Some Factors Influencing the Fertilizer Requirement of Winter Wheat

I. KÁDÁR, J. SARKADI and B. THAMM

Research Institute for Soil Science and Agricultural Chemistry of the Hungarian Academy of Sciences, Budapest

Crop yield is the result of the interaction between ecological, genetic and technical factors. For research purposes, however, it is necessary to separate these factors and analyse them individually. Factors influencing the nutrient requirements of winter wheat, particularly soil factors, were studied using the data of field experiments conducted by the Institute as well as relevant data from the literature.

Characterization of the nutrient uptake of winter wheat

It is well known that the mineral element content in plants is generally the highest in the middle or at the end of tillering and gradually decreases up to the end of the vegetation period. When analysing a large number of experimental data it was found that the degree of dilution of the individual elements differed quite significantly /KÁDÁR and LÁSZTITY, 1981/. Taking the concentration of an element in the above-ground portion of the plant at tillering as 100%, the following dilution rates could be observed at harvest time: 83-85% for B and Mo, 50-60% for P and Zn, about 40% for Mg and Cu, 30% for N and Mn, 20-25% for Na and K, and 15-16% for Fe and Ca.

Consequently, parallel with the aging process, the ratios of the elements in the plant tissues also changed. In the present investigations the greatest decrease till harvest was found for K, followed by N, while the proportion of P increased significantly compared to most of the elements, often reaching a multiple of the original value.

In Table 1 an attempt is made to characterize the dynamics of nutrient uptake by using the results of field experiments set up at three different sites. It is evident from the data that parallel with a 5-7% dry matter accumulation, the increase in the quantity of certain elements was much more pronounced in the above-ground portion of the plants /e.g. 30% of the K, 15-20% of the N and Ca, 10-16% of the P, 7-10% of the Mg and 7-15% of the microelements present at harvest time accumulated by the end of tillering/. Nutrient uptake is more intensive in this period than the formation of dry matter: the plant stores up the main nutrients for the following phase of intensive growth. Severe symptoms of nutrient deficiencies are often visible at this stage. This state of relative rest in plant growth /when there is as yet no sign of the dilution effect/ is the most favourable for the purpose of diagnostic plant analysis: in some

Table 1

Nutrient uptake of winter wheat at different sites during the vegetation period /Nutrient content of above-ground parts of the plants as a % of the value at harvest/

Nutrients	At tillering			At flowering		In grain yield			In straw yield		
	A	B	C	A	B	A	B	C	A	B	C *
N	14	19	19	62	78	72	75	70	28	25	30
P	20	14	16	60	81	76	75	63	24	25	37
K	28	30	30	129	107	26	23	33	74	77	67
Ca	17	14	20	83	83	10	8	26	90	92	74
Mg	9	10	7	72	78	57	37	23	43	63	77
Fe	10	6	15	59	57	23	19	23	77	81	77
Mn	6	7	15	69	80	34	36	54	66	64	46
Zn	7	11	12	55	135	64	64	60	36	36	40
Cu	7	7	15	51	91	52	42	47	48	58	53
Dry matter yield	5	7	6	55	89	43	52	43	57	48	57

* A = Nagyhörcsök, calcareous chernozem loamy soil, averaged for 1974-1975, variety Kavkaz
B = Őrbottyán, loamy sandy soil, 1976. Variety Yubileinaya 50.
C = Szilvásvárad, acidic brown forest soil, loamy, 1976. Variety Kavkaz.

cases sampling is carried out during this period, and the limit values published in the literature are valid for this stage of growth.

At the time of flowering nutrient uptake /with the exception of K/ and dry matter accumulation are more or less balanced. In the generative stage, after flowering, the increase in dry matter in wheat plants is considerable /even 20-40% depending on the weather and the soil properties/, and the absolute rate of nutrient accumulation, especially in the case of N, P, and some of the microelements, approaches that of dry matter accumulation. From 2/3 to 3/4 of N and P, 1/2 of Zn and Cu, and in some cases 1/2 of Mg, too, is found in the grain yield, while the greater part of Ca, Fe and Mn accumulates in the straw yield /ELEK and KÁDÁR, 1978; KÁDÁR and LÁSZTITY, 1979/.

Nutrient units required for one ton of winter wheat

Table 2 shows the average number of nutrient units necessary for the production of 1 t grain together with its by-products at three different sites, as well as the minimum and maximum values published in the literature /KÁDÁR, 1979; SARKADI, 1975/.

