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WINTER WHEAT YIELDS AND THEIR STABILITY IN DIFFERENT CROP ROTATION TYPES AND NITROGEN FERTILIZATION REGIMES

Alexandru I. Cociu

National Agricultural Research and Development Institute Fundulea, 915200 Fundulea, Calarasi County, Romania.
E-mail: acociu2000@yahoo.com

ABSTRACT

Usually, the long-term investigations compare only average crop yields and overlook their stability. This research was intended to evaluate the influence of long-term rotation of annual crops and nitrogen fertilization regime, as well as rotation breaking with a perennial alfalfa (*Medicago sativa* L.) plot, on winter wheat (*Triticum aestivum* L.) yields and their stability. Cropping systems were: (i) monoculture; (ii) 2 yr winter wheat – corn (*Zea mays* L.); (iii) 3 yr winter wheat – corn – soybean [*Glycine max* (L) Merr]); and (iv) 4 yr winter wheat – corn – sunflower (*Helianthus annuus* L.) – peas (*Pisum sativum* L.). Nitrogen fertilization regimes were: N_0 (no fertilization), N_{50} kg ha^{-1}, N_{100} kg ha^{-1}, and N_{150} kg ha^{-1}, applied on an uniform P_{70} back-ground. Rotation breaking with a perennial alfalfa plot resulted in a significant winter wheat yield increase of 4.8%, when compared with the variant without rotation breaking, on which a mean winter wheat yield of 4.024 t ha^{-1} was obtained. The highest winter wheat mean yield was registered in the 4 year rotation variant (4.592 t ha^{-1}) and the lowest - in the case of 2 yr rotation (3.656 t ha^{-1}), being 8.5% and 16.7% lower than the yields obtained with monoculture and 3 yr rotation, respectively. Nitrogen fertilization determined a substantial yield increase, from 2.639 t ha^{-1} without N fertilization, to 4.808 ha^{-1} recorded with N_{100} kg ha^{-1}. Large yield increases were recorded also with N_{50} kg ha^{-1} and N_{150} kg ha^{-1} fertilization, of 64.2% and 78.1%, respectively, compared to N_0. Winter wheat yield trends in time (along years) for all variants (annual crop rotations, rotation breaking with alfalfa, and different nitrogen fertilization regimes) were significantly positive, with an average of 0.196 t ha^{-1} year^{-1}. Rotation breaking with a perennial alfalfa plot resulted in 19.8% reduction of yield variation (as measured by the coefficient of variation - CV) in winter wheat, in all four rotation types. In the case of the four nitrogen fertilization regimes the CV reduction was of 27.6%. The CV's calculated for the mean winter wheat yields, recorded for the four nitrogen fertilization regimes, were higher at the 2 yr rotation variant: with 23.9% than with monoculture, 39.7% than with 3 yr, and 52.7% than with 4 yr rotations. The fertilization regime applied within the four rotation systems determined a significant reduction of wheat yield variation (CV) in comparison with N_0 variant, by 67.1% than with N_{50} kg ha^{-1}, by 76.8% than with N_{150} kg ha^{-1}, and by 82.9% than with N_{100} kg ha^{-1}. Regression analysis indicated that the introduction of a 3-4 year perennial alfalfa crop in rotation resulted in significant winter wheat yield stability gains at all four rotation systems, as well as at all nitrogen fertilization variants. The winter wheat yield was significantly more stable at 4 yr rotation than 3 yr rotation and monoculture. The least stable yields were registered with 2 yr rotation. Winter wheat yields were significantly less stable with N_0, when compared with all three nitrogen fertilization variants, which showed similar yield stability. The highest and most stable yields were obtained with N_{100} kg ha^{-1}. One of the main conclusions of this research is that winter wheat crop has to be placed in 3 or 4 year rotation systems. The 2 yr rotation, mainly winter wheat – corn, which has been widely practiced in small and medium sized farms, has to be interrupted after 3-4 cycles, or to be switched to at least a 3 yr rotation (ex. winter wheat – maize – grain legumes). Fertilization is one of the most important actions to be considered for increasing winter wheat yield, its stability and crop profitability. Introduction in rotation of a 3-4 year perennial alfalfa crop has a significant effect in this respect, bringing important nitrogen supplement and contributing to soil amelioration.

Key words: winter wheat, monoculture, crop rotation, crop rotation breaking, nitrogen fertilization.

