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Mineral and Organic Fertilization to Improve Soil Fertility and Increasebiomass Production and N Utilization by Cereals

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1. Introduction

Long term field experiments play a significant role in agronomy research, since they are sources of information from which we can learn a lot about the factors that influence soil fertility and its sustainability. In most cases, effects and interactions of experimental factors and treatments can be understood only from long-term data across different soil and climatic conditions (Kismanyoky & Toth, 2007).

Agronomic experiments are like conversations with the plant, the soil and the studied ecosystem in general. The results of long-term field experiments are valid for a given territorial unit and a given time interval but we want to use this information as the scientific basis for general recommendations over a larger area and for a longer period (Várallyay, 2009). Such recommendations are often communicated to individual farmers by agronomic advisory services and extension agencies.

Soil processes run very slowly and are often only measurable and/or quantifiable after decades. Long-term field experiments are an indispensable aid to our knowledge of predominantly practical solutions for sustainable land use. A large proportion of current agronomic problems can be clarified exclusively using long-term experiments (Körschens, 2005).

Several long-term field experiments were set up to study the effects and interactions of organic and mineral fertilizers on cereal production in Hungary. Adequate plant nutrition, especially nitrogen sufficiency, is a major preoccupation in agronomy due to the influence of nitrogen (N) on crop quantity or quality (Szentpétery et al., 2005; Berzsenyi & Lap, 2005; Tanács et al., 2005; Staugaitis et al., 2007; Rühlmann, 2006; Tajnsek et al., 2005; Hoffmann et al., 2006a). Since the N storage capacity of the soil is limited and fertilizers are expensive, N fertilizers should be applied precisely. There are several forms of N in the soil, but only nitrate and ammonium ions are absorbed in appreciable quantities by the roots. The soil NO_3^--N concentration plays an important role as a mineral nutrient for plants as well as for microorganisms involved in decomposition, nutrient cycling and other soil biochemical processes . On the other hand, excess NO_3 represents an environmental hazard due to its solubility, which causes it to leach through the soil profile (Bircsák et al., 2005; Kádár &

Németh, 2004; Tóth, 2006; Sethi et al., 2005). Since most of the soil N stock is stored by the soil organic matter (SOM), SOM management has also a great importance. In addition, humic substances are well known to influence the physical condition of the soil, resulting in several effects on the physical, chemical and biological processes of the soil. SOM stocks are also a sink and a source of the atmospheric CO_2, which is an important issue too (Reuter et al., 2007). In the upper soil layer, SOM is constantly being created and decomposed, but its pool is relatively stable (Jenny, 1941). Several authors reported the important role of mineral and organic fertilizers in maintaining or increasing SOM content (Uhlen, 1991; Teesalu et al., 2006; Rühlmann & Ruppel, 2005; Hoffmann et al., 2006b).

The international working group for soil fertility, under the leadership of Prof. Dr. Boguslawski, formed the IOSDV network with 10 participating European countries in 1984 (Boguslawski, 1995). Most of the field trials established under the auspices of this network continue to the present. In this paper, some results of the international mineral and organic nitrogen fertilization trial located in Keszthely (Hungary) are reported. The long-term field experiment testing mineral nitrogen fertilizer in combination with different forms of organic manure has provided specific results concerning the interactions of fertilizer and manure treatments on cereal production.

The present chapter gives a concise report of the most important results of the productivity and N use efficiency of cereals in the eighth crop rotation period (2005-2007). We report soil fertility data from the 24 year long-term experimental period (eight crop rotation cycles). We will discuss the effects of mineral and organic fertilization on biomass production (grain and straw), nutrient balances, N uptake of maize, winter wheat and winter barley, as well as on some indices of N utilization (N harvest index %, N use efficiency, agronomic efficiency, apparent recovery efficiency) and soil fertility. The figures, results and conclusions introduced in the chapter are based on experimental results.

2. Material and methods

The study was conducted in the international mineral and organic nitrogen fertilization trial (IOSDV) located in Keszthely in the west part of Hungary (46°44' N, 17°13' E, 112 m above sea level). The experiment was set up in the autumn of 1983 and the first harvest year was 1984.

The soil class at the study site was a Ramann-type brown forest soil (Eutric Cambisol) containing 410 g kg^{-1} sand, 320 g kg^{-1} silt, and 270 g kg^{-1} clay. The natural available phosphorus (P) content of this sandy loam soil was low (ammonium-lactate soluble [AL] P_2O_5: 60-80 mg kg^{-1}), the potassium (K) content medium (AL-K_2O: 140-160 mg kg^{-1}) and the humus (H) content fairly low (16-17 g kg^{-1}), with a pH_{KCl} value of 7.1. The bulk density of undisturbed soil is 1.53 g cm^{-3}. The 100 year average annual precipitation was 683 mm, but the distribution was often unequal (most rainfall occurs in June –79.0 mm - and low rainfall can be observed in January – 34.5 mm). The long-term annual mean temperature was 10.8 ^{o}C.

The factorial experiment has a strip-plot design with three replications. The size of the subplots is 48 m^2. The factorial treatments were mineral N fertilization (5 rates) combined with organic fertilizers (3 levels). Treatments were applied in a field with three-year cereal crop rotation (maize, winter wheat, winter barley) system. The mineral N fertilizer rates were 0, 70, 140, 210 and 280 kg N ha^{-1} in case of maize, 0, 50, 100, 150 and 200 kg N ha^{-1} for winter wheat and 0, 40, 80, 120, 160 kg N ha^{-1} for winter barley. N rates are referred to in the text as N_0, N_1, N_2, N_3 and N_4. Supplemental P and K fertilizers at rates of 100 kg ha^{-1} P_2O_5 and K_2O were applied on all the experimental plots (even on the N control plots). The organic fertilizer treatments were applied as a complementary fertilization with the mineral NPK fertilizers having 3 different variants: (I) no organic fertilizer application (control), (II) farmyard manure (FYM) application (35 t ha^{-1}, in every third years before maize), (III) straw (St) incorporation (completed with 10 kg mineral N for each t straw ha^{-1}). After winter barley on the "St" plots an extra green manure (GM) was applied (*Raphanus sativus* var. Oleiformis) as a 2nd crop sowing on barley stubble.