From the data it can be seen that, for the production of 1 t grain and its by-products the plants need 25-42 kg N, 3-6 kg P /=7-14 kg P_2O_5/, 13-25 kg K /= 16-30 kg K_2O/, 4-8 kg Ca, 2-5 kg Mg, 150-160 g Fe, 50-130 g Mn, 26-68 g Zn and 13-16 g Cu.

When planning the fertilizer requirements of a certain winter wheat yield, these data may serve as guidelines. In the future, when the aim is to achieve a 10 t/ha grain yield, a 25-300 kg N, 40-50 kg P /=90-120 kg P_2O_5/, 150-200 kg K /=180-240 kg K_2O/, 50-60 kg Ca, 30-40 kg Mg, 2-4 kg

Table 2

Specific nutrient content necessary for producing one ton grain yield and the relevant by-products of winter wheat

Sites	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
	kg/ha					g/ha			
					Averages of experimental sites in Hungary				
Nagyhörcsök	30	5	13	5	3	234	126	32	14
Őrbottyán	31	4	16	7	3	478	117	40	14
Szilvásvárad	39	3	21	6	4	225	64	55	13
					Minimum and maximum values in the literature				
Minimum	21	3	13	4	2	150	55	26	13
Maximum	42	6	25	8	5	600	133	68	16

Fe, 600-800 g Mn, 400-600 g Zn and 130-150 g Cu, i.e. a total of about 600 kg nutrients are needed to cover the nutrient requirements of the planned yield.

Of course, the nutrient requirement of the plants is not the same as their fertilizer requirement. This latter depends on the soil properties, particularly on the nutrient content and nutrient supplying capacity of the soil. If the soil is well supplied with nutrients, there will be no need for supplementary fertilization in order to obtain maximum biological production. If fertilization rates nevertheless equal the nutrient requirements of the planned yield, the aim may be the maintenance or improvement of the nutrient status of the soil.

The fertilizer requirement also depends on the interactions existing between the soil and the plants. On a given soil one plant species may need supplementary fertilization where another does not. Since the activity of the plant roots is different, their ability to utilize the nutrient reserves of the soil is different too. For this reason the required quantity of certain fertilizer elements may be very high in a monoculture.

Fertilizer requirement and fertilizer response of winter wheat

Table 3 shows the results of field experiments carried out at the Research Institute for Soil Science and Agricultural Chemistry. The experiments were set up at three sites in order to study the effect of PK fertilization. Normal doses and "build-up" or ameliorative rates of PK fertilization were applied /i.e. 500 and 1000 kg of nutrients per ha/ together with a uniform N fertilization rate of 200 kg/ha. The experimental sites differed with respect to the nutrient status of the soils: the soil at Szilvásvárad had a very low P content, that at Nagyhörcsök was poor in P, while the soil at Őrbottyán had a medium P supply. At the experimental stations winter wheat does not respond to K fertilization, as the moderate K requirement of winter wheat can be covered by the K reserves of the soils without using K fertilization. Therefore, the fertilizer effects and yield increase can be attributed to the better P supply in the soil /KÁDÁR and LÁSZTITY, 1979/.

The aim of ameliorative fertilization, similarly to that of high rates of liming, is to increase the soil nutrient status for a longer period,

Table 3

The efficacy of fertilization on the grain yield of winter wheat and on changes in the AL-P values of the soils as a function of the P supply of the sites

Fertilization		Nagyhörcsök, 1975			Őrbottyán, 1977			Szilvásvárad, 1976		
P_2O_5	K_2O	Grain yield		$AL-P_2O_5$	Grain yield		$AL-P_2O_5$	Grain yield		$AL-P_2O_5$
kg/ha		t/ha	%	ppm	t/ha	%	ppm	t/ha	%	ppm
-	-	3.54	100	62	3.41	100	100	1.61	100	30
50	100	4.68	136	70	4.35	128	96	2.90	181	38
100	200	5.16	146	90	4.13	121	119	3.12	195	33
500	500	5.40	153	190	4.18	123	160	3.78	236	96
1000	1000	5.46	154	361	4.32	127	203	4.52	283	171
$LSD_{5\%}$		0.30		49	0.30		44	0.56		23

