Efficiency of Fertilization in Sustainable Wheat Production

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SUMMARY

In sustainable (wheat) production plant nutrition supply and fertilization play decisive roles among the agrotechnical elements, because of their direct and indirect effects on other agronomical factors.

In long-term experiments, we studied the roles of agroecological, genetic-biological and agrotechnical factors in the nutrient supply, fertilization and its efficiency in wheat production under continental climatic conditions (eastern part of Hungary, Trans-Tisza) on chernozem soil. Our results have proved that there are different (positive and negative) interactions among ecological, biological, and agrotechnical elements of wheat production. These interaction effects could modify the nutrient demand, fertilizer (mainly nitrogen) response of wheat varieties and efficiency of fertilization in wheat production.

The optimum N-doses (+PK) of wheat varieties varied from 60 kg ha^{-1} (+PK) to 120 kg ha^{-1} (+PK) depending on cropyears, agrotechnical elements and genotypes. The winter wheat varieties could be classified into 4 groups according to their fertilizer demand, natural and fertilizer utilization, fertilizer response and yield capacity.

Appropriate fertilization (mainly N) of wheat could affect both the quantity and quality of the yield. By using optimum N (+PK) fertilizer doses, we could manifest genetically- coded baking quality traits of winter wheat varieties and reduce quality fluctuation caused by ecological and other management factors. The efficiency of fertilization on different baking quality parameters (wet-gluten, valorigraph index etc) were variety specific (the changes depended on genotypes).

Our long-term experiments proved that appropriate fertilization provides optimum yield, good yield stability and excellent yield quality in sustainable wheat production. We could this get better agronomic and economic fertilization efficiency with less harmful environmental effects.

INTRODUCTION

In the management of several field crops, nutrient supply and fertilization play central and decisive roles because they could directly and indirectly modify the efficiency of the other agrotechnical elements. Fertilization is especially important in those crops which sensitively react to the deviation of nutrient-supply (like small grain cereals: winter wheat etc.).

In nutrient supply and fertilization, it is important to obtain optimum yield quantity and quality, to ensure good yield stability, to get better biological, agronomical, and economical efficiency, while reducing harmful environmental effects (*Figure 1*).

In the sustainable environmentally-friendly fertilization of winter wheat, the nutrient demands of different elements (macro- and micro-elements), the dynamics of nutrient uptake during the vegetation period, the nutrient-husbandry of soils and the climatic conditions are the most important factors. Furthermore, we have to take some additional factors into consideration in determining wheat fertilization doses and splitting which could directly and indirectly modify the efficiency and utilization of fertilizers. These factors could be classified into ecological, biological-genetic and agrotechnical factor groups (*Figure 2*).

Fertilization (mainly nitrogen) is a very important agrotechnical factor in wheat production. Appropiate fertilization could increase the yield and quality (Láng, 1974; Bocz, 1976). Species-specific fertilizer demand of winter wheat is 300-350 kg/ha NPK, which could be modified by different ecological, biological and agrotechnical factors (Ruzsányi, 1975; Koltay-Balla, 1982; Bocz-Pepó, 1985). In sustainable wheat production, we could increase the efficiency of fertilization by the using of variety-specific fertilization (Jolánkai, 1982; Pepó, 1995; Korobskoi et al., 1997; Podolska, 1997; Pepó, 1999; Filipov-Dachev, 1999; Weber et al., 1999).