In this paper, the productivity and N use efficiency of winter wheat, maize and winter barley was analysed in the eighth crop rotation period (2005-2007) Yield data was collected by threshing the grain collected a 2 m wide swath in the center of each plot and expressed on a dry matter (DM) basis converted into t ha^{-1} units. The indices of N use efficiency were calculated according to Huggins & Pan (1993) (1-2) and Crosswell & Godwin (1984) (3-4) as follows:

$$\text{N harvest index [\%]} = \frac{\text{N accumulated in grain}}{\text{N accumulated in total biomass}} \times 100 \quad (1)$$

$$\text{N use efficiency (NUE)} = \frac{\text{Grain yield [kg ha}^{-1}\text{]}}{\text{N absorbed at maturity [kg ha}^{-1}\text{]}} \quad (2)$$

$$\text{Agronomic efficiency (AE)} = \frac{\text{Grain yield of fertilized crop [kg ha}^{-1}\text{] - Grain yield of unfertilized crop [kg ha}^{-1}\text{]}}{\text{Quantity of N applied [kg ha}^{-1}\text{]}} \quad (3)$$

$$\text{Apparent recovery efficiency of N (AREN)} = \frac{\text{N uptake of fertilized crop [kg ha}^{-1}\text{] - N uptake of unfertilized crop [kg ha}^{-1}\text{]}}{\text{Quantity of N applied [kg ha}^{-1}\text{]}} \quad (4)$$

Soil fertility parameters were evaluated each year after harvest on topsoil (0-20 cm depth) collected from each plot. One composit soil sample was collected per plot. Soil tillage as all the soil and pest managent practices were applied as usual in convential farming systems. The soil organic carbon (SOC) and humus content (H) was quantified by Tyurin's method, the total N content was determined by Kjeldahl's method, while the soluble P_2O_5 and K_2O content of soil was quantified from Ammonium-lactate (AL) extraction by spectrophotometric and flamephotometric method, respectively (Ballenegger and Di Gléria 1962).

The statistical significance of the experimental factors and treatments (increasing rates of N fertilizer, organic fertilizer and the mineral N x organic fertilizer interaction) was tested by regression analysis and analysis of variance as two factor experiment on a $P<0.05$ level. SPSS statistical software was used for tests.

3. Results and discussion

3.1 Yields of the crops in the rotation as a function of different rates and forms of fertilizers

The relationship between N fertilization and yield can be described by a quadratic equation. The yield of winter wheat varied between 1.5-5 t ha^{-1} depending on the different manure treatments when averaged over the rotation cycle (Figure 1, Table 1). The maximal grain yield was obtained when 150 kg ha^{-1} N was applied.

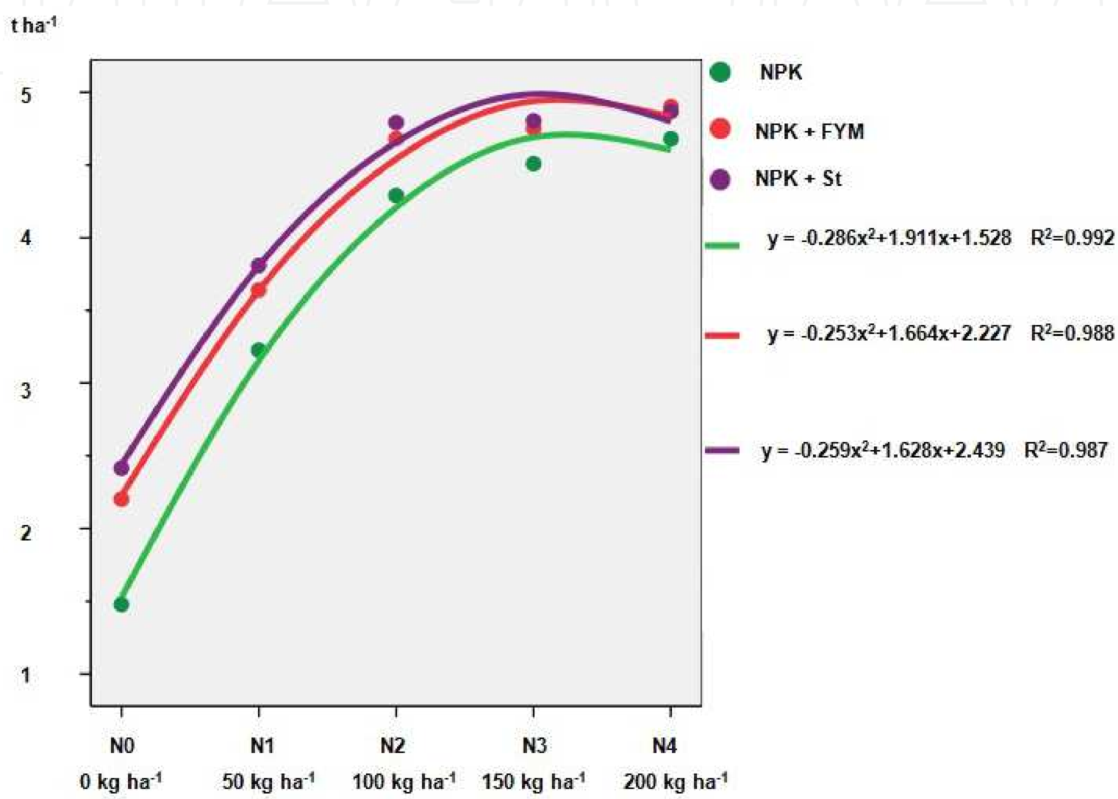

Fig. 1. Grain yield of winter wheat as a function of increasing rates of N fertilizer in the 8th rotation (2005-2007) at the long-term IOSDV trial, Keszthely, Hungary.

The average yield was lower when plots received NPK fertilizer alone (no organic fertilizer) compared to plots that received FYM or straw applied to complement the mineral fertilizer inputs. The N_0 plots yielded only ca. 2 t ha^{-1} when averaged over the two decades, whereas N_o plots with complementary organic fertilizer application N_0 plots yielded 1000 kg ha^{-1} more. The positive effect of organic fertilizer compared to the NPK fertilizer alone was significant in all of the N fertilizer treatments (Table 1).

The maximal biomass production in grain and straw was measured in the N_3 treatment, when 150 kg ha^{-1} N fertilizer was applied. However, the complementary organic fertilizer application resulted in significantly higher biomass production in the N_3 treatment. The ratio between the grain and straw yields was closely to 1:1 (in DM values).