at the same time ensuring a higher level of productivity. Consequently, the costs of ameliorative fertilization must be calculated for a number of years, because considerable residual effects can be expected on all types of soil. If it is accepted that a 3-4 kg increase in the grain yield of winter wheat is required to repay the application of 1 kg P_2O_5, then the highest rate of P fertilization, i.e. 1000 kg P_2O_5/ha, will be recovered at Szilvásvárad in the first two years, at Nagyhörcsök in 3-4 years and at Őrbottyán in 5-6 years after application. If high yields cannot be reached because of the deficiency in a single nutrient /e.g. the soil is poor or very poor in P/, the productivity of the soil can be improved in a short time, even in the course of one year, by ameliorative fertilization with large fertilizer doses /Table 4/.

In Table 4 the fertilizer requirement of winter wheat is represented by the results of the last two years of a long-term experiment. This long-term factorial experiment was carried out on a calcareous chernozem soil involving wheat and maize in a two year rotation for 14 years. In spite of the approx. 3% humus content of the soil, when no N fertilizer was used the yield level of wheat was about 2 t/ha and the very high N requirement of wheat could only be covered by annual doses of 120-160 kg N/ha. To reach a P level sufficient for the wheat plants, 100-120 kg P_2O_5/ha had to be given annually /i.e. the $AL-P_2O_5$ value of this soil had to be 150-200 ppm/. The easily soluble P and K contents of the soil were determined by the procedure of EGNER-RIEHM and DOMINGO, modified by SARKADI, KRÁMER and THAMM. At the same time the K fertilizer response of wheat is more moderate; although it takes up a significant quantity of K from the soil, it can utilize the less soluble K fractions, too, so its K fertilizer requirement is equal to 70-80 kg K_2O/ha/year.

Fertilizer requirement of winter wheat in a monoculture - Table 5 shows the grain yield of winter wheat as a function of the P supply of the soil in an 8-year monoculture. At the beginning of the experiment, in autumn 1972, the poor P supply of the soil was improved by 360 kg P_2O_5/ha and 720 kg P_2O_5/ha fertilizer doses. Later only NK fertilization was carried out. In the first year the variety Kiszombori lodged on plots well

Table 4

Efficacy of fertilization on the yield of winter wheat in a wheat-maize crop rotation /2 years each/
/Nagyhörcsök, calcareous chernozem soil, variety Kavkaz/

	1	2	3	4	5	6	7	$LSD_{5\%}$
				Experiment with N /on the basis of PK/				
N kg/ha/year								
1964-1973	64	114	114	117	114	117	117	
1974-1977	-	-	40	80	120	160	320	
Grain yield								
1976	2.74	3.33	3.66	5.68	6.28	5.26	5.26	0.81
1977	1.84	2.57	4.08	3.80	5.61	5.08	4.94	0.63
Mean	2.29	2.95	3.87	4.74	5.94	5.17	5.10	
				Experiment with P /on the basis of NK/				
P_2O_5 kg/ha/14 years	-	270	540	810	1050	1290	1530	
AL-P_2O_5 ppm, 1977	46	48	57	74	108	124	161	24
Grain yield								
1976	3.07	3.26	3.65	4.86	5.38	6.01	6.16	1.27
1977	2.74	3.72	4.74	5.36	5.94	5.41	6.00	1.07
Mean	2.90	3.49	4.20	5.11	5.66	5.71	6.08	
				Experiment with K /on the basis of NP/				
K_2O kg/ha/14 years	-	360	720	1080	1320	1560	1800	
AL-K_2O ppm, 1977	138	161	160	168	176	206	227	33
Grain yield								
1976	5.19	5.56	5.57	6.28	5.77	6.03	6.46	0.63
1977	4.56	5.43	5.56	5.57	5.23	5.52	5.23	0.50
Mean	4.88	5.50	5.56	5.92	5.50	5.78	5.84	

supplied with P, and the mildew-infected stems were unable to support the bigger, heavier ears. Thus, at harvest time a decrease in grain yield was registered on plots fertilized with P. In the following years of the experiment, when other wheat varieties were sown, no lodging was experienced. In a monoculture the following trends could be observed:

1. The grain yield may decrease rapidly on soils poor in P, in some years dropping to as little as half or one third of the yield level on well supplied soils. The fluctuation in the yield level increases, the quotient of the maximum to minimum yield may be as much as quadrupled.

