MINERAL NUTRITION OF MAIZE, PRODUCED FOR BIO ETHANOL. THE HUNGARIAN CASE-STUDY

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ABSTRACT

Following grinding and heat treatment, maize kernels become fit for bio ethanol production. The higher the maize kernel carbohydrate content, the more economic the bio ethanol production will be. This is why maize hybrids were bred recently especially for these purposes.

A database was compiled from the results of Hungarian long-term N, and K fertilization field trials published between 1960 and 2000. On the basis of the database correlations were described between the soil organic matter (SOM) content of (N control) plots and the responses of maize to N application, as well as between the soil K test (ammonium lactate, AL) values of (K control) plots and the responses maize to K application, using the Bray–Mitscherlich equation approach. The nutrient responses were expressed as both relative yields and surplusses.

The database also made it possible to investigate how the responses of maize to N, and K fertilization were affected by the available nutrient contents, the soil texture, the soil type and the nutrient supply category of the control plots.

Based on the correlations established in the database, new, more accurate soil N, and K supply categories were elaborated for maize, providing opportunities for cost saving and environmentally sound fertilizaton of this very important Hungarian crop. Based on the findings of the database, it became evident, that maize is a N and K demanding, and a less P demanding crop.

Crop nutrition technology must be also adopted to the maize hybrids for bio ethanol production: The cost-saving, environmentally friendly fertiliser recommendation system, elaborated for the Hungarian soil and climatic conditions, makes difference between maize, produced for fodder, or sown for bio ethanol production. For the latter N demand is decreased by 20%, while, potassium demand is increased by the same 20%, providing optimal conditions for the higher carbohydrate synthesis rate.

Special attention must be paid for the potassium fertilisation of maize for bio fuel production in Hungary, due to the negative K balances and decaying soil K status of the country in the last, almost 20 years.

INTRODUCTION

It became evident already at the dawn of motorisation, that bio ethanol is excellent for Otto engine fuel. However, due to the cheap fossil petrol production, its percentage was minimal in the world fuel production.

The use of bio ethanol as fuel for Otto engines draws more attention again because of A) the Kyoto Agreement requirements, B) the increased energy-dependence, and C) the overproduction of agricultural crops.

In 2007, world bio ethanol production was 49,5 billion litres (about 2% of the total petrol production). The major producers were the US (24,5 billion litres), Brazil (19,7 billion litres), the EU27 (1,85 billion litres), China (1,6 billion litres) and Canada (0,6 billion litres).
Following grinding and heat treatment, maize kernels become fit for bio ethanol production. The higher the maize kernel carbohydrate content, the more economic the bio ethanol production will be. This is why maize hybrids were bred recently especially for these purposes.
Over the last 50 years marked changes have taken place in the plant nutrition practices of Hungarian farmers, cooperatives and state farms: the increasing application of NPK fertilizers in the 70's and 80's resulted in positive NPK balances and the enrichment of available NPK inf soils. Since the beginning of the 90's, however, NPK use has dropped to one-third or one-fifth of that in the previous period, and NPK balances have become strongly negative – similarly to the period between 1900 and 1960 (Csathó and Radimszky, 2005). In order to estimate the NPK demands of Hungarian crop production, it is essential to synthesize the results of NPK fertilizer field trials, and to elaborate a new, environmentally friendly fertilizer recommendation system based on the correlations found in the data sets of these trials. In this paper the summary of the evaluation of the database of the Hungarian N, and K fertilization field trials with maize, as well as the new soil N, and K supply categories derived from the correlations found in the databases are discussed.
Crop nutrition technology must be also adopted to the maize hybrids for bio ethanol production: The cost-saving, environmentally friendly fertiliser recommendation system, elaborated for the Hungarian soil and climatic conditions, must make difference between maize, produced for fodder, or sown for bio ethanol production.

