The Effect of Soil Organic Matter Content on Crop Responses to N Given in Mineral or Organic Form

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Research on soil organic matter has always been a key-question in the investigations on soil fertility and related environmental issues. Benefits ascribed to organic matter (OM) include increased soil cation-exchange capacity, increased water-holding capacity, decreased soil compaction, improved stability of soil aggregate, and retention of micronutrients (BAVER, 1968). Organic matter plays an important role in controlling the level of Al in the soil solution (BLOOM et al., 1979). Changes in soil OM content as affected by the different N sources have been modelled in the Classical Rothamsted Long-term Field Trials recently (JENKINSON et al., 1987; POWLSON & JOHNSTON, 1994). The connection between soil OM and nitrogen turnover was reviewed and evaluated recently by NÉMETH (1996).

The distribution of Hungarian soils according to their organic matter content is represented in a soil map. This mapping activity was based on national soil surveys by 6-12 hectare units every three years (BARANYAI et al., 1987).

Nitrogen balances of Hungarian agricultural soils in different periods characterize the ratio between organic and mineral N source inputs, as well as the intensity of the balance, i. e. the ratio of N given in the percentage of N uptake (ZUKKER, 1938; FARKAS, 1942; GYŐRFFY, 1965; SARKADI, 1979; KÁDÁR, 1979, 1987; DEBRECZENI, 1988; CSATHÓ, 1994).

Field trials for the comparison of effects of farmyard manure and mineral fertilizers on the principle of NPK active agent equivalence were set up in Hungary in the late fifties, utilizing international experience as well (IVERSEN, 1960). Results of the experiments that existed for more than 6-8 cycles were adapted to practice in the past decades (ÁRENDÁS, 1993; BERZSENYI & GYŐRFFY, 1994; HOLLÓ, 1993; SARKADI, 1991). An attempt was made to synthesize the results of the above-mentioned Hungarian field trials (ÁRENDÁS & CSATHÓ, 1996).

As in Hungarian agriculture winter wheat – occupying more than 1 millon hectares of arable land – is one of the main crops, the synthesis of the national field trial series of the above crop related to soil OM contents is especially important. As a first attempt, the dataset of N fertilization trials with winter wheat has been established (CSATHÓ et al., 1996).

Material and Methods

Data on farmyard manure and mineral fertilizer application in Hungary are published by the National Office of Statistics (KSH), and by the Ministry of Agriculture (FM STAGEK, AKII Inf. Ig.).

Hungarian N-balances were calculated according to KÁDÁR (1987). This simplified method takes the following sources into consideration: A) The amount of N applied with fertilizers was determined by using the data of the Hungarian Statistical Booklet of Agriculture. B) The N amounts of the by-products remaining on the fields were estimated as follows: The total amount of maize and sunflower stalk remaining on the fields. On 1/3 of winter wheat fields straw was incorporated into the soil. On these areas it was considered that 20% of the total aboveground N contents at harvest remained in the fields in the straw. C) 50% of the total aboveground N of Leguminaceae was considered to be taken up through biological N fixation, this way the above amount was counted also in the "Replaced" column. D) The amount of farmyard manure used in agriculture was taken from the Statistical Yearbook between 1932 and 1975, while from 1984 to 1991 the yearly amount produced was estimated by using the animal husbandry data. According to our estimation, 10 tonnes of farmyard manure (with average contents of 0.3% N, 0.3% P_2O_5 and 0.6% K_2O) are produced yearly by one animal unit. 1 horse or cattle, 10 pigs or sheep, or 500 poultry were considered as one animal unit. Because of serious losses during the storage of farmyard manure, and the introduction of strawless technologies in animal husbandry, with a great loss of liquid manure, too, only 50% of the produced farmyard manure was considered to be applied in the fields between 1984 and 1991. E) Other sources (i. e. seed N content, mineralization of N etc.) and losses (removed by erosion, or leaching etc.) were assumed to eliminate each other.

The N supply of Hungarian soils was determined by the organic matter (OM) content, according to TYURIN (1951).

The dataset of 34 fertilization trials set up at 13 locations throughout the country was compiled for the years 1955-1975 (Table 1). Among the various treatments, the yields of the absolute control, the farmyard manure treatment and the one with equivalent amounts of NPK in the form of mineral fertilizer were evaluated. The average yields of the various field crops were converted into grain units (GU).