Figure 1: **Most important aims in the sustainable, environmentally friendly fertilization of winter wheat**
(Péter Pepó, 1999)

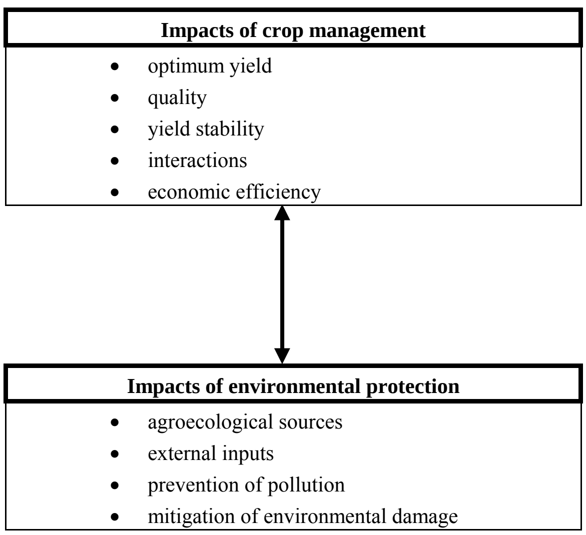
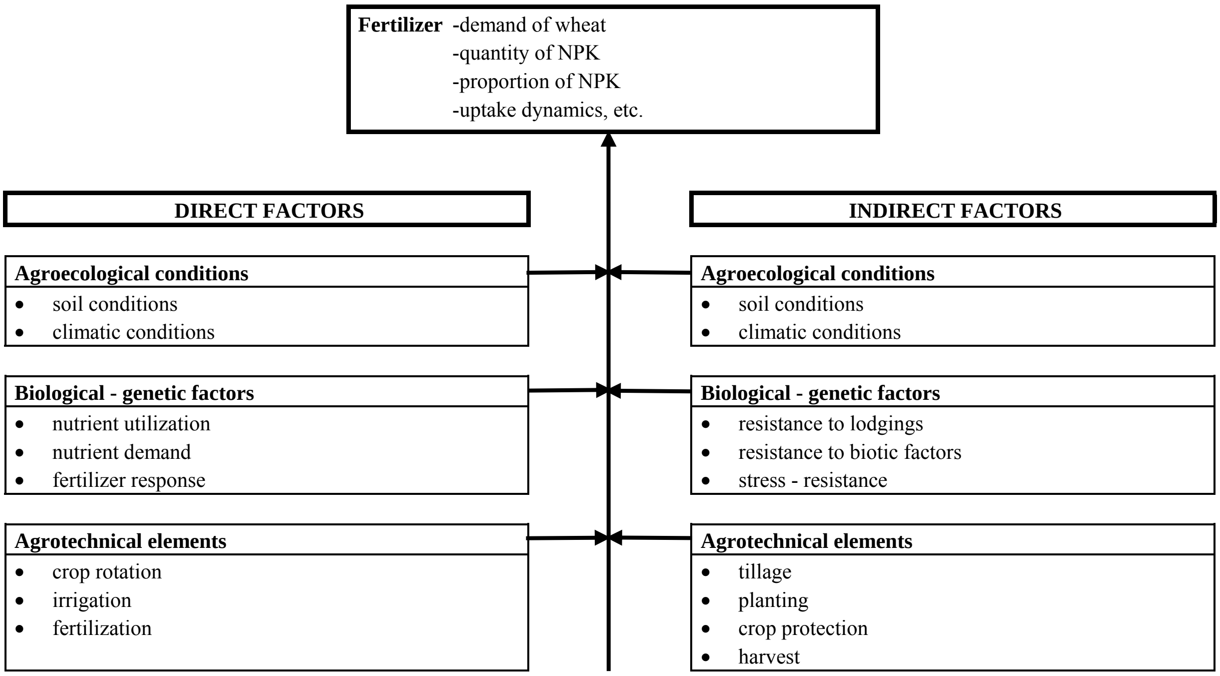


Figure 2: **Different modifying factors influencing the fertilizer demand of winter wheat**
(Péter Pepó, 1999)



MATERIALS AND METHODS

Long-term experiments on winter wheat were carried out in eastern Hungary under continental climatic conditions on chernozem soil. In the fertilizer treatments, there was a constant ratio of 1N:0,75 P_2O_5:0,88 K_2O. The basic total dosage was 158 kg/ha containing 60 kg/ha N and we used 1-2-3-4-5 fold amounts of the basic dosage with a non-fertilized control (1978-1996). From 1997, we have been using half of the dosage of the previous total dosage with the same N: P_2O_5:K_2O ratio (N=30 kg/ha; 22,5 kg/ha P_2O_5; 26,5 kg/ha K_2O). Since all treatments used the same NPK ratio, in the evaluation the dosages are referred to simply by the N-content. The trial was set up in strip arrangement with four replications. There were 6 random fertilizer treatments in each replication. Each year, we evaluated 15-15 different genotypes of winter wheat.