2. The yield level exceeded the national and county averages, but it showed a tendency to decrease year by year, while the county and national averages increased. The quotient of the maximum-minimum yield /6.37 t/ha and 2.64 t/ha/ decreased to a value of 2-2.5-fold, though it did not reach the national and county averages, which were 1.5-1.6 in the years tested.

Table 5

Grain yield /t/ha/ of winter wheat as a function of the P supply of the soil in an 8-year monoculture /1973-1980/

Years	Variety	P-fertilization in autumn 1972					County $\bar{x}$	National $\bar{x}$	Difference from county $\bar{x}$		Precipitation, mm	
		0	360	720	720-0	$LSD_{5\%}$			0	720	Σ /Sept.-July/	Difference from 50 year average
		kg P_2O_5/ha										
1973	Kiszombori	3.87	3.96	3.55	-0.32	0.22	3.71	3.48	+0.16	-0.16	470	- 65
1974	Kavkaz	5.83	6.72	6.37	+0.54	0.26	4.52	3.75	+1.31	+1.85	673	+138
1975	Kavkaz	1.39	4.47	4.64	+3.25	0.45	4.00	3.20	-2.61	+0.64	763	+228
1976	Kavkaz	2.08	4.37	4.88	+2.80	0.34	4.37	3.88	-2.29	+0.51	442	- 93
1977	Mv 4	2.90	4.33	4.48	+1.58	0.50	4.66	4.05	-1.76	+0.18	533	- 2
1978	Mv 5	3.74	5.63	5.53	+1.79	0.42	4.86	4.28	-1.12	+0.67	563	+ 28
1979	Rana 1	1.53	2.11	2.64	+1.11	0.23	3.49	3.26	-1.96	-0.85	393	-142
1980	Mv 4	4.78	5.70	6.36	+1.58	0.32	5.82	4.76	-1.04	+0.54	455	- 80
Average		3.26	4.66	4.81	+1.54	0.30	4.42	3.83	-1.16	+0.42	536	+ 2
1973	AL-P_2O_5 ppm	80	194	284	+204	30						
1975	AL-P_2O_5 ppm	93	120	180	+ 87	12						
1977	AL-P_2O_5 ppm	80	100	136	+ 56	12						

3. In the case of wheat the yield level does not depend on the amount of precipitation alone; the years favourable for wheat production are not those with maximum precipitation.

While the decrease in maize yield in a monoculture is mainly significant in dry years /GYŐRFFY, 1976, and confirmed by the authors as well/, the monocultural yield depression in the case of wheat can be explained by pathogenic factors induced by the weather. In a monoculture the wheat stand became thinner, weeds were a problem in some places and in years rich in precipitation foot diseases developed in many cases.

In summary it can be said that crop rotation may be an effective way of increasing plant production, and that the application of crop rotation is justified in order to maintain a sound nutrient balance in the soil. In a monoculture the fertilizer requirement of wheat may increase, while the yield level and stability show an unfavourable trend. The extreme reduction in yield can only partly be counterbalanced by using large quantities of expensive N and P fertilizers.

Nutrient supply of wheat in Hungary - future tasks

According to the recent results of soil tests conducted by the Plant Protection and Agrochemistry Centre of the Ministry of Agriculture and Foo the area of soils poor in macro-nutrients /NPK/ is decreasing year by year. At present about 2/3 of the arable land in Hungary can be qualified as well or medium well supplied with these nutrients. National nutrient balances lead to the conclusion that nowadays fertilization replaces the total quantity of N and K taken up by the crops, or even 20-30% more, and about twice the amount of P taken up by the plants /SARKADI, 1979; KÁDÁR, 1979; DEBRECZENI, 1977/.

When analysing the farming methods and nutrient management of a progressive large-scale farm in the Mezőföld region it was found that over a five year period /1974-1978/ about 200-300 kg of N, 400-500 kg of P_2O_5 and 500-600 kg of K_2O remained in the soil as a result of over-fertilization, considerably exceeding the quantity of nutrients taken up by the yield /KÁDÁR, LÁSZTITY and SIMON, 1981/. Considering that a large part of the fields in this farm were well or medium well supplied with P and K, further PK fertilization is certainly unjustified and possibly dangerous. Therefore, under such conditions, it is recommended that PK fertilization be reduced to half and that a study of the efficacy of Zn and Cu fertilization be initiated on the basis of plant analysis data.