Table 1

Basic data and references of Hungarian long-term field experiments with farmyard manure and mineral fertilizers, set up on the principle of nutrient equivalence (ÁRENDÁS & CSATHÓ, 1996)

Location	Soil type		Number of trials	References
	Hungarian classification	FAO classif.		
Hortobágy-Halastó	Meadow solonetz	Solonetz	1	BÁNSZKI, 1992
Karcag	Meadow chernozem	Phaeosems	2	NMKI Évkönyv, 1966; BOCSKAI 1974
Keszthely	Brown earth, according to Ramann	Cambisols	1	NÉMETH et al. 1989; NÉMETH 1991
Kiskundorozsma	Sandy soil, calcareous in the sub-soil, slightly humous	Regosols	1	ANTAL et al. 1966
Kisújszállás	Salt-affected soil, non- calcareous, ameliorated	Solonetz	1	MIHÁLYFALVI, 1968
Kompolt	Chernozem brown forest soil	Phaeosems	3	PEKÁRY, 1970; HOLLÓ, 1993
Kompolt-Albertmajor	Brown forest soil with clay illuv.	Luvisols	3	HEGYI, 1969
Martonvásár	Chernozem with forest residues	Chernozems	10	BALLA, 1964a,b, 1974, 1980; GYŐRFFY, 1979a,b; KOLTAY, 1967; SARKADI, 1965, 1975, 1991; SARKADI & BÁNÓ, 1967; SARKADI & THAMM, 1991
Mezőnagymihály	Meadow soil, salty in the deeper layers	Vertisols	3	BALLA, 1967
Nagykálló	Brown forest soil, sandy	Acrisols	3	BALLA, 1967, 1974
Nyírlugos	Brown forest soil, sandy, with alternating thin layers of clay substance (kovárvány)	Acrisols	1	LÁNG, 1973
Őrszentmiklós	Sandy soil, calcareous, slightly humous	Regosols	1	LATKOVICS, 1977
Pesthidegkút	Brown forest soil, silty	Lavisols	4	BALLA, 1967; LATKOVICS, 1977

A database was compiled from the results of 1- to 10-year-old Hungarian nitrogen fertilization field trials with winter wheat found in literature. In all trials by-products were removed from the fields. Soil characteristic data of PK (N-control) treatments, grain yield data of PK and also PK + N treatments giving maximum economic yields (about 95% of the maximum yields) were collected. The results were classified according to soil OM groups.

Results and Discussion

N balances in Hungary, 1932 - 1991

From the turn of the century to the late 50's, N balances in Hungary were strongly negative: 20-30 kg/ha/year less N was given to the fields in different forms (farmyard manure, mineral fertilizer and by-products, etc.), than was removed by the harvested yields (Table 2). N balances became positive in the early 70's, and were positive by 10-20 kg/ha/year for 20 years. From the early 90's, however, the dramatic decrease in fertilizer use resulted in the change of nutrient balances: in 1991 the N balance was -60 for the whole country, resp. In 1992 and 1993 the situation was similar, while in 1994 and 1995 a slight increase was registered in mineral fertilizer use.

The ratio between organic and mineral N inputs as sources went through a tremendous change during the last 60-year period. At the beginning the majority was given in organic forms, from the early 60's the mineral source became more and more dominant (up to 80%), while in the early 90's the percentage of organic N sources started to increase again (nearly 50%) (Table 2).

Table 2

Average N balance of Hungarian soils, kg/ha agricultural area, 1932-1991. (KÁDÁR, 1979, 1987; CSATHÓ, 1994)

Items of balance	1932-1936	1960-1964	1971	1975	1984	1990	1991
Taken up with yield	40	47	64	80	96	80	103
Replaced							
- With farmyard manure	7	7	8	9	8	6	6
- With fertilizer	-	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
Ratio of organic and mineral N sources, %	100/0	44/56	20/80	18/82	17/83	25/75	46/54

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

Changes in the N supply of Hungarian soils, 1960 - 1990

The long-term positive nutrient balances during the 70's and 80's resulted in the N(PK) enrichment of our soils, which was also proved by the national soil test series (Table 3). The improvement in the N status of the soils is evident: while in the early 60's only 7% of the fields were well supplied, at the end of that decade 20%, at the end of the 70's 30%, and at the end of the 80's 40% of the fields were well or very well supplied with N (STEFANOVITS & SARKADI, 1963; KÁDÁR,1992; KOVÁCS, 1984; BARANYAI et al.,1987; BUZÁSNÉ et al., 1988).