INTRODUCTION

Meteorological conditions, such as temperature evolution, light duration and intensity, and precipitation amount and distribution, as well as how much the crop is affected by diseases, pests and weeds, are the main factors which influence the crop yield variability from year to year. This variability is in inverse relationship with yield stability. Yield fluctuation becomes more a concern in the actual global climate change projections (Dai et al., 2001). In this respect, Swift (1994) considers that crop yield evaluation has to be

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based on both – yield and yield stability across variable climatic conditions. Long term studies are essential to identify the cropping systems that assure, with low risks, high and stable yields (Raun et al., 1993). This type of research helps identify crops which improve soil properties and its productivity across variable environments over time and also delivers important management recommendations for production (Varvel, 2000).

Usually, long-term investigations have compared only average crop yields and overlooked their stability. Yield stability analysis within long term experiments has advantages over simple mean yield reporting, because the mean yield does not reflect the variation over years and locations – a larger variation being more disadvantageous (Săulescu, 1984).

Interpretation of “Year/Cropping System” interaction is quite difficult when is based on the conventional analysis of variance for long term experiments, due to complexity of factors influencing the environment**.** Hildebrand (1984) and Raun et al. (1993) considered that regression stability analysis is an efficient technique for interpretation of „Year/Cropping System” interactions. It was used for the first time in plant breeding research for “Genotype/Environment” interaction estimation by Yates and Cochran (1938), and later it was extended to crop management studies (Guertal et al., 1994).

Estimation of the coefficient of variation has also been efficiently used to estimate and compare year to year yield variability, higher values indicating a larger variability (Smith et al., 2007; Mustăţea et al., 2009).

A great role in obtaining high and stable yields with reduced costs is played by crop rotation. It constitutes an important link of the complex measures for weed, disease and pest integrated control, reducing the infestation and respectively infection degrees, and also reducing the need of chemical treatments, and so the overall pollution (Petcu and Ioniţă, 1998). Crop rotation contribution to soil fertility maintenance and improvement, through the physical properties amelioration, organic matter and nutritive reserve contents increase, and energizing soil biologic activity, has been proved to be significantly economic efficient, when higher levels of fertilizer dozes were applied (Picu, 1984).

The present research had in view to evaluate the influence of long-term rotation of annual crops and the nitrogen fertilization regime, as well as of rotation breaking with a perennial alfalfa (*Medicago sativa* L.) plot, on winter wheat (*Triticum aestivum* L.) yields and their stability.

MATERIAL AND METHODS

Winter wheat yields and their stability from a long term cropping system and nitrogen (N) fertilising stationary research were evaluated. The experiment comprised the main actually practiced crop rotation systems, with cereals (winter wheat), oil crops (soybean and sunflower), annual legumes (peas, and again soybean), and perennial legumes (alfalfa). Nitrogen fertilizations were applied differentially, depending on each crop, on a moderate phosphor fertility level.

This research was initiated at the National Agricultural Research & Development Institute (NARDI) Fundulea, situated in Romanian Southern Plain, at 44º27’45” latitude and 26º31’35” longitude, east of Fundulea town. The climate is of temperate continental type, with a 50 year multi-annual mean temperature of 10.7ºC and 580 mm precipitations. These data were registered by a meteorological station located at 250 m from the experimental site. The soil was cambic chernozem formed on loessoide deposits, well-drained, with a high productivity potential. The amount of precipitations received at the site during the period of March to June varied considerably among the years of the study (2002-2011), ranging from 78.1 mm in 2007 to 295.2 mm in 2005 (Table 1**),** with an average of 186.3 mm.

The experiment was designed as a randomised complete block (four blocks) with a split-plot arrangement of treatments. Crops rotation treatments were assigned to whole plots and included monoculture, 2 year rotation (winter wheat – maize), 3 year rotation (winter wheat – maize – soybean) and four year rotation (winter wheat – maize – sunflower – pea). Subplot treatment was N fertilization levels (0, 50, 100 and 150 kg N ha^{-1}), applied on a uniform P (70 kg ha^{-1}) background.

The same experiments were also carried out after 3-4 year rotation breaking with a perennial alfalfa plot. Whole plots were 32 by 5 m and subplots were 8 by 5 m.

Winter wheat plots were seeded in the first half of October and harvested in the middle of July, each year. Planting was performed in close rows (12.5 cm apart) with a rate of 500 viable grains per m^2, and harvest was made with a Wintersteiger Delta plot combine of 2 m working width. Grain yield was adjusted to constant moisture of 14%.