The grain yield of maize varied between 5-10 t ha^{-1} depending on the different N fertilizer and manure treatments (Figure 2). The maximal grain yield was obtained when 210 kg ha^{-1} N was applied.

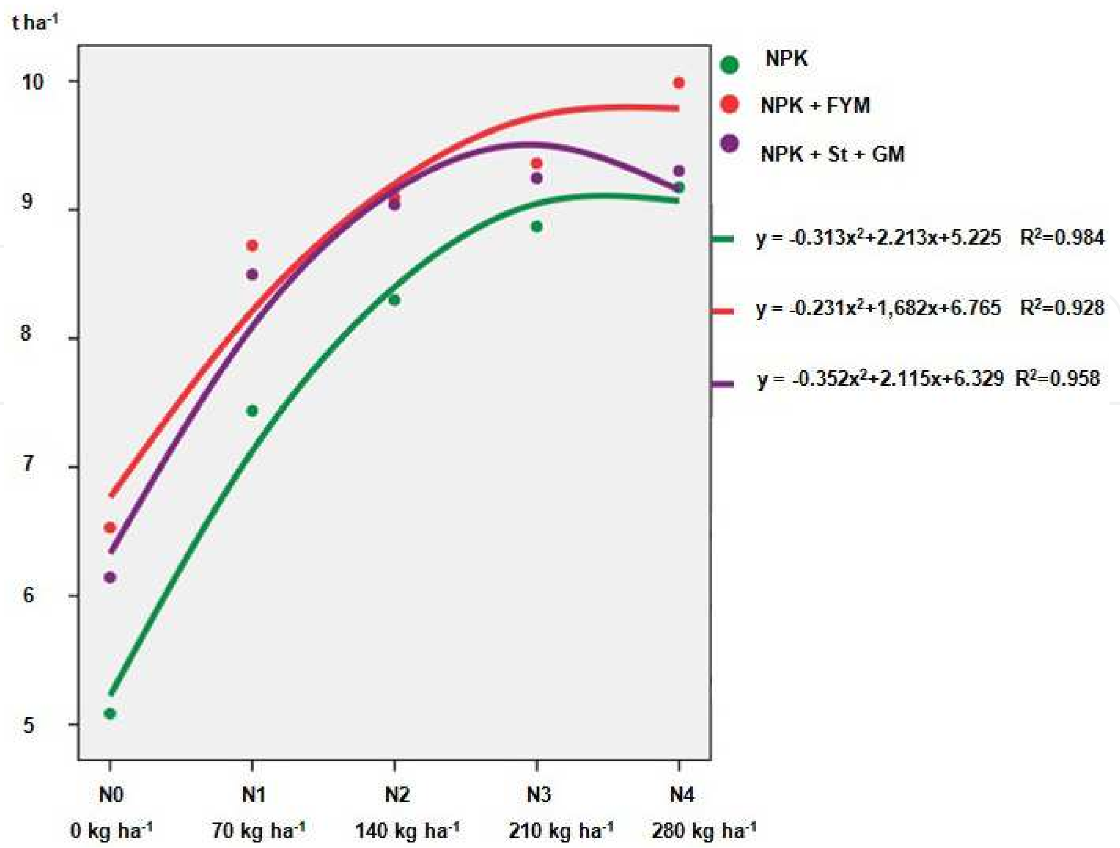

Fig. 2. Grain yield of maize as a function of increasing rates of N fertilizer in the 8th rotation (2005-2007) at the long-term IOSDV trial, Keszthely, Hungary.

Maize		Winter wheat		Winter barley			
Grain D.M. t ha^{-1}	Stalk D.M. t ha^{-1}	Grain D.M. t ha^{-1}	Straw D.M. t ha^{-1}	Grain D.M. t ha^{-1}	Straw D.M. t ha^{-1}	Treatments	
4.37	3.03	1.48	1.33	1.68	1.56	N_0	NPK (I)
7.12	5.74	4.29	5.17	3.95	4.23	N_2	
7.88	7.38	4.68	5.27	4.44	4.70	N_4	
6.46	***5.38***	***3.48***	***3.92***	***3.36***	***3.50***	***4.35***	***Mean***
5.73	4.27	2.20	2.24	2.78	2.88	N_0	NPK+FYM (II)
8.34	6.66	4.68	5.49	4.40	4.65	N_2	
8.31	8.46	4.90	5.60	4.70	4.90	N_4	
7.46	*6.46*	*3.93*	*4.44*	*3.96*	*4.14*	*5.07*	*Mean*
5.71	4.28	2.42	2.16	2.68	2.97	N_0	NPK+St (+Gm) (III)
8.29	6.98	4.79	5.26	4.27	4.61	N_2	
8.05	8.45	4.87	5.45	4.70	4.28	N_4	
7.35	***6.57***	***4.03***	***4.29***	***3.88***	***3.95***	***5.01***	***Mean***
1.01	*1.04*	*0.40*	*0.36*	*0.58*	*0.51*	*$LSD_{5\%}$ between combinations*	

Table 1. Yields of crops from selected treatments in the 8th rotation (2005-2007) at the long-term IOSDV trial, Keszthely, Hungary.

Average yield level was significantly lower with NPK fertilizer alone than when organic fertilizers were applied to complement mineral fertilizers. On the N_0 plots, the complementary organic fertilizer application resulted in 1.0-1.5 tha^{-1} extra yield. No significant difference in yield was detected between the NPK+FYM and the NPK+St+GM treatments.. The yield of the N_0 plots was significantly lower than each of the fertilized ones. The yield increase tended to diminish with higher N rates and the interactive effect of mineral N x organic fertilizer applications was also smaller at the high N rates.

In case of stalk/straw yield the tendencies are similar, but the values were registered within a greater interval (lower minimum and higher maximum values) than in case of grain. In addition the high N rates resulted in higher stalk yield increase than in case of grain. The extra yields resulting from complementary organic fertilizer application was proportional to the additional nutrient input from organic fertilizers.

The ratio between the grain and stalk yields was close to 1:1 (in DM values) at the highest fertilizer rates, while at the lower rates, the ratio of the grain yield was higher. In the case of the N_0 plots, this ratio was 1.37. The increase in grain yield due to organic fertilizer was higher at the lower rates of mineral N treatments and reached a plateau, but stalk/straw yield showed a continual linear increase over the range of mineral N x organic fertilizer combinations in this study. At higher N fertilizer rates, the efficiency of N fertilization decreased.

