of 1995 and 1996 years at Turda Agricultural Research Station

If at the seeding density of 250 germinative grains/m^2 and at an optimum nitrogen fertilization level of 126 kg a.i./ha, the expected yield is 84.80 q/ha, it has been observed that, along with seeding density increase, the expected yield increases up to the maximum value of 89.40 q/ha (I), corresponding to a seeding density of 482 germinative grains/m^2. The further increase of the seeding density determines yield decrease (according to the curve trend), so that at a density of 650 germinative grains/m^2, the expected yield, at the optimum fertilization level, is 86.99 q/ha.

Transylvania cultivar, at the optimum nitrogen fertilization level of 124 kg a.i./ha and at a density of 350 germinative grains/m^2, realizes an expected yield of 79.81 q/ha.

The seeding density increase determines an ascending trend of the expected yield curve, reaching the maximum value of 85.00 q/ha (II) at the density of 518 germinative grains/m^2, then it decreases even if the density increases up to 650 germinative grains/m^2.

It should be underlined that at high, as well as optimum seeding densities, the expected yield of Transylvania cultivar is higher than of Turda 81 cultivar.

With a seeding density of 250 germinative grains/m^2 and an optimum nitrogen fertiliza-

tion level of 132 kg a.i./ha Turda 81 cultivar realizes an expected yield of 80.04 q/ha. The increse of the seeding density up to 499 germinative grains/m^2 determines an ascending trend of the expected yield curve up to 83.40 q/ha (III). At a higher seeding density, up to 650 germinable grains/m^2, the yield decreases to 82.08 q/ha, this being also confirmed by the expected yield curve trend down.

As a general rule, higher seeding densities did not contribute to the increase of the expected yield levels of tested cultivars, a thing explained by the fact that, in the case of these densities, the lodging tendency and the occurrence of some ear and leaf diseases were favoured.

In 1996, a year less suitable for winter wheat growing due to climatic conditions which favoured the occurrence of the wheat diseases, the Arieºan cultivar kept on ranking the first as concerns the yield levels, determined at experimented seeding densities, for the nitrogen optimum rates.

The expected yield levels for the three experimented winter wheat cultivars were, in this year, lower than those in 1995, although the optimum nitrogen fertilization rates were higher as compared to the mentioned year. Therefore the conclusion could be drawn that, in the years presenting stresses for winter wheat crop, to reach a certain yield level, the mineral fertilizer consumption increases, hence, the economic effort as well as the plant effort to reach an acceptable yield level is higher.

At a seeding density of 250 germinative grains/m^2 and at an optimum nitrogen fertilization level of 148.3 kg a.i./ha, the determined yield of the Arieºan winter wheat cultivar was 64.25 q/ha, than it increased up to 69.88 q/ha (I') at a seeding density of 510 germinative grains/m^2, and afterwards the curve got a descending trend down to the level of 68.09 q/ha, at a seeding density of 650 germinative grains/m^2.

Transylvania cultivar ranked also the second place in that year, from the viewpoint of the expected yield, so that at a seeding density of 250 germinative grains/m^2 and at an optimum nitrogen fertilization level of 168 kg a.i./ha, this cultivar has given a determined yield of 60.66 q/ha. The curve trend was ascendant up to the seeding density of 506 ger-

GHEORGHE IONESCU AND GRIGORE MOLDOVAN: ASPECTS CONCERNING WINTER WHEAT
YIELD FORMATION UNDER TRANSYLVANIAN PLAIN CONDITIONS

81

minative grains/m^2, where the obtained expected yield was 65.00 q/ha (II'); after that it got a descending trend, even if the seeding density incresed up to 650 germinative grains/m^2, a density at which a yield of 63.05 q/ha was achieved.

The Turda 81 winter wheat cultivar, at an optimum nitrogen fertilization level of 159 kg a.i./ha and at a seeding density of 250 germinative grains/m^2, showed an expected yield of 60.76 q/ha.

The ascending curve trend of the expected yield was maintained up to the seeding density of 523 germinative grains/m^2, where the maximum expected yield achieved was 64.10 q/ha (III'). After this point, the curve presented a descending trend, at a seeding density of 650 germinative grains/m^2 the yield being of 63.37 q/ha.

The variations of the expected yields of three experimented winter wheat cultivars and their maximum points depending on the applied nitrogen rates and optimum seeding densities, are presented in figure 2.

This graph shows that, in all variants with experimented nitrogen rates, the maximum expected yield was obtained at the optimum level of the seeding densities, the Ariesan cultivar ranking the first in the two experimental years as compared with the other studied winter wheat cultivars.

In 1995, the Arieºan winter wheat cultivar, at a nitrogen fertilization rate of 50 kg a.i./ha and at an optimum seeding density of 482 germinative grains/m^2, produced an expected yield of 78.00 q/ha.