MATERIAL AND METHODS

Using a database compiled from the results of Hungarian N and K fertilization field trials with maize, one of the main crops in Hungary, occupying about 20% of the arable land, the correlation was described between the soil test values of the N and K control plots and the crop responses to N and K – expressed either in relative yields or in yield surpluses – using the Bray-Mitscherlich approach (Bray, 1944).
The relationship between the SOM% (Tyurin, 1937) of the soil in the N control (PK) plots and the responses to N fertilization, expressed in terms of relative yield (100 PK/NPK, %), was described using the Mitscherlich function as modified by Bray (1944) ($Y' = 100(1-10^{-cx})$), where Y' = response to N fertilization, expressed as the relative yield (100PK/NPK, %) achieved in soil with x % of SOM, while c is a constant value, known as the Mitscherlich working factor. On the other hand, a hyperbolic function ($Y' = 1/(ax+b)$) was found to give the best description of the correlation between SOM% and responses to N expressed in terms of yield surpluses (NPK-PK, t/ha).
A similar approach was applied when the database of Hungarian field experiments was evaluated for responses to K fertilization. The experiments were representative of the various soil and climatic conditions in Hungary. The P fertilization trials of maize, being a less P demanding crop, is not evaluated in this paper (Csathó, 2003a).
Changes in the N and K balances of Hungarian agriculture also is evaluated in the paper, using the OECD methodolgy.

RESULTS AND DISCUSSION

Evaluation of the database of Hungarian long-term field fertilization experiments with maize, 1960–2000

1. N Response Field Trials

It is a well-known fact that any soil test method is efficient only to the extent to which it has been calibrated in field trials. A soil test method is considered reliable if it is well reproducible and properly estimates the supply of a given nutrient in the case of various soil properties.

According to Bray (1944) the relationship between soil test and relative yield can be characterized with the Mitscherlich curve. Like Mitscherlich, Bray states that the value of the c (working) factor cannot be generalized, but differs in plants with varying fertilizer responses. When the relationships determined from the database of Hungarian N fertilization field trials on winter wheat, maize and alfalfa were compared, the Mitscherlich c factor, as modified by Bray and based on the equation $Y' = 100(1-10^{-cx})$, was found to be similar for winter wheat (0.2913) and maize (0.3195), while it differed greatly in the case of alfalfa (which has a moderate N demand) (0.8191), indicating the differences in the N fertilizer responses of the two plant groups. The higher the "c" value is, the less demanding the crop is for the given nutrient (Figure 1) (Csathó, 2003b).

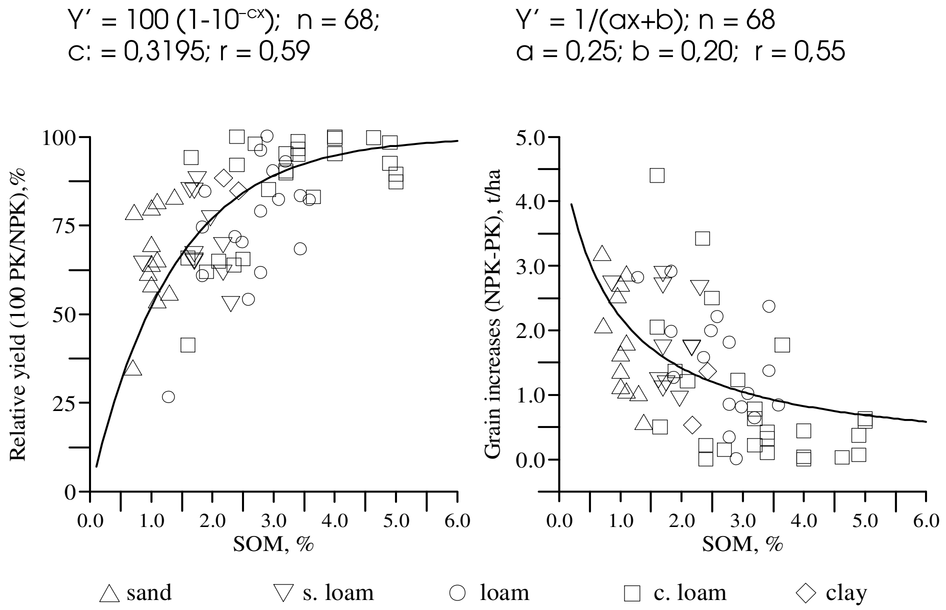

Figure 1. Relationship between soil organic matter (SOM) contents (%) of N control (PK) plots and responses of maize to N fertilization, calculated from the database of Hungarian field trials on N fertilization, 1960–2000, using the Bray-Mitscherlich approach (Csathó, 2003b)

On the basis of the above relationships, new N supply limit values were determined as a function of SOM% for maize (Table 1) (Csathó, 2003b).