In the crop rotation, the winter barley followed the winter wheat. The effects of N fertilizer on barley were similar to those observed for wheat (Figure 3). The maximal grain yield was obtained when 120 kg ha^{-1} N was applied.

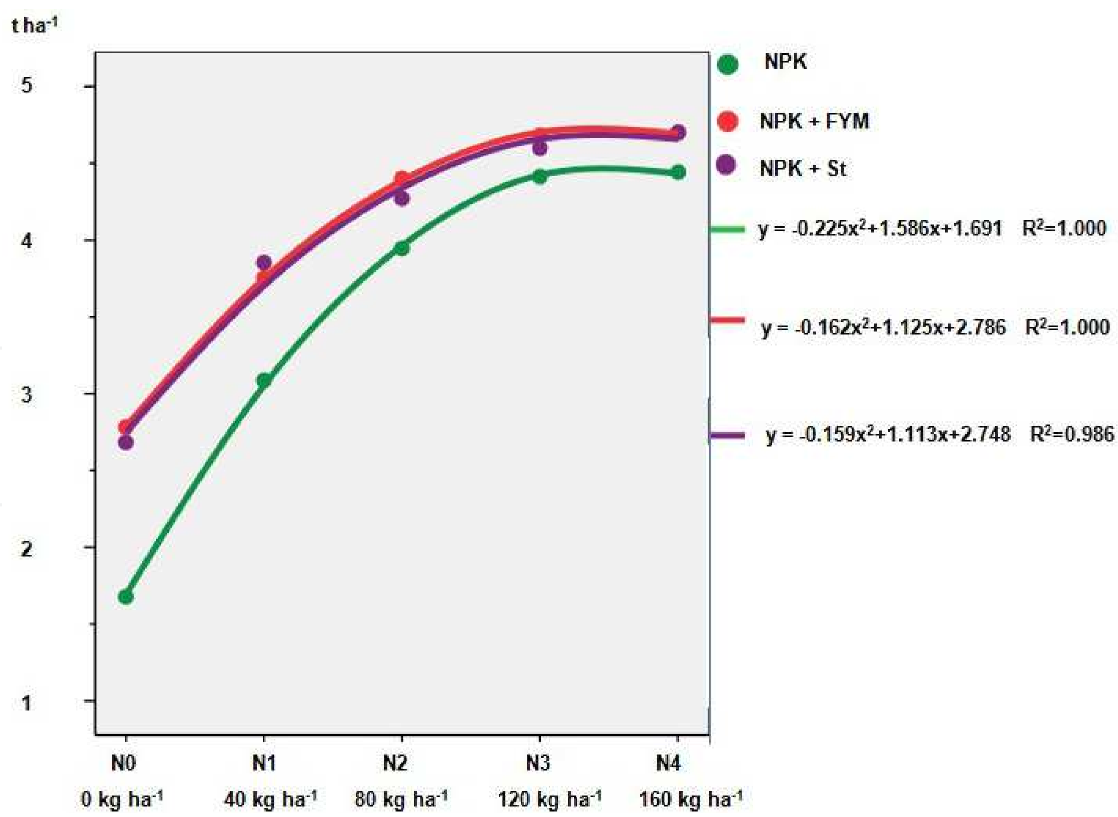

Fig. 3. Grain yield of winter barley as a function of increasing rates of N fertilizer in the 8th rotation (2005-2007) at the long-term IOSDV trial, Keszthely, Hungary.

The effect of FYM as a 3rd year effect in the crop rotation resulted in about 1000 kg ha^{-1} extra yield compared to the N0 plots. Straw incorporation (with complementary N application) resulted in the same yield increase as achieved with FYM. This positive effect of organic fertilizer was measured at higher N rates too. The biggest grain yield was harvested at N_4 treatment (160 kg ha^{-1} N). The grain:straw ratio was nearly 1:1 in alltreatments.

3.2 Nutrient content of the crops in the rotation as a function of different rates and forms of fertilizers

Table 2 demonstrates the nutrient content of wheat at harvest time. The N content of wheat grain was 23.80 g kg^{-1} while in case of straw it was merely 4.47 g kg^{-1} when averaged over the factorial mineral N x organic fertilizer combinations. The results are consistent with other experimental results (Sarkadi, 1975; Huggins & Pan, 1993; Bischoff, 1995; Berecz & Kismányoky, 2005).

More than 80% of the N uptake was found in the grain and less than 20% remained the straw at harvest, with some deviation depending on the rate of N supply. The N content (concentration – g kg^{-1}) in the grain and straw increased significantly with greater N fertilizer inputs compared to the N0 treatments.

Treatments		N g kg^{-1}		P_2O_5 g kg^{-1}		K_2O g kg^{-1}	
		Grain	Straw	Grain	Straw	Grain	Straw
NPK	N0	21.70	3.33	5.44	1.93	4.24	11.93
	N2	20.50	3.47	4.88	1.58	4.01	10.81
	N4	27.20	4.28	5.23	1.23	4.09	14.35
NPK+FYM	N0	22.80	5.40	5.17	2.12	3.88	13.26
	N2	23.20	3.86	5.12	1.69	4.16	13.53
	N4	25.60	5.09	5.94	1.53	3.82	15.63
NPK+St	N0	23.30	3.61	5.37	1.79	4.36	12.43
	N2	23.60	4.51	5.08	1.63	4.15	12.60
	N4	26.80	6.15	5.05	1.56	3.94	15.66
$LSD_{5\%}$		1.44	1.12	0.45	0.28	-	3.64
Probability		**	***	*	***	n.s.	***

Table 2. Nutrient content of winter wheat biomass from selected treatments in the 8th rotation (2005-2007) at the long-term IOSDV trial, Keszthely, Hungary.

The P_2O_5 values were fairly similar (constant) in each treatment, regardless of the N fertilizer inputs (4.88-5.94 g kg^{-1} P in grain and 1.23-2.12 % P in straw). The K_2O content of grain was rather stable (3-4 g kg^{-1} K) while that of straw increased in parallel with rising N rates (10-15 g kg^{-1} K). This is why the K ratio between the grain and straw was 1:3 in the N_0 treatment and increased to 1:4 in the N_4 treatment.