The most important parameters of chernozem soil: 2,9% humus content; 70-90 cm of humus layer; 6,2 pH (KCl); 150 mg/kg AL-P_2O_5; 260 mg/kg AL-K_2O.

RESULTS AND DISCUSSION

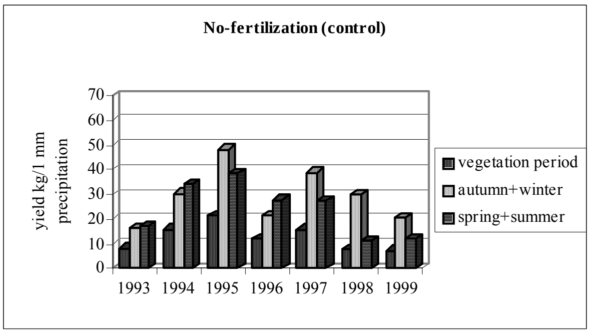
In Hungary, the agroecological conditions of winter wheat production are fairly different (soil conditions: from chernozem soil to meadow and sandy soils) and changeable (climatic conditions: basically continental modified by humid and mediterranean effects). Our long-term experiments proved that the eastern part of Hungary (Great Hungarian Plain) which could be characterized by typical continental climatic conditions, the weather factors of cropyears deeply modify the yield level of wheat, even on chernozem soil, which has excellent water and nutrient husbandry. The 12 year results for the GK Öthalom variety indicated that, in a favourable cropyear and with optimum fertilizer treatment, the yield level was 7,5-8,0 t/ha and, in an unfavourable cropyear (under continental climatic conditions this means mainly shortage of precipitation and its unfavourable distribution in vegetation period), with optimum fertilizer treatment, we obtained 4,9-5,0 t/ha yields. The fluctuation of yields comparing favourable and unfavourable cropyears were even greater in the non-fertilized, control treatment. Our long-term experimental data show that it is possible to reduce the effects of climatic conditions on the yields of winter wheat if we use appropriate fertilization (and other agrotechnical elements) under continental climatic circumstances. The yield fluctuation (*Table 1*) of wheat was 71% in control (non-fertilized) treatment and it was 48% in optimum fertilization (in control 2936-6139 kg/ha, in optimum fertilization 5072-8087 kg/ha, respectively). By using appropriate fertilization, we could increase the water utilization of wheat during the vegetation period (*Figure 3*). The parameters of water utilization for wheat (yield per 1 mm precipitation in whole vegetation period; in autumn + winter; in spring + summer) were greater with optimum fertilizer treatment (13-28; 27-69; 19-49 kg/1 mm precipitation, respectively) than for the control treatment (7-20; 15-47; 10-37 kg/1 mm precipitation, respectively).

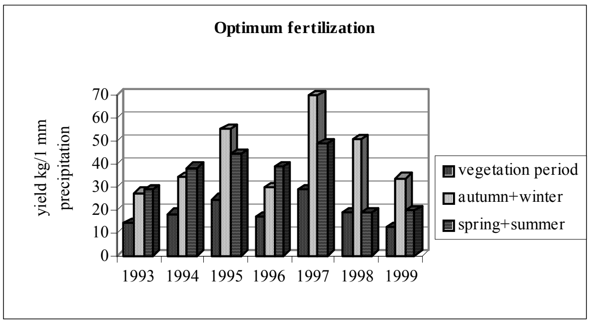
To build up sustainable, environmentally-friendly fertilization of wheat, we have to take not only climatic conditions into consideration, but the soil parameters (physical, chemical characters, pH, humus %, nutrient-, water-husbandry etc.), too. The role of soil conditions grows especially with unfavourable soil types and on environmentally sensitive sites.