Table 3
Changes in the N supply of Hungarian soils, 1960-1987.

Category of supply *			Date	Remarks	References
Very poor, poor	Medium	Good, very good			
64	29	7	1960	on agric. cultivated areas	STEFANOVITS & SARKADI, 1963
40	40	20	1960-70	on agric. cultivated areas	KÁDÁR, 1992
26	44	30	1977-81	on agric. cultivated areas (1st nat. soil anal. series)	KOVÁCS, 1984
30	32	37	1982-85	on 75% of arable lands (2nd nat. soil anal. series)	BARANYAI et al., 1987
25	37	38	1987	on >800 000 ha maize	BUZÁSNÉ et al., 1988

* in % of area

During the intensive fertilizer use in the 80's, for example, the amount of yearly applied mineral fertilizer was 230 - 280 kg/ha N + P_2O_5 + K_2O/arable land. In certain regions N leaching could cause environmental damages (ÁNGYÁN & MENYHÉRT, 1988; DEBRECZENI & DEBRECZENI, 1994; KÁDÁR, 1988,1992; NÉMETH et al. 1987-88; NÉMETH & BUZÁS, 1991).

Organic matter map of Hungarian soils

The distribution of Hungarian soils according to their organic matter content is represented in Table 4 and Figure 1. This evaluation was based on national soil surveys by 6-12 hectare units every three years (BARANYAI et al., 1987).

Soil organic matter content is between 1 and 3% in about 2/3 of Hungarian soils. In sandy soils it is usually below 1% (15% of the area), while in clay loams between 3 and 4% (also 15% of total area). It is over 4% in about 5% of the territory (Table 4).

Sandy soils with low organic matter contents are situated in the south-western, in the central, and in the eastern part of Hungary, while those with the highest OM contents are found in the south-eastern part, resp. (Figure 1) (BARANYAI et al. 1987).

Table 4

Distribution of Hungarian soils according to soil organic matter content groups (BARANYAI et al., 1987)

Land area	Soil organic matter (OM) content, %				
	< 1.00	1.01-2.00	2.01-3.00	3.01-4.00	> 4.01
In 1000 ha	516	1173	1063	530	158
In per cent	15.0	34.1	30.9	15.4	4.6

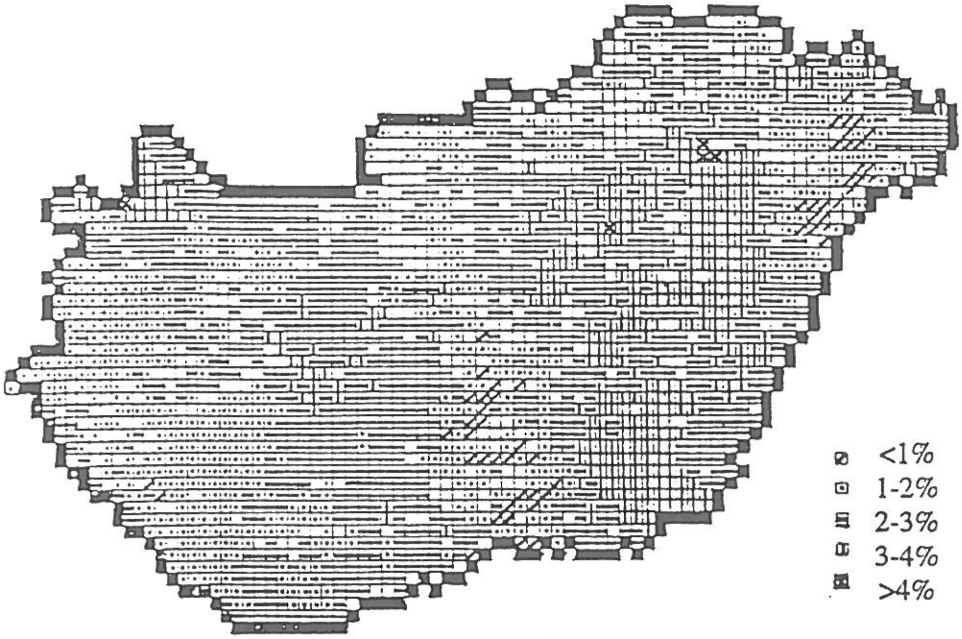

Figure 1

Distribution of Hungarian soils according to their organic matter content (BARANYAI et al., 1987)