The nutrient content of maize biomass is presented in Table 3. The N content was 9-14 g kg^{-1} in the grain, while that of stalk was 3-9 g kg^{-1}. Greater N supply increased the N content (concentration – g kg^{-1}) in both grain and stalk.

Treatments		N g kg-1		P_2O_5 g kg-1		K_2O g kg-1	
		Grain	Stalk	Grain	Stalk	Grain	Stalk
NPK	N0	9.31	3.86	2.62	2.10	2.48	9.42
	N2	10.79	5.41	2.71	1.89	2.41	11.60
	N4	11.40	7.32	2.74	2.27	2.45	10.80
NPK+FYM	N0	12.65	6.70	2.95	1.81	2.76	11.00
	N2	12.70	7.50	3.05	1.92	2.67	6.36
	N4	13.60	8.33	3.15	1.89	2.83	12.56
NPK+St+Gm	N0	12.66	5.67	2.98	170	2.70	6.63
	N2	12.86	7.35	2.89	1.69	2.49	10.90
	N4	14.36	9.04	3.33	2.08	2.93	11.57
$LSD_{5\%}$		1.90	2.38	0.52	-	-	3.64
Probability		***	**	*	n.s.	n.s.	*

Table 3. Nutrient content of maize biomass from selected treatments in the 8th rotation (2005-2007) at the long-term IOSDV trial, Keszthely, Hungary.

The P and K level in the grain and straw of maize were lower than in wheat biomass and N fertilization resulted in no consistent change.

The nutrient content of winter barley biomass is given in Table 4. The N content of grain ranged from 17-21 g kg^{-1} while it was 03-05 g kg^{-1} in straw depending on the different rates of N fertilizers. In general, N content of grain was lower while that of straw was higher than values for winter wheat. The P_2O_5 content (concentraqtion - g kg^{-1}) of grain and straw were not affected by N fertilization and remained constant around 5 g kg^{-1} and 2 g kg^{-1}, respectively.

The K_2O content of winter barley was also fairly constant - grain contained 7 – 8 g kg^{-1} K and straw had 7 – 12 g kg^{-1} K..

Treatments		N g kg-1		P_2O_5 g kg-1		K_2O g kg-1	
		Grain	Straw	Grain	Straw	Grain	Straw
NPK	N0	17.66	3.87	5.67	2.26	6.97	7.96
	N2	18.96	3.68	6.67	2.27	8.62	11.05
	N4	19.63	5.39	5.53	2.40	7.13	11.32
NPK+FYM	N0	15.00	3.22	5.49	2.22	7.78	8.82
	N2	16.63	4.54	5.59	2.44	8.29	11.00
	N4	20.56	5.16	6.02	2.32	7.29	11.90
NPK+St	N0	12.76	5.39	4.94	2.32	7.14	9.60
	N2	21.16	5.16	6.94	2.38	8.51	11.00
	N4	20.03	5.67	5.67	2.30	7.16	12.76
$LSD_{5\%}$		4.14	1.26	n.s.	n.s	1.07	2.13
Probability		**	**	+	+	***	***

Table 4. Nutrient content of w. barley biomass from selected treatments in the 8th rotation (2005-2007) at the long-term IOSDV trial, Keszthely, Hungary.

3.3 Nutrient balance and soil test results

The nutrient balance was calculated from the yield results (grain and total aboveground biomass) the absorbed nutrients (NPK) in crops. Tables 5, 6, and 7 show the nutrient balances of winter wheat, maize and winter barley from the IOSDV experiment.

The nutrient balance of winter wheat is presented in Table 5. Without organic fertilizer (I), the yield of crops was smaller than in the treatments (II-III) that included complementary organic fertilizers. Without fertilization (N_0), the inherent soil fertility produced about 2 t ha^{-1} cereal grain when averaged over the three crops. The addition of FYM increased the yield by about 1000 kg ha^{-1} compare to the N_0 treatments in three crops. The biomass production (grain and straw) was maximal at the amount of 150 kg ha^{-1} N doses (N_3) in the I-II-III fertilizer systems alike where the N balances were at equilibrium or slightly positive.

Treatments	NPK (I)			NPK+FYM (II)			NPK+St (III)		
	N_0	N_2	N_4	N_0	N_2	N_4	N_0	N_2	N_4
Nutrient balance kg ha^{-1}									
N	-37.07	+8.34	+47.10	-61.38	+29.76	+46.03	-64.05	+36.79	+36.04
P_2O_5	+89.25	+70.89	+69.06	+83.88	+66.72	+67.24	+83.18	+67.04	+64.73
K_2O	+77.82	+27.52	+5.05	+62.52	+6.41	-6.16	+62.70	+13.92	-4.48
Soil test results									
H g kg^{-1}	19.1	19.9	19.8	23.9	24.0	22.5	23.0	22.0	23.1
N_{total} g kg^{-1}	1.3	1.2	1.2	1.6	1.7	1.6	1.4	1.3	1.4
AL-P_2O_5 mg kg^{-1}	361	394	320	660	713	749	331	331	275
AL-K_2O mg kg^{-1}	243	198	209	463	332	357	260	247	170

$LSD_{5\%}$ H A×B: n.s., $LSD_{5\%}$ H Fert. Sys.: 1.8, $LSD_{5\%}$ H N rates: n.s., $LSD_{5\%}$ N total A×B: 0.3, $LSD_{5\%}$ AL-P_2O_5 A×B: 95, $LSD_{5\%}$ AL-K_2O A×B: 135

Table 5. Nutrient balance of winter wheat and soil test results in the 8th rotation (2005-2007) of the IOSDV long-term trial in Keszthely, Hungary.

The amount of N (kg ha^{-1}) removed by the plants in the N_0 plots indicates the N supplying ability of soil. The absorbed N was 37 kg ha^{-1} in case of wheat on the N_0 plots and the 2nd year effect of FYM resulted in 30 kg ha^{-1} above this, while organic fertilization with straw produced 29 kg ha^{-1} extra yield. It is well known that without N fertilizer input (N_0) soil N stocks are depleted, wich is also related to SOM cycle due to the lower amount of residues it is resulted in a negative H balance. The humus content of soil (concentration – g kg^{-1}) was increased by FYM application by some 5 g kg^{-1} (20 t ha^{-1} C_{org}). The effect of N fertilizer was negligible in this respect. The straw input (St) was valuable and increased the soil humus content by 2 to 3 g kg^{-1} as well.