Table 1: **Effect of fertilization on yield stability of winter wheat varieties**
(Debrecen, chernozem soil, 1989-1999, average of varieties)

Years	No fertilization		Optimum fertilization	
	Yield kg/ha	Rel. (%) to average	Yield kg/ha	Rel. (%) to average
1989	4736	107	7311	111
1990	5120	115	8087	123
1991	4593	103	7239	110
1992	2936	66	4981	75
1993	2952	67	5072	77
1994	6101	137	6845	104
1995	6139	138	7008	106
1996	3681	83	5104	77
1997	4503	101	8069	122
1998	4023	91	6301	95
1999	4042	91	6598	100
Average	**4439**	**100**	**6601**	**100**
Yield min.-max.	**2936-6139**	**66-137**	**4981-8087**	**75-123**
Fluctuation of yield, %		**71**		**48**

Figure 3: **Water utilization for wheat in different fertilization levels**
(Debrecen, 1993-1999)





In the environmentally sound and efficient fertilization of winter wheat, biological-genetic factors play a decisive role. Our twenty-year long experiments show the following parameters could characterise the nutrient and fertilizer response of different winter wheat genotypes:

- natural nutrient utilization (yield of control treatment)
- utilization of fertilizers (yield-surplus/1 kg NPK)
- utilization of genetic yield ability (maximum yield in optimum fertilizer treatment)

- fertilizer demand of genotype (N_{opt} + PK)
- curves of fertilizer response

In natural nutrient utilization of genotypes, we found 800-1200 kg/ha yield difference in the same cropyear. This parameter was weakly modified by the climatic conditions of the cropyear (*Table 2*).

Table 2: **Natural nutrient utilization of winter wheat varieties**
(yields kg/ha in control treatment)
(Debrecen, chernozem soil, continental climatic conditions)

Variety	1997	1998	1999	Average
GK Öthalom	4618	4520	4149	4429
GK Kalász	5135	4233	4167	4512
Fatima	4835	4020	4024	4293
Mv Vilma	4731	4617	4154	4501
Mv Matador	4527	4670	4206	4468
Mv Magdaléna	4365	3517	3767	3883
Average	**4702**	**4263**	**4078**	**4348**
Yield interval	**4,4-5,1**	**3,5-4,7**	**3,8-4,2**	**3,9-4,5**
Min.-Max. %	**93-109**	**83-110**	**92-103**	**89-104**
Fluctuation of yield, %	**16**	**27**	**11**	**18**

Our experimental data proved that there were huge differences in the fertilizer utilization of wheat genotypes (*Table 3*). If we used larger doses of fertilizers, we obtained less fertilization efficiency (in N_{30}+PK treatment 20,80 kg yieldsurplus/1 kg NPK, in N_{60}+PK treatment 9,49 kg yieldsurplus/1 kg NPK in average of varieties and 1997-1999 years).

The difference in fertilizer utilization varied 18-23 kg yield surplus/1 kg NPK and 6-13 kg yield surpluses/ 1 kg NPK, respectively. The effects of cropyear on the fertilizer utilization of genotypes were significant (in N_{30}+PK treatment 24,54, 19,97, 17,88 kg yield susplus/ 1 kg NPK; in N_{60}+PK treatment 14,33, 6,93, 7,22 kg yield susplus/ 1 kg NPK in 1997, 1998, 1999 years, respectively).

In fertilizer response parameters, the maximum yield and the optimum dose of fertilizers are very important characters (*Table 4*). Results from 1997-1999 proved that the difference between maximum yields among the wheat genotypes was 500-1100 kg/ha and maximum yields were also influenced by cropyear (7885-8404 kg/ha in 1997; 5936-7012 kg/ha in 1998; 6142-6598 kg/ha in 1999; respectively).