The curve trend of the expected yield is ascending up to the nitrogen rate of 126 kg a.i./ha, where the maximum expected yield was obtained, giving a yield of 89.40 q/ha (I) for the optimum seeding density, and after that, the curve had a descending trend, reaching 80.00 q/ha at a nitrogen fertilization rate of 200 kg a.i./ha

The Transylvania winter wheat cultivar, at an optimum seeding density of 518 germinative grains/m^2 and at a nitrogen fertilization rate of 50 kg a.i./ha, achieved an expected yield of 77.00 q/ha.

The yield curve has an ascending trend up to the nitrogen rate of 124 kg a.i./ha, where the maximum yield of 85.00 q/ha (II) was achieved; after that it showed a descending trend, even if the nitrogenfertilization rates

increased, reaching 76.70 q/ha at the nitrogen rate of 200 kg a.i./ha At the nitrogen fertilization rate of 50 kg a.i./ha and the optimum seeding density of 499 germinative grains/m^2, the Turda 81 cultivar achieved a yield of 76.60 q/ha. In the graph presented in figure 2 it could be observed that the ascending trend of the expected yield is maintained up to the nitrogen fertilization rate of 132 kg a.i./ha, where the maximum obtained yield was 83.40 q/ha (III). At the nitrogen fertilization rate of 200 kg a.i./ha, the yield of Turda cultivar was higher than that obtained by Transylvania cultivar, which confirms the intensive character of this cultivar, its capacity to better turn to account the high nitrogen rates under the conditions of ensuring also the other factors at an optimum level.

As concerns the Arieºan cultivar, its optimum seeding density was, in 1996, 510 germinative grains/m^2. With this seeding density and a nitrogen fertilization rate of 50 kg a.i./ha, the expected yield achieved was 62.10 q/ha. The ascending trend of the yield curve was maintained up to the nitrogen fertilization rate of 148 kg a.i./ha (I'), after which it presented a descending trend, so that, at the fertilization rate of 200 kg a.i./ha, the obtained production was 67.70 q/ha.

In the same year, Transylvania cultivar ranked the second, with an optimum seeding density of 506 germinative grains/m^2. With a nitrogen fertilization rate of 50 kg a.i /ha, this cultivar achieved an expected yield of 60.50 q/ha. The curve trend has increased up to the nitrogen rate of 168 kg a.i./ha at which it reached the maximum productive level of 65.00 q/ha (II), and then the curve trend has become descending, reaching a yield of 64.28 q/ha, corresponding to the nitrogen fertilization rate of 200 kg a.i./ha, Turda 81 cultivar, at the optimum seeding density of 523 germinative grains/m^2 and at the tested nitrogen rates, ranked the third from the view point of the expected yields. At the optimum seeding density and the nitrogen fertilization rate of 50 kg a.i./ha the determined yield was 57.70 q/ha, the yield curve having an ascending trend up to the nitrogen rate of 159 kg a.i./ha at which the maximum value of 64.10 q/ha (III') was reached, then this curve had a descending

trend, reaching a yield of 63.30 q/ha at a nitrogen fertilization rate of 200 kg a.i./ha

The expected yield levels of the three winter wheat cultivars, at the tested nitrogen rates, were different, due to climatic conditions and the aggressiveness of diseases. In 1995, the maximum expected yields of the three winter wheat cultivars were obtained with reduced nitrogen rates, while the maximum yield levels, were obtained in 1996 with higher nitrogen rates.

The obtained mathematical model of the functional dependencies between the winter wheat yield and the technological factors under study does not supply, from the geometric viewpoint, an easily visible representation of the response area form.

On the basis of the regression coefficients previously determined (Table 1), the yield mathematical model of the Arieºan winter wheat cultivar for 1995, could be represented as follows:

$$P_{95} = 33.37 + 0.518N - 0.0018N^2 + 0.0965D - 0.000083D^2 - 0.00013ND$$

were: N: = nitrogen rates (kg a.i./ha);

D: = seeding densities (germinative grains/m^2).

Applying the transformation methodology of this mathematical model in a standard form, called canonic form, the centre of the response area in the new system of $x_1 o x_2$ coordinates is obtained as follows:

$$x_e = -\frac{1}{2} \cdot \begin{bmatrix} -571.72 & 447.735 \\ 447.735 & -1239.883 \end{bmatrix} \cdot \begin{bmatrix} 0.518 \\ 0.0965 \end{bmatrix} = \begin{bmatrix} 126 \\ 482 \end{bmatrix}$$

$$y_e = 33.37 + \begin{bmatrix} 0.518 & 0.0965 \end{bmatrix} \begin{bmatrix} 126 \\ 482 \end{bmatrix} + \begin{bmatrix} 126 & 482 \end{bmatrix} \cdot$$

$$\cdot \begin{bmatrix} -0.0018 & -0.000065 \\ -0.000065 & -0.00008 \end{bmatrix} \cdot \begin{bmatrix} 126 \\ 482 \end{bmatrix} = 89.4$$