Data were analysed using a split plot multi-annual analysis of variance. The Duncan multiple comparisons test at the $P \leq 0.01$ level (Steel and Torrie, 1980) was used to compare the mean yields recorded in the four annual crop rotations and in the four N fertilization regimes, as well as to compare the influence of interrupting the rotation with a perennial alfalfa plot.

For the regression stability analysis, environment mean was calculated as the annual mean yield of all treatments which were compared (Eberhart and Russell, 1966). Environments were then ranked by yield means, to make a quantitative gradient of environmental productivity, regardless of the cause of yield variability (Hildebrand, 1984). The individual treatment means were then regressed on the environment means, and the regression lines were compared among treatments. The stability analysis assumes that year to year yield variability is affected mainly by the environmental variability. Guertal et al. (1994) showed that, for a reliable stability analysis, change in yield over time should not differ among the treatments which are compared. Considering this assumption, as a first step, we examined whether the trends of winter wheat yields over time differed among the annual crop rotations under study, by comparing their linear trends within each N fertilization regime and within the variant representing the rotation breaking with a perennial alfalfa plot. Because the interaction among years, cropping systems, N fertilization regimes, and rotation break with a perennial alfalfa plot was significant, we compared the regression of annual means of cropping system treatments over the environment means (the annual mean winter wheat yield of all treatments under this study).

Linear slopes of winter wheat yields on the environment means were compared among monoculture winter wheat and the three crop rotations, using the tests for equality of slopes of several regression lines described by Sokal and Rohlf (1995) (at $P<0.05$). The trends over years and yield stability influenced by rotation interruption with a fertility perennial crop, as well as the influence of rotation systems and different N regimes were also evaluated using the tests for equality of slopes of several regression lines (Sokal and Rohlf, 1995).

Variability of winter wheat yield was compared by computing the coefficients of variation (CV's) of yields over time for the 8 variants of the interaction of rotation breaking with a fertility perennial crop and rotation systems, 8 variants of interaction of rotation breaking with a fertility perennial crop and N fertilization regimes, and 16 variants of the interaction among rotation systems and N fertilizing regimes. Analysis of variance on the results was then performed. The Duncan multiple comparisons test at the $P \leq 0.01$ level (Steel and Torrie, 1980) was used to compare the mean CV's.

In order to estimate if precipitations were responsible for crop yield variability, we regressed yields on seasonal monthly growing season precipitation over the years of study using the multiple regression for three independent variables (Sokal and Rohlf, 1995).

RESULTS

Precipitation

Total precipitation registered in the period of wheat vegetation (March - June) of the 10 experimental years ranged from 4.9 to 154.6 mm (Table 1). In addition, total precipitation in this period of 10 experimental years was below the multi-annual mean, of 186.4 mm. Within a growing season, the coefficient of variation (CV) of total monthly precipitation showed values between 0.412 and 0.657.

Table 1. Total monthly precipitation, precipitation variability during the growing season, and winter wheat grain yields from 2002-2011 at Fundulea

Year	Precipitation (mm)					Winter wheat grain yield (t/ha)
	March	April	May	June	March - June	
2002	42.4	25.4	19.0	64.7	151.5	3.647
2003	46.0	45.4	17.5	19.5	128.4	1.766
2004	21.8	7.1	73.9	79.3	182.1	5.220
2005	23.5	18.1	99.1	154.6	295.2	4.658
2006	41.3	66.2	50.5	73.3	231.3	4.045
2007	33.4	4.9	21.3	18.5	78.1	2.360
2008	21.4	61.6	59.9	30.6	173.5	4.960
2009	32.3	22.1	35.8	103.6	193.8	3.711
2010	38.3	41.8	31.2	104.5	215.8	5.892
2011	5.1	28.9	76.8	102.4	213.2	4.944
CV*	0.412	0.657	0.582	0.581	0.320	0.314

*CV, coefficient of variation of total monthly precipitation occurring in the same month over the period of study.