The mineral nutrient content of plants, and their ratios and optimum values are characteristic of the plant species and more or less independent of the plant production conditions. So they are suitable for international comparison. In 1975, under the leadership of SILLANPÄÄ /1982/, the FAO started a worldwide research programme on microelements with the participation of 30 countries, including Hungary. 144 wheat and 106 maize samples were supplied, with 250 corresponding soil samples. The contents of 9 elements in wheat samples grown in Hungary are shown in Table 6 together with the international averages.

Tests carried out within the framework of FAO using the same soil and plant testing methods have the advantage that they enable international comparisons to be made, provided the sampling sites are representative. A brief survey will now be given of the contents of this study, including some conclusions on the nutrient supply of wheat produced in Hungary.

1. The N content of the wheat samples was the highest in Hungary; this can be explained by the large N fertilizer doses and the high N content of the wheat-producing soils.

Table 6

Nutrient element content at tillering for wheat plants grown in Hungary in 1975 /A/ /n = 144/ and international averages /B/ /n = 1768/*

Nutrient element content	N	P	K	Ca	Mg	Mn	Zn	Cu	Mo
	%					ppm			
A.									
Mean	5.46	0.49	4.15	0.53	0.18	76	26	8.5	0.29
± s	0.78	0.13	0.86	0.11	0.05	31	7	1.8	0.25
Minimum	2.72	0.26	1.50	0.30	0.10	27	14	5.1	0.03
Maximum	7.45	0.83	6.55	0.77	0.40	176	48	13.6	1.87
B.									
Mean	4.27	0.38	4.03	0.43	0.17	74	27	9.4	0.94
± s	1.15	0.12	0.97	0.17	0.06	40	11	5.7	1.03
Minimum	0.60	0.05	0.94	0.11	0.04	9	3	1.5	0.01
Maximum	7.45	1.02	6.84	1.68	0.95	423	128	100.6	11.04
Optimal	4-5	0.4-0.5	3.5-4.5	0.5-1.0	0.2-0.4	30-60	30-40	5-10	0.7-1.5

* International averages taken from an FAO analysis /FAO Soils Bulletin No. 48. Rome, 1982/

2. With respect to the P content of the plants at the time of tillering, Hungary was among the first three countries. This fact can be explained by the high $NaHCO_3$-soluble P content in Hungarian soils and by the level of P fertilization. There was considerable heterogeneity in the P contents of soils and plants even on an international scale.

3. The available K content of the soils was below average, while the percentage K value of the plants was above average. This can be attributed partly to the large-scale, heterogeneous use of K.

4. The Ca content was high, both in soils and plants. Only wheat samples sent from Turkey had higher Ca contents than those from Hungary.

5. The supply of Mg, B, Cu, Fe, Mn and Mo seemed to be satisfactory in general. There was a good agreement between the Mn content of the plants and the pH conditions of the soil. On acid soils both soil tests /EDTA and DTPA/ and plant tests indicated a higher Mn content.

6. According to soil and plant tests the Zn supply of winter wheat was relatively low. For plants requiring Zn, Zn fertilization is often effective. In recent years similar conclusions have been reached when evaluating the data of tests carried out at the Budapest Institute /ELEK and KÁDÁR, 1978/.

Conclusions

1. When determining the N requirement of wheat no real reliance can be placed either on the results of soil tests or on those of plant analyses. Consequently, to be on the safe side, Hungarian wheats are over-fertilized with N. This is obvious from farm practice, where the N fertilizer doses applied to wheat and maize are almost the same, though the wheat crop needs approximately 2/3 of the quantity required by maize crop.

2. On Hungarian soils classified as well supplied with P, the quantity of P supplied should be approximately the same as that taken up by the plants. Progressive farms continue to over-fertilize with P, though this often seems to be unjustified.

3. Wheat is well known to require very little K. On soils fairly well supplied with K there is no justification for fertilization with this nutrient. It would be better to save K for the fertilization of crops requiring potassium in larger quantities. At the same time it would be useful to revise the practice of regular fertilization with high K rates.

4. Unfortunately, only a few experiments have been made on microelement fertilization, and these are not sufficiently reliable. Further research will be needed before recommendations can be made on microelement fertilization in wheat. The results gained so far indicate that the fertilization of crops with microelements is unlikely to produce spectacular results except in extreme cases.

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