The optimum doses of fertilizer (N_{opt}+PK) varied between 60-120 kg/ha N+PK, depending on genotype and cropyear (in our long-term experiments, N played a decisive role when we applied appropriate P and K). Correlation between maximum yield and optimum dose of fertilizers we could estimate from two aspects: on the one hand, we obtained the same maximum yields with the application of different N_{opt}+PK doses (in 1997 the yields of GK Kalász and Mv Vilma were 8365 kg/ha and 8404 kg/ha, and N_{opt}+PK doses N_{60}+PK and N_{120}+PK, respectively etc.); on the other hand, we obtained different maximum yields with the application of the same N_{opt}+PK doses (in 1998 the yields of Fatima and Mv Matador were 6280 kg/ha and 7012 kg/ha, and N_{opt}+PK doses were N_{60}+PK and N_{60}+PK, respectively etc.).

Table 3: **Utilization of fertilizers on winter wheat varieties**
(surplusyield kg/1 kg NPK fertilizers)
(Debrecen, chernozem soil, continental climatic conditions)

Variety	**1997**		**1998**		**1999**		**Average**	
	0-30	**30-60**	**0-30**	**30-60**	**0-30**	**30-60**	**0-30**	**30-60**
GK Öthalom	30,33	4,49	19,78	10,43	20,16	4,52	23,42	6,48
GK Kalász	27,51	13,38	19,20	8,86	17,75	4,11	21,49	8,78
Fatima	22,78	17,52	21,27	7,34	16,48	7,03	20,18	10,63
Mv Vilma	22,15	13,14	13,46	3,75	17,91	4,84	17,84	7,24
Mv Matador	18,41	24,10	26,33	3,32	15,49	12,25	20,08	13,22
Mv Magdaléna	26,05	13,39	19,78	7,85	19,51	10,56	21,78	10,60
Average	**24,54**	**14,33**	**19,97**	**6,93**	**17,88**	**7,22**	**20,80**	**9,49**
Min.-Max. (kg/1kg NPK)	**18-30**	**4-24**	**13-26**	**3-10**	**15-20**	**4-12**	**18-23**	**6-13**

Table 4: **Maximum yield and optimum dose of fertilizers on winter wheat varieties**
(yield kg/ha and N_{opt} kg/ha fertilizer)
(Debrecen, chernozem soil, continental climatic conditions)

Variety	**1997**	**1998**	**1999**	**Average**
GK Öthalom	8154 $_{(90)}$	6907 $_{(60)}$	6572 $_{(90)}$	7211 $_{(80)}$
GK Kalász	8365 $_{(60)}$	6450 $_{(60)}$	6563 $_{(90)}$	7126 $_{(70)}$
Fatima	8019 $_{(60)}$	6280 $_{(60)}$	6299 $_{(60)}$	6866 $_{(70)}$
Mv Vilma	8404 $_{(120)}$	6380 $_{(90)}$	6598 $_{(120)}$	7127 $_{(110)}$
Mv Matador	7885 $_{(60)}$	7012 $_{(60)}$	6398 $_{(60)}$	7098 $_{(60)}$
Mv Magdaléna	7942 $_{(120)}$	5936 $_{(90)}$	6142 $_{(60)}$	6673 $_{(90)}$
Average	**8128**	**6494**	**6429**	**7017**
Yield-interval.	**7,9-8,4**	**5,9-7,0**	**6,1-6,6**	**6,7-7,2**
Max.-Min. %	**97-103**	**91-108**	**96-103**	**95-103**
Yield-fluctuation, %	**6**	**17**	**7**	**8**
N-interval. (kg/ha)	**60-120**	**60-90**	**60-120**	**60-110**

The fertilizer response types of winter wheat varieties could be defined by making algorithms of our long-term experimental data. According to our results, the genotypes of wheat could be classified into 4 groups, regarding nutrient utilization and fertilizer response (*Figure 4*):