Winter wheat grain yields

Winter wheat yields were significantly influenced by the four factors under this study: A – year, B – crop rotation breaking by a perennial fertility restoration crop (alfalfa), C – annual crop rotation, and D – nitrogen (N) fertilization (Table 2). The effect of the studied factors on yields varied from year to year, as indicated by the very significant interactions of „year x crop rotation breaking by a perennial fertility restoration crop", "year x annual crop rotation", "year x N fertilization", and by the significant interaction of "year x crop rotation breaking by a perennial fertility restoration crop x annual crop rotation x N fertilization"

Table 2. Analysis of variance of winter wheat yield obtained within different cropping systems under this study, during 10 years (Fundulea 2002-2011)

Source of variation	df	SS	Mean square	F
Factor A – year	9	1927.517	214.169	383.9292***
Error	27	15.062	0.558	
Factor B – crop rotation breaking	1	11.924	11.924	47.9238***
AB	9	15.862	1.762	7.0836***
Error	30	7.464	0.249	
Factor C – annual crop rotation	3	154.915	51.638	203.0710***
AC	27	86.127	3.190	12.5444***
BC	3	4.300	1.433	5.6362***
ABC	27	30.082	1.114	4.3814***
Factor D – nitrogen fertilization	3	975.501	325.167	1278.7386***
AD	27	219.496	8.129	31.9697***
BD	3	23.463	7.821	30.7570***
ABD	27	15.002	0.556	2.1851***
CD	9	40.400	4.489	17.6529***
ACD	81	82.455	1.018	4.0032***
BCD	9	7.492	0.832	3.2736***
ABCD	81	27.456	0.339	1.3330*
Error	900	228.859	0.254	

*Significant at the 0.05 probability level; **Significant at the 0.01 probability level;
***Significant at the 0.001 probability level.

In the respective 10 year period, winter wheat mean yields were differentiated significantly due to “crop rotation breaking by a perennial fertility restoration crop”, “annual crop rotation”, and “N fertilization” (Table 3).

Table 3. Mean winter wheat yields obtained within the variants “crop rotation breaking by a perennial fertility restoration crop”, “annual crop rotation”, and “N fertilization” (Fundulea, 2002-2011)

1. Crop rotation breaking by a perennial fertility restoration crop	Winter wheat mean yield (t ha^{-1})
Without interruption	4.024 b
With interruption	4.217 a
2. Annual crop rotation	Winter wheat mean yield (t ha^{-1})
Monoculture	3.965 c
2 yr. rotation	3.656 d
3 yr. rotation	4.268 b
4 yr. rotation	4.592 a
3. N fertilization (kg a.i./ha)	Winter wheat mean yield (t ha^{-1})
N_0	2.639 d
N_{50}	4.333 c
N_{100}	4.808 a
N_{150}	4.701 b

Treatment means followed by the same letters are not significantly different according to Duncan New Multiple-Range Test (P< 0.01)

Crop rotation breaking by a perennial fertility restoration crop resulted in a significant yield increase of 4.8% compared to the variant without rotation breaking, which yielded 4.024 t ha^{-1} (Table 3/1). The highest yield was recorded with 4 year rotation (4.592 t ha^{-1}), and the lowest - in the case of 2 year rotation (3.656 t ha^{-1}), which was with 8.5% and 16.7% lower than the mean yields recorded for monoculture and 3 year rotation, respectively (Table 3/2). The differences were significant and economically important. N fertilization brought an increase of winter wheat yield from 2.639 t ha^{-1}, at N0, to 4.808 t ha^{-1}, at N_{100}. It has to be mentioned also that in comparison with N_0, the winter wheat yields were with 64.2% and 78.1% higher at N_{50} and N_{150} variants (Table 3/3). These differences were significant and economically important too.

Significant positive winter wheat mean yield trends were observed over all annual crop rotation systems, rotation interruption with a fertility amelioration perennial crop, and N fertilization regimes, with a 0.196 t/ha/year average (Figure 1). The differences among the linear regression slopes were non significant (F = 0.194 << F0.05 [3.32] = 2.92).