Table 1. New N supply categories for N-demanding maize, established on the basis of the relationships calculated from the database of Hungarian N fertilization field experiments in the period 1960–2000, according to SOM%, as a function of soil texture (Csathó, 2003b)

Soil	N supply categories (SOM%)				
texture	Very poor	Poor	Moderate	Good	Very good
Sand	≤ 0.60	0.61 - 1.20	≥ 1.21	-	-
Sandy loam	≤ 1.40	1.41 - 2.00	2.01 - 2.60	≥ 2.61	-
Loam	≤ 1.80	1.81 - 2.40	2.41 - 3.20	3.21 - 3.80	≥ 3.81
Clay loam	≤ 2.00	2.01 - 2.60	2.61 - 3.40	3.41 - 4.00	≥ 4.01
Clay	≤ 2.20	2.21 - 2.80	2.81 - 3.60	3.61 - 4.20	≥ 4.21

Limit values were established up to the good supply category for sandy soils, and up to the very good supply category for soils with sandy loam, loam, clay loam and clay texture. The above limit values were included in a new, cost-saving and environment-friendly fertilizer recommendation system (Csathó, Árendás and Németh, 1998). When setting the limit values, the texture and SOM% of the soil and the magnitude of responses to N application were taken into consideration, using the relationships determined from the database. Interpolation was carried out if the supply category could not be determined from the database. Soil N (SOM%), and K (AL-K) supplies had a great influence on the N and K responses in maize and on the optimum N and K rates (Tables 2 and 4) (Csathó, 2003b and 2005).

A synthesis of the results of Hungarian long-term N fertilization field experiments revealed that over the past 15-20 years the average 50–70 kg/ha rate of N fertilizer application has not ensured the N level required for the maximum economical yield of crop groups with high N requirements, due to the declining N supplying capacity of Hungarian soils and the very modest farmyard manure application rates resulting from the low livestock density.

Table 2. Average responses to N fertilization in the database of Hungarian N fertilization field trials on maize grouped according to the soil organic matter (SOM) content of the soils, 1960–2000 (Csathó, 2003b)

SOM content, %	Number of trials, n	K_A	SOM %	N-supply* t/ha	Applied N, kg/ha**	Grain, t/ha in N control (PK)	Relative yield, % (PK/NPK)	Yield surplus (NPK-PK)
≤ 1.0	8	28	0.90	1.9	181	4.16	64	2.18
1.01-2.00	20	37	1.59	1.9	134	4.49	69	1.82
2.01-3.00	20	43	2.52	2.6	90	4.66	78	1.29
3.01-4.00	16	43	3.48	3.6	70	6.62	88	0.87
≥ 4.01	5	44	4.89	6.0	48	5.44	94	0.32
Mean	69	39	2.46	2.8	106	5.06	77	1.38

Remarks: *Supply categories: 1: very poor; 2: poor; 3: moderate; 4: good; 5: very good; 6: excessive; ** N required for maximum economical yield (~ 95% of maximum yield)