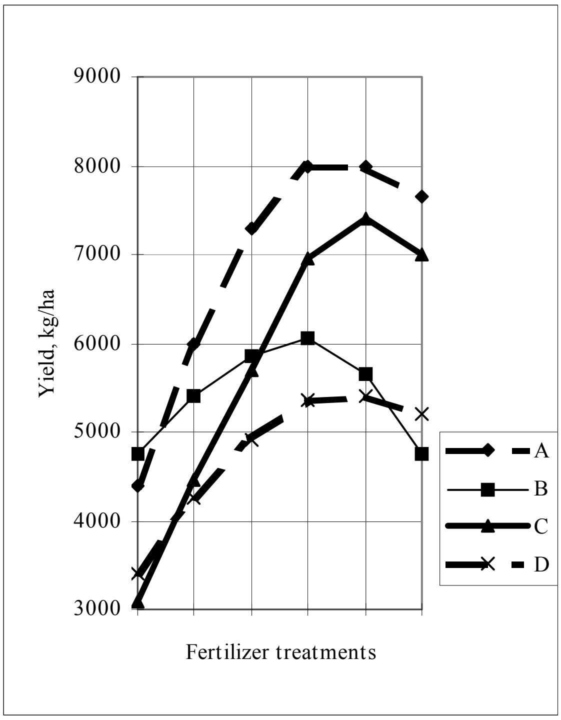
- type A - characterized by good natural nutrient utilization and excellent fertilizer response (modern genotype)
- type B - characterized by good natural nutrient utilization and weak fertilizer response (extensive genotype)
- type C - characterized by bad natural nutrient utilization and excellent fertilizer response (intensive genotype)
- type D - characterized by bad natural nutrient utilization and weak fertilizer response (out-of-date genotype)

On the basis of our classification, varieties in type A (GK Kalász, Mv Pálma, GK Véka, Mv Matador etc.) are favourable from the aspects of agronomic-economic efficiency and environmental protection. In sustainable wheat production, varieties of type B could be efficiently used, also.

In the environmentally-sound fertilization system for winter wheat, the direct and indirect effects of agrotechnical elements also have important roles, besides of the above-mentioned agroecological and biological factors. The agrotechnical elements could individually and interactively modify fertilization. Among the agrotechnical elements the croprotation has decisive effect on natural nutrient utilization, the optimum doses (mainly N) and efficiency of fertilization (*Table 5*). After an excellan forecrop (peas), we obtained 6397 kg/ha in non fertilized treatment (control), after average forecrop (sugar maize) the yield was 4024 kg/ha in control. The maximum yield of wheat was 7047 kg/ha (after peas, N_{50}+PK optimum doses) and 6302 kg/ha (after sugar maize, N_{90}+PK optimum doses), respectively.

The results of our long-term experiments proved that the doses of fertilizers (mainly N) over the demand of crops (winter wheat) could cause NO_3-N accumulation in 80-160 cm soil layers (*Figure 5*). This NO_3-N accumulation has been varied in quantity (increasement of NO_3-N) and in distribution in different soil layers (leaching into deeper soil layers).

Figure 4: **Types of fertilizer response in winter wheat varieties**



The appropriate fertilization (mainly N) of wheat could affect not only yield quantity but yield quality. By using optimum fertilizer doses, we could manifest genetically-coded baking quality traits of winter wheat varieties could reduce quality fluctuation caused by ecological and agrotechnical factors (*Table 6*). The efficiency of fertilization on baking quality parameters (wet-gluten, valorigraph index etc.) were variety-specific (changes depended on genotypes).

Our long-term experiments pointed out that the sustainable, environmentally-friendly fertilization of winter wheat could be realized by using fertilizer doses (NPK) and splitting (N) atteched to crop (wheat) nutrient-demand and nutrient uptake during vegetation period. In the agronomically and economically efficient fertilization of wheat, ecological, genetic and agrotechnical factors have very important modifying and interactive effects.