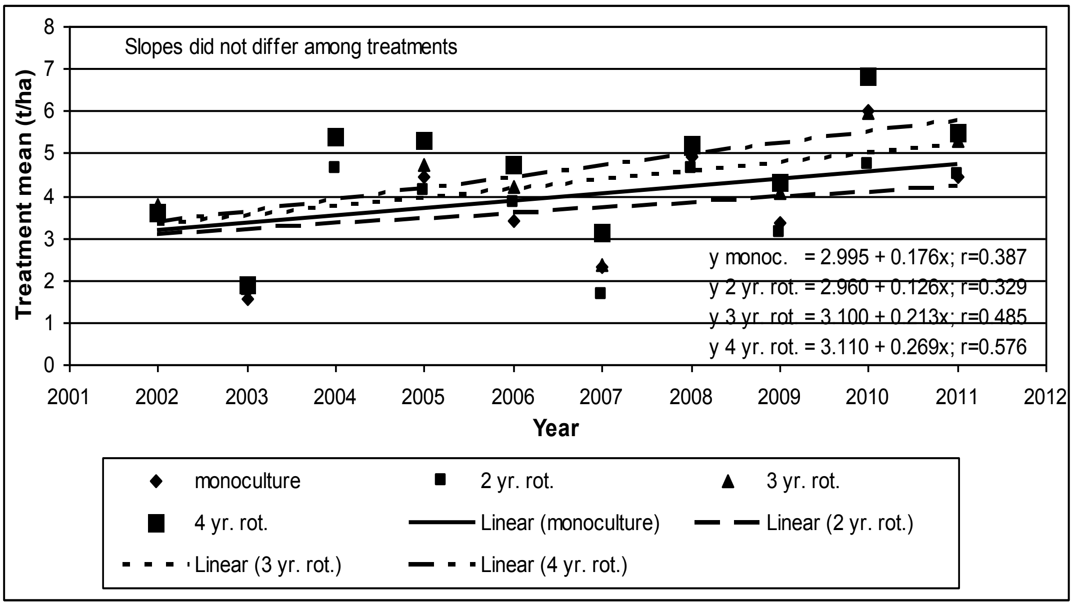

Figure 1. Linear regressions of winter wheat mean yields obtained within an annual crop rotation breaking with a fertility restoration perennial plot, at Fundulea, in the period of 2002-2011

Individual data points are means of four replications (n=4). Slopes were compared among variants using the tests for equality of slopes of several regression lines (Sokal and Rohlf, 1995). Differences were considered significant at P< 0.05.

Stability of winter wheat yields

Crop rotation breaking with a fertility restoration perennial plot determined a reduction of CV with 19.8% of winter wheat mean yields, registered for the four crop rotation types (Table 4/1).

CV value reduction within the four N fertilization regimes was of 27.6% (Table 4/2). These two reductions are statistically significant.

CV's calculated for the yields obtained within the four N fertilization regimes were higher in the case of 2 year rotation with 23.9, 39.7 and 52.7% than with monoculture, 3 year rotation and 4 year rotation, respectively (Table 4/3). The differences were also statistically significant.

N fertilization regimes applied to the four crop rotation systems determined a significant reduction of CV value of winter wheat mean yield in comparison with the N_0 variant, with 67.1%, 76.8% and 82.9%, respectively when the variants N_{50}, N_{150}, and N_{100} were considered (Table 4/4).

Table 4. Means of year to year variation of winter wheat yield, expressed as the CV's, due to interaction of: crop rotation breaking with a fertility restoration perennial plot x annual crop rotation, crop rotation breaking with a fertility restoration perennial plot x N fertilization regimes, annual crop rotation x N fertilization regimes, and N fertilization regimes x annual crop rotation

1. Rotation breaking x Annual crop rotation	Mean CV
Without rotation interruption	0.111 a
With rotation interruption	0.089 b
2. Rotation breaking x N fertilization	Mean CV
Without rotation interruption	0.286 a
With rotation interruption	0.207 b
3. Annual crop rotation x N fertilization	Mean CV
Monoculture	0.270 b
2 yr rotation	0.355 a
3 yr rotation	0.214 c
4 yr rotation	0.168 d
4. N fertilization x Annual crop rotation	Mean CV
N_0	0.280 a
N_{50}	0.092 b
N_{100}	0.048 b
N_{150}	0.065 b

Treatment means followed by the same letters are not significantly different according to Duncan New Multiple-Range Test ($P< 0.01$).

The regression stability analysis revealed that the response of crop rotation systems and N fertilization regimes to environmental conditions differed when a crop rotation breaking with a fertility restoration perennial plot was used.

The linear regressions in Figure 2 show that winter wheat yields obtained in different annual crop rotations were significantly differentiated ($F = 7.0 \gg F0.05[1.12] = 4.75$) by the rotation breaking with a fertility restoration perennial plot.

The slopes of linear regressions, presented in Figure 3, indicate that winter wheat mean yield obtained within the N fertilization variants were also significantly influenced by the rotation breaking with a fertility restoration perennial plot ($F = 36.46 \gg F0.05[1.12] = 4.75$).