2. K Response Field Trials

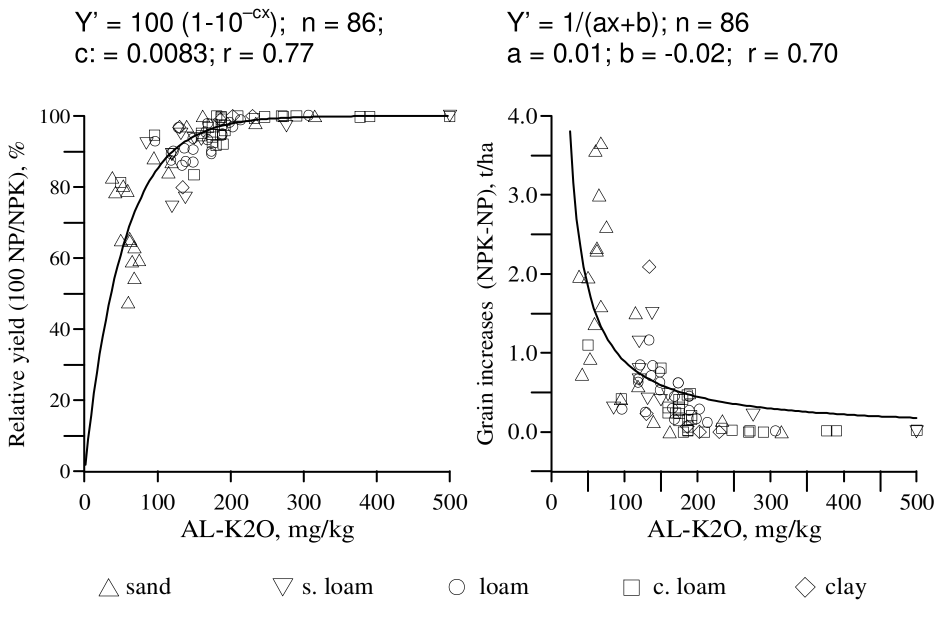

Figure 2. Relationship between the AL-K_2O contents of K control (NP) plots and responses of maize to K fertilization, calculated from the database of Hungarian field trials on K fertilization, 1960–2000, using the Bray-Mitscherlich approach (Csathó, 2005)

Comparing the relationships between AL-K contents (Egner, Riehm and Domingo, 1960) of NP (K control) plots and responses to K fertilization expressed as relative yields (NP/NPK, %), using the database of Hungarian K fertilization field trials on winter wheat and maize, it was shown that the the Mitscherlich "c" factor, as modified by Bray and based on the equation $Y' = 100(1-10^{-cx})$, was 0.0083 for maize (which has a high K demand), while its value was twice as high (0.0153) for winter wheat (which has a moderate K demand). The higher the „c" value is, the less demanding the crop is for the given nutrient. The data indicates the differenes between the two crops in their responses to K fertilization (Figure 2) (Csathó, 2005).

In the Hungarian K fertilization trials on winter wheat and maize published between 1960 and 2000 and included in the evaluation, the by-products were always removed from the plots, so information on field experiments involving straw and stalk fertilization treatments will be required if the results are to be interpreted correctly. It should be noted that no organic manure was applied to any of the winter wheat and maize experiments found in the literature from the period 1960–2000. However, it would be very important to know the extent to which mineral fertilizers can be substituted by farmyard manure (Sarkadi, 1993 and 1996; Árendás and Csathó, 1994 and 2002).

The new AL-K_2O supply limit values set up for crops with a high K demand are much lower than the values given in the previous intensive fertilizer recommendation system (MÉM NAK, 1979), especially in the case of soils with clay loam or clay texture (Table 3).

Table 3. New K supply categories for K-demanding maize, established on the basis of the relationships calculated from the database of Hungarian K fertilization field experiments in the period 1960–2000, according to AL-K_2O contents, as a function of soil texture (Csathó, 2005)

Soil	K supply categories (mg/kg AL-K_2O					
texture	Very poor	Poor	Moderate	Good	Very good	Excessive
Sand	≤ 60	61-90	91-120	121-160	161-200	≥201
Sandy loam	≤100	101-140	141-170	171-220	221-270	≥271
Loam	≤120	121-150	151-180	181-230	231-290	≥291
Clay loam	≤130	131-160	161-190	191-250	251-310	≥311
Clay	≤140	141-170	171-200	201-260	261-320	≥321

The limit values were based on the relationships calculated from the database, the soil texture and the level of K responses. When the supply category could not be determined from the database, interpolation was conducted.