The humus content (concentration - g kg^{-1}) and the humus pool (t ha^{-1}) increased significantly with organic fertilizer addition. It draws our attention to the fact that straw as a by-product is a very important C resource that has to be recycled by leaving straw residue in the field and tilling it into the soil, especially if there is no animal husbandry in the farm, in order to keep the C balance in the soil. This idea has also appeared in earlier publications on Hungarian soils (Kismányoky & Toth, 1997; Kismányoky & Toth, 2010).

The yield of maize (Table 1) varied between 3-8 t ha^{-1} depending on the amount of mineral N fertilizer applied. After farmyard manure (FYM) application and straw incorporation (St), 1000 kg ha^{-1} yield increase could be realized. In plots with the highest yield, the effect of straw was not so favourable (i.e., a yield plateau was reached), possibly because of the lack of required amount of K (negative K balance).

The highest yield was obtained at the equilibrium N nutrient balance (slightly positive). N supplying ability of soil was 50 kg ha^{-1} on the N_0 plots, while FYM resulted in 100 kg ha^{-1} N and straw+green manure resulted in 96 kg ha^{-1} N.

The P balance was positive in each treatment and there were significant P accumulation after farmyard manure (FYM) application. FYM and straw application resulted in increasing K_20 content in the soil. The K balance was positive in almost any case but at and more than 9 t ha^{-1} maize yield the amount of applied K fertilizer (100 kg ha^{-1} K_2O) proved to be insufficient and became negative.

Treatments	NPK (I)			NPK+FYM (II)			NPK+St+GM (III)		
	N_0	N_2	N_4	N_0	N_2	N_4	N_0	N_2	N_4
Nutrient balance kg ha^{-1}									
N	-52.37	+32.13	+136.15	-101.08	+5.48	+96.56	-96.54	-20.09	+88.03
P_2O_5	+82.11	+69.87	+64.47	+75.95	+61.79	+57.66	+76.23	+64.26	+56.25
K_2O	+60.63	+16,.27	+1.00	+37.23	+35.39	-31.01	+56.23	+3.28	-21.34
Soil test results									
H g kg^{-1}	18.2	18.7	17.6	21.4	19.7	22.4	19.6	19.5	20.3
N_{total} g kg^{-1}	1.2	1.3	1.4	1.7	1.7	1.7	1.5	1.7	1.7
AL-P_2O_5 mg kg^{-1}	392	404	382	646	559	598	537	492	404
AL-K_2O mg kg^{-1}	211	230	181	316	247	259	388	265	220

$LSD_{5\%}$ H A×B: n.s., $LSD_{5\%}$ H Fert. Sys.: 1.8, $LSD_{5\%}$ H N rates: n.s., $LSD_{5\%}$ N_{total} A×B: 0.3, $LSD_{5\%}$ AL-P_2O_5 A×B: 129, $LSD_{5\%}$ AL-K_2O A×B: 77

Table 6. Nutrient balance of maize and soil test results in the 8th rotation (2005-2007) of the IOSDV long-term trial in Keszthely, Hungary.

In case of winter barley (Table 7), the response to mineral and organic fertilization was similar to results from the wheat phase of the rotation. The 3rd year after effect of FYM and straw incorporation resulted in 1000 kg ha^{-1} extra yield in the crop rotation.

In the N_0 treatments 35 kg ha^{-1} N were absorbed by the barley plant. The 3rd year effect of FYM was 17 kg ha^{-1} N, while straw incorporation resulted in 15 kg ha^{-1} extra N absorption of barley in the crop rotation. The optimal N dose for winter barley was 120 kg ha^{-1}.

The P and K balance were positive in every treatment except at the highest N rate (N_4). The grain and straw removed 20-30 kg ha^{-1} P_20_5 and 20-80 kg ha^{-1} K_20 from the soil annually. Plots receiving straw + GM exhibited notable K consumption (luxury uptake), supported by the high K_2O values in the laboratory analyses of harvested tissues.

Treatments	NPK (I)			NPK+FYM (II)			NPK+St (III)		
	N_0	N_2	N_4	N_0	N_2	N_4	N_0	N_2	N_4
Nutrient balance kg ha^{-1}									
N	-35.64	-10.04	+47.71	-52.40	-14.28	+38.05	-50.24	-34.11	+41.60
P_2O_5	+81.10	+64.10	+64.15	+78.33	+64.06	+60.34	+79.85	+59.42	+63.51
K_2O	+79.27	+26.89	+15.22	+52.94	+12.44	+11.96	+59.67	+19.47	+11.75
Soil test results									
H g kg^{-1}	19.76	19.40	18.53	22.03	23.73	22.19	22.16	21.40	23.53
N_{total} g kg^{-1}	1.31	1.31	1.24	1.30	1.36	1.35	1.33	1.38	1.39
AL-P_2O_5 mgkg^{-1}	539	399	332	583	553	521	403	361	327
AL-K_2O mgkg^{-1}	311	262	211	393	303	284	297	376	274

$LSD_{5\%}$ H A×B: 2.9, $LSD_{5\%}$ H Fert. Sys.: 1.7, $LSD_{5\%}$ H N rates: n.s., $LSD_{5\%}$ N_{total} A×B: n.s., $LSD_{5\%}$ AL-P_2O_5 A×B: 137, $LSD_{5\%}$ AL-K_2O A×B: n.s.

Table 7. Nutrient balance of winter barley and soil test results in the 8th rotation (2005-2007) of the IOSDV long-term trial in Keszthely, Hungary.

Balance	NPK			NPK+FYM			NPK+St		
	N_0	N_2	N_4	N_0	N_2	N_4	N_0	N_2	N_4
Average nutrient balance kg ha^{-1}									
N	-41.7	4.5	77.0	-71.8	6.9	60.2	-70.3	-6.1	55.3
P_2O_5	84.1	68.3	65.9	79.4	64.2	61.7	79.7	63.5	61.4
K_2O	72.6	23.5	7.1	50.8	18.1	-8.4	59.5	12.2	-4.7
Average soil test results									
H g kg^{-1}	19.00	19.34	18.63	22.43	22.47	22.35	21.58	20.96	22.32
N_{total} g kg^{-1}	1.27	1.26	1.26	1.53	1.56	1.55	1.42	1.46	1.47
AL-P_2O_5 mg kg^{-1}	430	399	344	630	608	623	423	394	335
AL-K_2O mg kg^{-1}	255	230	200	390	294	300	315	296	221

Table 8. Annual average nutrient balance of a winter wheat – maize – winter barley rotation grown from 2005-2007 in the IOSDV long-term trial in Keszthely, Hungary. Values were averaged (over 3 years) from the annual nutrient balances.