The regression stability analysis presented in Figure 4 emphasizes that the response of winter wheat yield to annual crop rotation systems, in time, with the studied N fertilization regimes differed significantly: $F = 41.267 \gg F0.05[3.8] = 4.07$. Almost a similar image is in the case of the interaction of N fertilization regimes with annual crop rotation (Figure 5): $F = 26.652 \gg F0.05\ [3.8] = 4.07$.

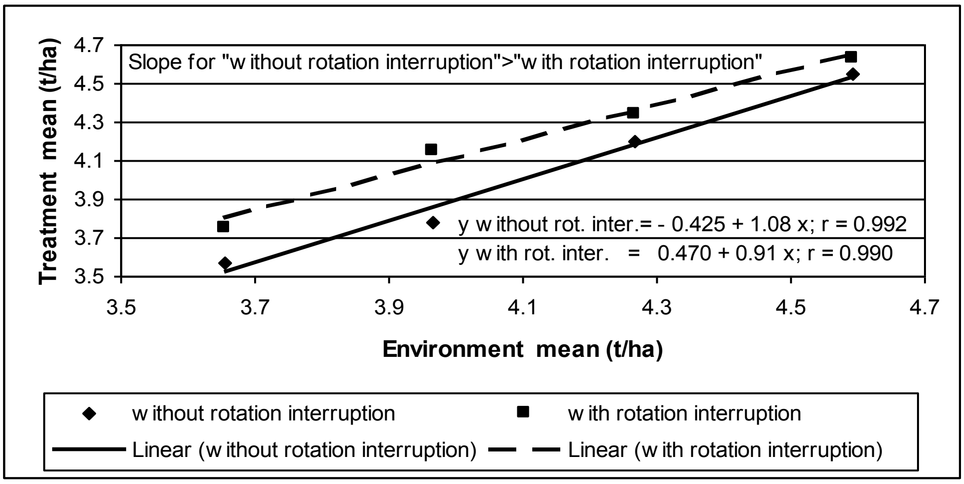

Figure 2. Linear regressions of winter wheat mean yields obtained within an annual crop rotation breaking with a fertility restoration perennial plot in interaction with annual crop rotation systems, at Fundulea, in the period of 2002-2011

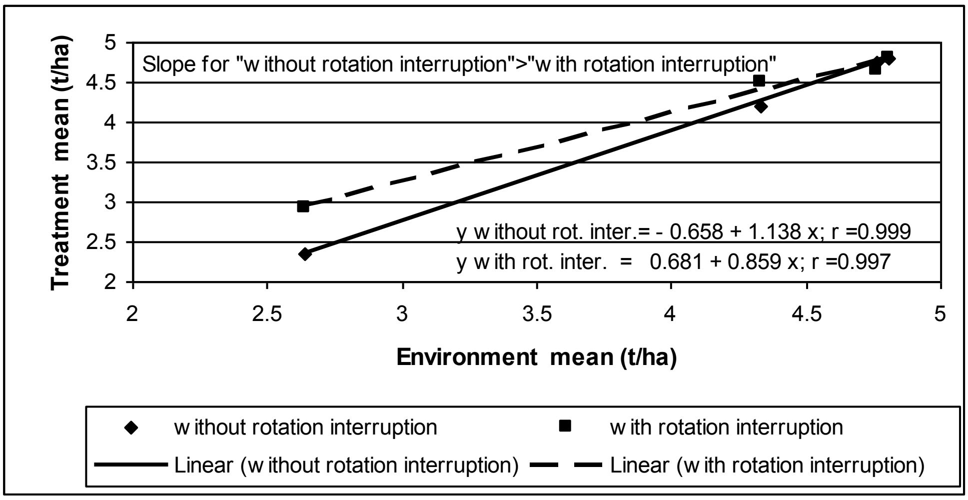

Figure 3. Linear regressions of winter wheat mean yields obtained within an annual crop rotation breaking with a fertility restoration perennial plot in interaction with N fertilization regimes, at Fundulea, in the period of 2002-2011