The new AL-K_2O supply limit values are lower for crops with lower K demands than for K demanding crops (Csathó, 2005) (Table 3). A K supply that is moderate for crops with a high K demand (potato, sugar-beet, maize, etc.) may be good for crops with a low K demand (cerals, sunflower, etc.). This should be the basis for K fertilization in crop rotations: in soils with a moderate K supply, K fertilizers should be applied to crops with a high K demand, while the residual effect of K fertilization will provide sufficient K for crops with a low K demand (periodic K fertilization).

The high K demand of maize is designated by the fact that, in the case of similar average AL-K contents, maize required twice as much K_2O to achieve maximum economical yields as winter wheat (Table 4) (Csathó, 2005).

Table 4. Average responses to K fertilization in the database of Hungarian K fertilization field trials on maize grouped according to the AL-K content of the soils, 1960–2000 (Csathó, 2005)

AL-K_2O, mg/kg	Number of trials, n	K_A	SOM %	AL-K_2O, mg/kg (NP)	K supply *	Applied K_2O, kg/ha**	Grain, t/ha on K control (NP)	Relative yield, % (NP/NPK)	Yield surplus, t/ha (NPK-NP)
≤ 40	-	-	-	-	-	-	-	-	-
41-80	10	30	1.19	62	1.6	129	4.08	64	2.35
81-120	11	35	1.78	110	1.8	97	4.97	88	0.67
121-160	16	39	2.64	144	2.2	63	6.02	92	0.53
161-200	24	43	2.67	181	3.2	40	5.93	97	0.21
≥ 201	12	48	2.93	237	4.3	0	8.08	100	0.00
Mean (Total)	73	40	2.37	155	2.7	59	5.90	90	0.61

The average yield surpluses obtained as the result of K fertilization were five times higher in maize than in winter wheat. Relative yields – showing the percentage yield reached without K fertilization – also indicate the differences in K fertilizer responses between maize and winter wheat. The same soil may provide a more adequate K supply, resulting in lower K responses for winter wheat, which is less K-demanding than for maize and alfalfa, which have high K demands (Csathó, 2005)

The results of present the evaluation suggest that the K fertilization of fine-textured soils in Eastern Hungary in the 70's and 80's was a false step, since the AL-K_2O content of these soils reached 300–500 mg/kg by the mid-80s.

The K enrichment of coarse or moderately coarse textured soils to achieve a good K supply level is justified, and is one of the prerequisites of high average yields (SLAN = sufficient level of available nutrients). This is the practice at present in the developed, densely populated West European countries and in the maize belt of the U.S. It should be noted, however, that the highest economical yields can probably be reached with less intensive K fertilization.

A synthesis of the results of Hungarian long-term K fertilization field experiments revealed that the K required for the maximum economical yield of crops with a high K demand – as in the case of nitrogen and phosphorus – has not been ensured by the average annual 5–10 kg/ha K_2O fertilizer applied over the past 15–20 years. Mention should be made of the fact that the natural K-supplying capacity of Hungarian clay loam and clay soils is rated as good or very good even without K fertilization.

N and K balance of Hungarian agriculture, 1901 to 2000

The livestock density per unit agricultural land in Hungary is only one-eighth to one-tenth of that in Western European countries. The farmyard manure produced annually by Hungarian livestock only provides 5–10% of the NPK nutrient requirements of crops. This is underlined by the fact that a significant increase in the N(P)K taken up by plants in Hungary was only observed when, as a result of increasing fertilizer application, there was a 2–3-fold increase in average yields. From the early 70's to the end of the 80's the NPK balance of Hungarian soils became strongly positive, which resulted in improvements in their NPK supplying capacity. Since 1990, however, the drastic decline in fertilizer application has again resulted in negative nutrient balances and Hungarian agriculture is now characterized by soil-exhausting plant nutrition practice (Table 5).