Table 5: **Effect of forecrops on fertilizer response of winter wheat varieties**

(Debrecen, 1998)

Parameters	**Forecrops**	
	sugar maize	**peas**
Control yield (kg/ha)	**4024**	**6397**
Control yield-interval of varieties (kg/ha)	3100-4670	5416-6859
Maximum yield, (kg/ha)	**6302**	**7047**
Max. yields of varieties (kg/ha)	5382-7012	6447-7965
Optimum N-fert.+PK (kg/ha)	90 N+PK	50 N+PK
Yield surplus of fertilization (kg/ha)	2278	650
Yield surplus of fert. of varieties (kg/ha)	1763-2633	356-1556

Figure 5: **NO_3-N content of chernozem soil**

(Debrecen, 1990, 1993, 1996)

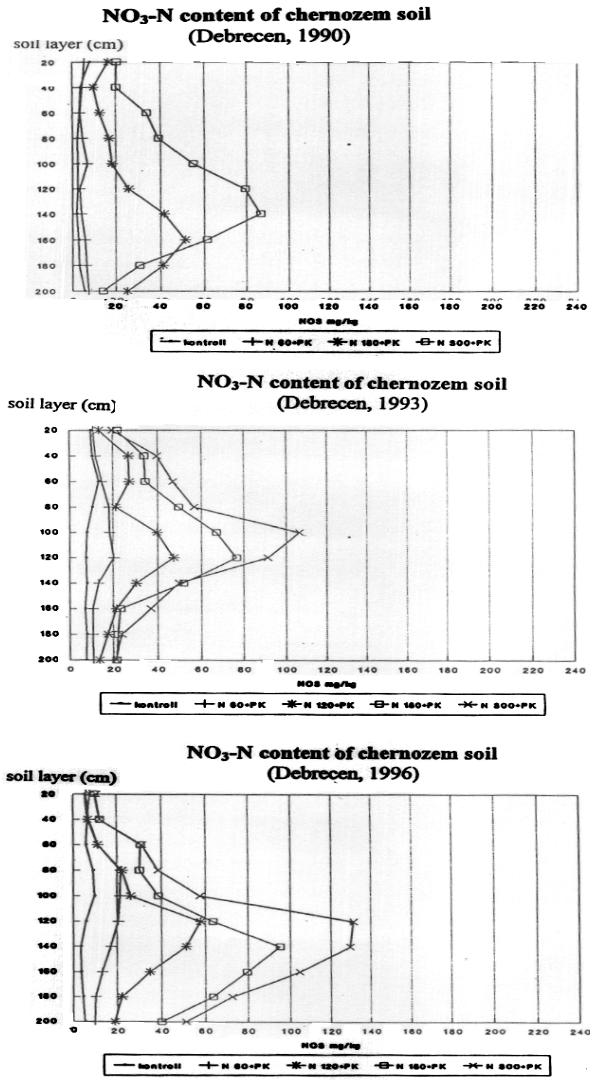


Table 6: **Effect of fertilization on quality stability and the variety-specific response on quality in winter wheat production**
(Debrecen, chernozem soil)

Variety	Wet gluten %				Average	Interval of fluctuation %	
	1994	1995	1996	1997		min.-max.	wide
GK Öthalom							
Ø	31,85	28,50	31,90	24,60	29,21	**84-109**	**25**
N_{120}+PK	36,65	33,25	36,20	30,75	34,21	**90-107**	**17**
Fatima							
Ø	29,10	30,00	30,40	26,80	29,08	**92-105**	**13**
N_{120}+PK	31,25	31,75	33,20	35,00	32,80	**95-107**	**12**

Variety	Valorigraph index				Average	Interval of fluctuation %	
	1994	1995	1996	1997		min.-max.	wide
GK Öthalom							
Ø	43,40	56,10	70,10	58,80	57,10	**76-123**	**47**
N_{120}+PK	53,70	67,40	73,80	69,50	66,10	**80-112**	**31**
Fatima							
Ø	45,80	50,80	61,60	58,20	54,10	**85-114**	**29**
N_{120}+PK	61,50	55,90	66,70	60,30	61,10	**91-109**	**18**

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