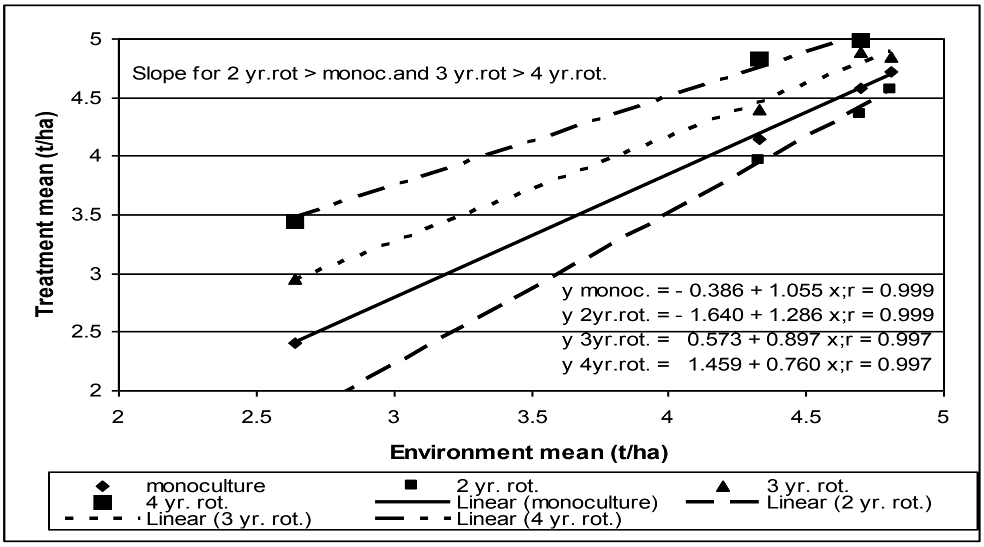

Figure 4. Linear regressions of winter wheat mean yields due to the interaction of annual crop rotation with N fertilization regimes, at Fundulea, in the period of 2002-2011

Individual data points are means of four replications (n=4). Slopes were compared among variants using the tests for equality of slopes of several regression lines (Sokal and Rohlf, 1995). Differences were considered significant at $P< 0.05$.

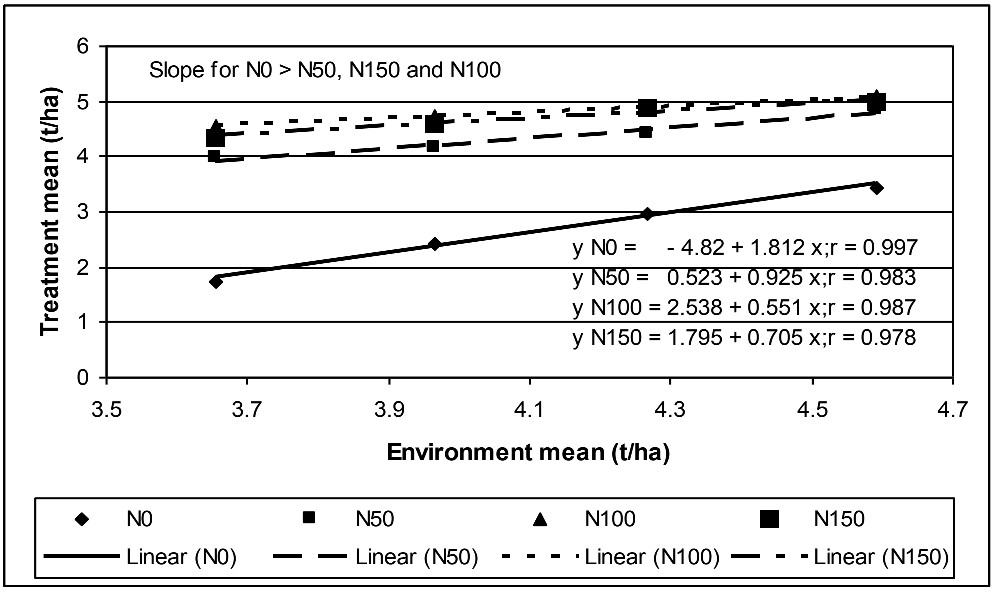

Figure 5. Linear regressions of winter wheat mean yields due to the interaction of N fertilization regimes with annual crop rotation, at Fundulea, in the period of 2002-2011

Individual data points are means of four replications (n=4). Slopes were compared among variants using the tests for equality of slopes of several regression lines (Sokal and Rohlf, 1995). Differences were considered significant at $P < 0.05$.