Table 5. Average N, and K_2O balance of Hungarian soils, kg/ha agricultural area, 1932-1991. (Kádár 1979 and 1987, Csathó 1994)

Items of balance	1932-36	1960-64	1971	1975	1984	1990	1991
			A. N balances				
Taken up by yield	40	47	64	80	96	80	103
Replaced							
- With farmyard manure	7	7	8	9	8	6	6
- With fertiliser	-	16	57	79	96	55	23
- With by-products	-	-	6	8	12	10	14
Total	7	23	71	96	116	71	43
Balance	-33	-24	7	16	20	-9	-60
Intensity of balance%*	18	49	111	120	121	89	42
			B. K_2O balances				
Taken up by yield	38	48	61	76	84	71	88
Replaced							
- With farmyard manure	16	18	20	21	15	12	12
- With fertiliser	-	7	45	82	71	29	6
With by-products	-	-	17	25	24	18	26
Total	16	25	82	128	110	59	44
Balance	-22	-23	21	52	26	-12	-44
Intensity of balance%*	42	52	134	168	131	84	49

* Quotient, which expresses how much N, or K (in percentage) taken up by the yield was replaced on the whole.

An investigation on the average NPK balances for Hungary over 10-year periods shows that NPK balances were negative in seven out of ten decades, and positive in only three. The 100-year cumulative N balances – based on agronomic approach – were negative for N (–800 kg/ha; -8 kg N/ha/year), positive for P (400 kg/ha, 4 kg P_2O_5/ha/year), and negative for K (–400 kg/ha, -4 kg K_2O/ha/year) (Csathó and Radimszky, 2005).

N and K supply of Hungarian soils, 1901 to 2000

From the turn of the century to the late 50's, nutrient balances in Hungary were strongly negative: 20-30 kg/ha/year less N and K_2O was given to the fields in different forms (farmyard manure, mineral fertiliser and by-products, etc.), than was removed by the harvested yields. Nutrient balances of N and K became positive in the early 70's, resp. Then, for 20 years, N balances were positive by 10-20 kg/ha/year, while K_2O balances by 30-50 kg/ha/year, resp. (Table 6).

Table 6. N and K supply of Hungarian soils, in % of area, 1960-2006.

Category of supply: very poor, poor	medium	good, very good	Date	Remarks	References
				N supply	
64	29	7	1960	on agr. cultiv. areas	Stefanovits and Sarkadi (1963)
40	40	20	1960-70	on agr. cultiv. areas	Kádár (1992)
26	44	30	1977-81	on agr. cultiv. areas	Kovács (1984)
30	32	38	1982-85	on 75% of arable lands	Baranyai et al. (1987)
25	37	38	1987	on >800 000 ha maize	Buzásné et al. (1988)
35	40	25	2000	estimation	Csathó (2009)
40	35	25	2008	estimation	Csathó (2009)
				K supply	
18	32	50	1960	on agr. cultiv. areas	Stefanovits and Sarkadi (1963)
25	35	40	1960-70	on agr. cultiv. areas	Kádár (1992)
12	39	49	1977-81	on agr. cultiv. areas	Kovács (1984)
16	27	57	1982-85	on 75% of arable lands	Baranyai et al. (1987)
13	22	65	1987	on >800 000 ha maize	Buzásné et al. (1988)
20	30	50	2000	estimation	Csathó (2009)
25	30	45	2008	estimation	Csathó (2009)

CONCLUSIONS

Based on the correlations established in the database, new, more accurate soil N, and K supply categories were elaborated for maize, providing opportunities for cost saving and environmentally sound fertilizaton of this very important Hungarian crop. Based on he findings of the database, it became evident, that maize is a N and K demanding, and a less P demanding crop.

Crop nutrition technology must be also adopted to the maize hybrids for bio ethanol production: The cost-saving, environmentally friendly fertiliser recommendation system, elaborated for the Hungarian soil and climatic conditions, makes difference between maize, produced for fodder, or sown for bio ethanol production. For the latter N demand is decreased by 20%, while, potassium demand is increased by the same 20%, providing optimal conditions for the higher carbohydrate synthesis rate.

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