In Table 8 the nutrient balance in the complete crop rotation is demonstrated. The key points to note from this table are (1) the negative N balance in N_0 plots, which rely on the inherent soil N supply for crop production, (2) mineral N fertilization led to an equilibrium or positive N balance, with or without complementary organic fertilization, (3) the mineral P fertilization was sufficient for winter wheat, maize and winter barley production, evidenced by the positive P balance over the rotation, and (4) the mineral K fertilization was positive at most levels of mineral N input (N_0 to N_3) but a negative balance was observed in the N_4 plots that received complementary organic fertilizers, presumably due to the higher yields in these treatments.

3.4 N use indices of the crops in the rotation as a function of different rates and forms of fertilizers

Table 9, 10 and 11 shows the nitrogen use indices for each crop related to the effect of mineral N fertilization and organic fertilizer application.

Harvest index of N ($HI_{N\%}$) shows that wheat absorbed the highest proportion - more than 80 % - of the total above-ground N content in the grain, barley absorbed less than 80 %, while maize absorbed the lowest proportion – less than 70 % - when averaged over the different fertilizer treatments. The rest of the absorbed N was located in the vegetative above-ground biomass. When complementary organic fertilizers – both FYM and straw – were applied the $HI_{N\%}$ values were slightly reduced due to the dilution processes induced by the increase in biomass yield. With the rise in mineral N fertilizer rates (N_0-N_4) a definite reduction of $HI_{N\%}$ values was observed in case of maize, while in case of wheat and barley similar tendencies were not observed.

$HI_{N\%}$	NUE (kg ha^{-1})	AE (kg ha^{-1})	AREN (kg ha^{-1})	Treatment	
86.5	49	-	-	N_0	Min. fert.
81.7	30	28.13	0.71	N_2	
87.8	31	16.01	0.58	N_4	
85.3	**37**	**22.07**	**0.64**		**Mean**
81.8	36	-	-	N_0	Min. fert. +FYM
83.7	36	16.53	0.68	N_2	
81.5	30	13.50	0.46	N_4	
82.3	**34**	**15.01**	**0.57**		**Mean**
86.5	34	-	-	N_0	Min. fert. +St
82.7	35	23.77	0.73	N_2	
79.6	30	12.26	0.50	N_4	
82.9	**33**	**18.01**	**0.61**		**Mean**
83.5	**34**	**18.37**	**0.61**		**Overall mean**

Table 9. N use indices of winter wheat from selected treatments in the 8th rotation (2005-2007) at the long-term IOSDV trial, Keszthely, Hungary.

$HI_{N\ \%}$	NUE (kg ha-1)	AE (kg ha-1)	AREN (kg ha-1)	Treatment	
77.7	83	-	-	N_0	Min. fert.
71.2	66	19.64	0.40	N_2	
62.5	55	12.54	0.33	N_4	
70.5	**68**	**16.09**	**0.36**		**Mean**
71.7	57	-	-	N_0	Min. fert. +FYM
68.0	54	18.65	0.39	N_2	
61.6	45	9.21	0.29	N_4	
67.1	**52**	**13.93**	**0.34**		**Mean**
74.9	59	-	-	N_0	Min. fert. +St+GM
67.5	53	18.43	0.44	N_2	
60.2	42	8.36	0.34	N_4	
67.5	**51**	**13.39**	**0.39**		**Mean**
68.4	**57**	**14.47**	**0.36**		**Main mean**

Table 10. N use indices of maize from selected treatments in the 8th rotation (2005-2007) at the long-term IOSDV trial, Keszthely, Hungary.

$HI_{N\ \%}$	NUE (kg ha-1)	AE (kg ha-1)	AREN (kg ha-1)	Treatment	
83.1	47	-	-	N_0	Min. fert.
82.8	44	28.35	0.68	N_2	
77.5	39	19.76	0.55	N_4	
81.1	**43**	**24.05**	**0.61**		**Mean**
81.8	55	-	-	N_0	Min. fert. +FYM
77.6	47	20.24	0.54	N_2	
79.3	39	13.71	0.51	N_4	
79.6	**46**	**16.97**	**0.52**		**Mean**
68.2	53	-	-	N_0	Min. fert. +St
79.2	37	19.83	0.80	N_2	
79.5	40	14.40	0.49	N_4	
75.6	**43**	**17.11**	**0.64**		**Mean**
78.8	**44**	**19.38**	**0.59**		**Main mean**

Table 11. N use indices of winter barley from selected treatments in the 8th rotation (2005-2007) at the long-term IOSDV trial, Keszthely, Hungary.

N use efficiency (NUE) shows the amount of grain yield (kg ha^{-1}) produced per each kg of absorbed N at maturity. Since winter wheat accumulated the highest proportion of N in the grain (the $HI_{N\%}$ values were the highest), the NUE values were the lowest in case of wheat (34,37 kg when averaged over the fertilizer treatments), while that of maize – which had the lowest $HI_{N\%}$ values – was the highest (57,03 kg). When complementary organic fertilizers were applied, NUE values were slightly reduced for wheat and maize. In the case of barley, the second year post effect of FYM application slightly increased N use efficiency. With the rise in mineral N fertilizer rates (N_0-N_4) due to the luxury consumption a definite reduction of NUE values was observed in case of maize, while in case of wheat and barley such definite tendencies were not observed.

Agronomic efficiency (AE) values show the amount of extra grain yield (kg ha^{-1}) production (yield increase) above the control per each kg of applied fertilizer N. The applied N fertilizer treatments resulted in higher AE values (higher extra yield) in case of wheat and barley than maize, when averaged over the fertilizer treatments. On the other hand it has to be mentioned that maize yielded much higher in the N control plots than the other cereals therefore the yield gain due to N fertilization was less. . When complementary organic fertilizers were applied, AE values were reduced in case of each crop. With the rise in mineral N fertilizer rates (N_0-N_4) a definite reduction of AE values can be observed for each crop.