DISCUSSION

The experimental results revealed that high and stable winter wheat yields were obtained when wheat was placed in rotation after favourable crops. The yield increases due to the previous crop were of 600 kg ha^{-1} to 1000 kg ha^{-1} (Table 3/2). The best previous crops proved to be the grain legumes, as peas and soybean, which deposit in soil important nitrogen amounts and contribute to its physical and biological properties. Crops with long vegetation period, as late maize hybrids, which delay plot liberation and preparation for winter wheat seeding, determined large yield losses, so they are less recommended.

Winter wheat monoculture more than two years resulted also in important yield losses, mainly due to the increase of disease infection, and especially damaging weed and insect infestation, of which control is difficult.

Introduction in rotation of a perennial crop, such as alfalfa, determined significant winter wheat yield increases, starting with the second after ploughing, and a reduction of nitrogen fertilizer need (Table 3/1).

Winter wheat enhanced substantially the value of nitrogen (N) fertilizers, because wheat needs large quantities of N in spring, when, because of lower temperatures, soil nutrition elements are less mobilized, while water from precipitation is generally well available. The yields raised significantly, from 2.6 t/ha at N_0 to 4.3 - 4.8 t/ha in fertilized variants (Table 3/3).

The trends of winter wheat mean yields obtained within four rotation systems, in time, were positive (Figure 1). It is difficult to determine the exact cause of the increasing trends. Possible explanations, however, include role of advancements in wheat breeding, improved management of field operations, and favourable weather.

This study also demonstrated that the analysed cropping factors can greatly influence the temporal variability and stability of winter wheat yields. Crop rotation breaking with a fertility restoration perennial plot (e.g. alfalfa) resulted in decreasing the long term variability of winter wheat yields in both crop rotation systems (Table 4/1) and N fertilization regimes (Table 4/2). Favourable previous crops in rotation (Table 4/3), as well as N fertilization (Table 4/4), were very efficient in decreasing the long term variability of winter wheat yields.

The regression stability analysis showed that higher and more stable winter wheat yields were achieved in certain crop rotations (Figure 2) and with N fertilization regimes (Figure 3), as well as when a fertility restoration perennial crop was introduced in rotation during a 3-4 year period.

In the N fertilization treatments, winter wheat mean yields obtained with 4 year rotation were significantly more stable than the yields recorded for 3 year rotation and monoculture (Figure 4). These last two variants showed somewhat different regression slopes, but the differences were not statistically significant. The yields registered for 2 year rotation were significantly less stable than those obtained within the other rotations.

In the crop rotation variants (Figure 5), winter wheat mean yields obtained with no N fertilization were significantly less stable than those obtained within different fertilization regimes, while these last ones did not differ significantly. The highest and most stable winter wheat yields were obtained with N_{100} fertilization.

Many authors substantiated that the crop yield temporal variability is influenced by environmental factors, such as precipitations (Hu and Buyanovsky, 2003; Mallory and Porter, 2007). In this research, precipitation was responsible for 74% of winter wheat yield variability. The most significant predictors of the winter wheat variability were the amount of precipitation received during the months of June ($R^2 = 0.37$) and May ($R^2 = 0.36$). The regression equation that described the dependence of wheat yield on precipitations was:

$$\text{Yield} = 5.694 + 0.013 \text{ precipitation April} + 0.023 \text{ precipitation May} + 0.012 \text{ precipitation June} \ (R^2 = 0.74)$$

Regression analysis suggested that winter wheat yield increased with 0.013, 0.023, and 0.012 t/ha if the precipitations, in April, May and June respectively, increased with 1 mm and all the other factors stayed constant.

CONCLUSIONS

For obtaining high and stable yields, winter wheat should be placed within 3-4 year stable rotation systems. The 2 year rotation (i.e. winter wheat – maize), witch is very common in small or even medium sized farms in Romania, has to be interrupted after 3-4 two year rotation cycles. Another good option may be a 3 year rotation: winter wheat – maize – annual grain legumes. Crop rotation contributes substantially to soil fertility maintenance, but it is not enough for supplying the complete need of nutritive elements for achieving the expected high and stable yields in the present intensive crop systems. Fertilization has to be considered one of the most important measures for obtaining stable winter wheat yields over 4 t/ha, along with the increase of this crop economic efficiency. The introduction of 3-4 year perennial crop, such as alfalfa, used to interrupt annual crop rotation, influenced very favourably the level of winter wheat yield levels and stability, mainly due to the supplemental nitrogen made available and to the amelioration of soil properties.

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