Therefore, the extreme point of the analysed area is a maximum one and, in fact, represents the maximum expected yield of the Arieºan winter wheat cultivar, under the cropping conditions of 1995 year. So, the optimum nitrogen rate values of 126 kg a.i./ha and the optimum seeding density values of 482 germinative grains/m^2 secure the obtainment of the maximum yield of 89.40 q/ha. Further on, to determine the form of the response area, the following calculations could be carried out:

- translation of the old coordinates into the new origin:

$$x_1' = x_1 - 126$$
$$x_2' = x_2 - 482$$

- rotation of the coordinate axes by variable transformation:

$$x' = U \cdot x$$

where: U: = orthogonal matrix

The λ coefficient values of the characteristic equation are:

$$\lambda_1 = -0.00182$$
$$\lambda_2 = 0.000082$$

So the orthonormal vector will have the form:

$$U = \begin{bmatrix} 0.998 & 0.03 \\ 0.03 & -0.998 \end{bmatrix}$$

The equations of the new system of coordinates result from the following matricial formula:

$$\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} 0.998 & 0.03 \\ 0.03 & -0.998 \end{bmatrix} \cdot \begin{bmatrix} x_1 - 126 \\ x_2 - 482 \end{bmatrix}$$

Consequently, the canonic form of the original response area will be:

$$Y - 89.4 = -0.01018 \cdot x_1^2 - 0.0008 \cdot x_2^2$$

Analysing this canonic equation, it could be stated that, from the geometric viewpoint, the response area represents an "elliptic hill", the response curves for different yield levels having elliptic forms (Figure 3).
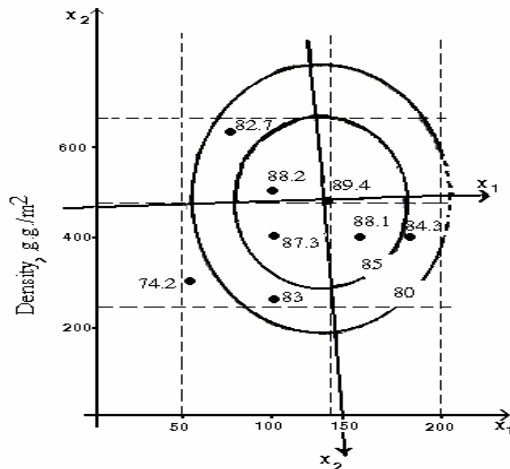
GHEORGHE IONESCU AND GRIGORE MOLDOVAN: ASPECTS CONCERNING WINTER WHEAT
YIELD FORMATION UNDER TRANSYLVANIAN PLAIN CONDITIONS

83

Figure 3. Response curves of area described by the
mathematical model od Arieºan winter wheat cultivar
yield and results determined in some experimental
points (Turda Agricultural Research Station, 1995)

These ellipses stretch in the direction of
the ox_2 axis (seeding density), and the extreme
of the area is a maximum point of the yield.

With the response curves laid out in this
case for the selected yield levels, using the
graph presented in figure 3, it is possible to
determine, in a relatively simple way, the
minimum levels of the nitrogen rates and seed-
ing densities as well as the combinations be-
tween them which may ensure to obtain ef-
ficient yields from the energetic and economic
viewpoint.

CONCLUSIONS

The results of the investigations con-
ducted during a four year period allow the
formulation of the following conclusions:

- In order to improve winter wheat crop
efficiency, all scientific cropping measures
should be applied along the whole growing
period. Application of general technologies
should be replaced by application of techno-
logical interventions in terms of yield compo-
nents formation and the evolution of vegeta-
tion cycle.

- The comparative study of the winter
wheat yield during the four experimental years
(1994-1997) revealed the complexity of the
causality relationships which contribute to
yield formation, the action of the natural fac-
tors being also associated with the action of
the genetic and technological factors.

- The trend of the yield variation curves
outlined on the basis of the mathematical

models elaborated for each winter wheat culti-
var and growing year (1995 and 1996) empha-
sizes the non-linear character of the relation-
ship between yield and the investigated tech-
nological factors.

- Both optimum values of seeding densi-
ties and nitrogen rates, although have contrib-
uted to the obtainment of high yields in 1995,
in the case of the three wheat cultivars study,
are smaller comparatively to the optimum
values corresponding to the cropping year
1996.

- The rainfalls of August-September, be-
fore sowing, as well as those from grain for-
mation-filling period, were determinant in ob-
taining high yields in the cropping year 1995.
The yields of the agricultural year 1996 were
diminished by the relatively early occurrence
of leaf and stem diseases.

- The Arieºan winter wheat cultivar mani-
fested a better adaptability to the ecological
conditions in the four experimental years and a
better resistance to diseases as compared to
Transylvania and Turda 81 cultivars.

- The standard form of the mathematical
model of Arieºan winter wheat yield, consid-
ered as an optimal method, permits to select
those levels of the technological factors which
determine the achievement of maximum yields
under positive energetic and economic balance
conditions.

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GHEORGHE IONESCU AND GRIGORE MOLDOVAN: ASPECTS CONCERNING WINTER WHEAT
YIELD FORMATION UNDER TRANSYLVANIAN PLAIN CONDITIONS

85