Apparent recovery efficiency of N (AREN) describes the amount of N (kg ha^{-1}) included in the extra grain yield above the control per each kg of applied fertilizer N. The applied N fertilizer treatments resulted in higher AREN values in case of wheat and barley than maize, when averaged over the fertilizer treatments. When complementary organic fertilizers were applied AREN values were slightly reduced in case of wheat and barley. With the rise in mineral N fertilizer rates (N_0-N_4) a definite reduction of AE values were observed for each crop.

4. Conclusion

The nutrient absorption of crops in the N_0 treatments indicates the inherent (original) fertility of soil regarding the N status. In case of winter wheat and winter barley, the soil N supply was 30-40 kg ha^{-1} N while in case of maize, 50 kg ha^{-1} N were removed from the soil by the plants annually. Accordingly wheat and barley yielded 1.5-2.5 t ha^{-1}, while the yield of maize was 5.0-6.5 t ha^{-1} in the control plots.

The mineral N fertilizer doses increased the yield significantly until the 150 kg N ha^{-1} dose at wheat, the optimum point was 120 kg N ha^{-1} at barley and 210 kg N ha^{-1} for maize. Additional mineral N fertilizer applications did not produce significantly greater yields, as the response curves exhibited a quadratic relationship at higher mineral N rates. The N balance was always slightly positive above the equilibrium in this cases.

The joint effect of mineral and organic fertilizers were favourable. Supposedly there are positive interactions between the two sorts of fertilizers. This interaction exists on high level of nitrogen application (N_4) too, but not significantly. FYM and straw application positively influenced soil fertility. Organic fertilizers produced a 1000 kg ha^{-1} yield increase in each phase of the crop rotation. The 2^{nd} and 3^{rd} year post-application effect of FYM was similar for wheat and barley. The effect of FYM in the first year (applied directly before maize) was 47.8 kg ha^{-1} extra N. The second year post effect (wheat) was 24.3 kg ha^{-1} N, while the 3rd year post effect (barley) was 16.7 kg ha^{-1} N. The nutrient value of straw and mineral N fertilizer was nearly equivalent to the value of FYM.

The amount of nutrients provided by FYM application was proportional to the yield. The humus content (H g kg^{-1}) of soil after the 8th cycle of the crop rotation as follows: FYM plots showed an increase in humus content (H g kg^{-1}) of 3.4 %, while straw (+GM) had a 2.6 g kg^{-1} increase, compared to the plots without organic fertilizers. After wheat 21.9 g kg^{-1} H, at barley 21.4 g kg^{-1} H, after maize 19.4 g kg^{-1} H were found in the soil samples in the average of the N fertilizer treatments. The different doses of N fertilizer did not influence the soil organic matter content.

The N_{total} values in the soil did not change as a result of the different amount of N fertilizer, but there were differences between organic fertilizer treatments (NPK - NPK+FYM - NPK+St+GM). Since soil samples were taken after harvest, supposedly the inorganic N forms had been utilized during the vegetation period.

K balance was positive in every treatment except at the high N fertilizer and yield level. Around and over 9 t ha^{-1} grain yield the K balance decreased, even turned to negative in case of maize. In consequence of organic fertilizer application, the K_2O content in the soil increased %. Compare to the initial 80 mg kg^{-1} value in soil, recently 200-300 mg kg^{-1} was measured. It means that in the course of 25 years 10 mg kg^{-1} increasing needed 30-40 kg ha^{-1} extra K_2O nutrient input above K balance.

P balance was positive in every treatment. The available (ammonium-lactate soluble) P_2O_5 content during the 25 years increased significantly. The soil AL-P_2O_5 content doubled after FYM. At the starting of the field experiment (1983) the soil P_2O_5 content was 12 mg kg^{-1} and recently it is 460 mg kg^{-1}. According to that 50 kg ha^{-1} extra P_2O_5 nutrient input above P balance equilibrium produces 10 mg kg^{-1} P_2O_5 increasing in the soil.

The proportional rates of mineral N fertilizer applied in the experiment allowed the calculation of some nitrogen use indices, which are in accordance with the results of the nutrient balances.

Harvest index of N ($HI_{N\%}$) was around 80 %for winter wheat and winter barley while in case of maize it was around 70 %. These values were decreased in parallel with the increase in N fertilizer rates.

Increasing N fertilizer rates generally decreased all the other N use indices as N use efficiency (NUE), agronomic efficiency (AE) and apparent recovery efficiency of N (AREN) as well, but on the other hand the yields (grain and straw) were increased significantly. Nitrogen use indices show the differences between the different crops regarding N utilization and productivity. It is remarkable that maize due to its high productivity (even on the control plots) performed the highest nitrogen use efficiency values, on the contrary $HI_{N\%}$, AE and AREN values were lower.

From the results it can be concluded that different rates and sorts of fertilizers influenced the productivity of crops as well as the efficiency of nutrients with interaction of the different characteristics of the certain crops. The different rates and types of fertilizers also have long-term effect on some important soil fertility parameters as well.

From the above mentioned results it can be concluded that optimal N fertilizer rates were 150, 210 and 120 kg ha^{-1} N in this order for winter wheat, maize and winter barley, respectively. The higher N rates do not increase the yield, even N surplus (strongly positive N balance) resulted in N losses and environmental hazard.

It also has to be emphasized that soil organic matter content can be sustained by organic fertilizer addition as well as recycling straw into the soil. It draws attention to the fact that straw as a by-product is a very important C resource that has to be recycled by leaving straw residue in the field and tilling it into the soil, especially if there is no animal husbandry in the farm, in order to keep the C balance in the soil.

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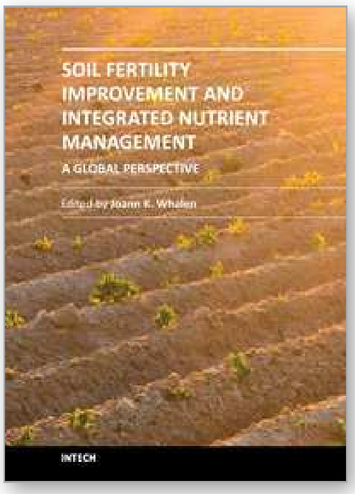

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