Comparison of the effect of equivalent nutrients given in the form of farmyard manure or fertilizers in Hungarian long-term field trials

The results of the Hungarian field trials with farmyard manure (FYM) and mineral fertilizers (FER) [set up on the basis of nutrient equivalency, grouped according to their soil texture] showed that - with the exception of extremely clayey soils - annual mineral fertilization was more favourable (by 0.42 t/ha GU on the average) than periodic farmyard manure (FYM) application (Table 5).

The efficiency of fertilization in both farmyard manure and fertilizer treatments was the best on the light (sandy, sandy loam) soils, which have the poorest natural nutrient supplying capacity. On the average of 34 trials found in literature, surpluses to the unfertilized control plots were 0.76 t/ha GU/year due to the effect of FYM application, and 1.18 t/ha GU/year to equivalent mineral fertilization. This means that the surpluses gained by the 32 t/ha/4 years aver-

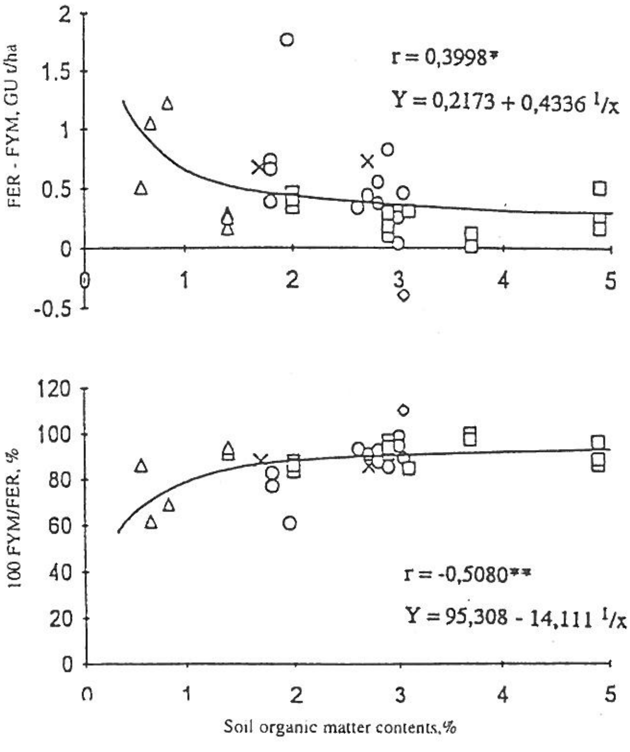

Figure 2
Correlation between the soil organic matter contents (OM) and absolute (GU t/ha) and relative (%) yield differences of farmyard manure (FYM) and fertilizer (FER) treatments in the nutrient equivalency experiments (ÁRENDÁS & CSATHÓ, 1996)

Table 5

Average fertilizer rates and yields in the nutrient equivalency experiments (ÁRENDÁS & CSATHÓ, 1996)

Soil texture	No. of trials	FYM t/ha/cycle	kg/ha/year				Main yields in GU*, t/ha/year			FYM/FER %
			N	P_2O_5	K_2O	Total	Ø	FYM**	FER***	
Sandy soils	6	27.8	42	23	46	111	2.00	2.96	3.49	84.8
Sandy loams	2	42.0	68	41	61	170	3.56	4.71	5.41	87.1
Loams	13	35.3	58	34	59	151	3.03	3.84	4.39	87.5
Clay loams	12	30.1	34	18	39	91	2.33	2.85	3.10	91.9
Clayey soils	1	50.0	53	36	54	143	3.30	4.26	3.87	110.1
Mean (total)	34	32.0	48	26	50	124	2.64	3.40	3.82	89.0

* GU = grain units; ** FYM = farmyard manure; *** FER = mineral fertilizer

Table 6

Correlation between soil OM content and responses to N application in Hungarian field trials with winter wheat, set up between 1960 and 1990 (CSATHÓ et al., 1996)

Soil organic matter (OM) groups, %	No. of trials	K_A*	Soil organic mater (OM) content, %	N dose, kg/ha**	Grain yield on PK plots (N control)	Relative yield, % (PK/NPK)	Surplus, t/ha (NPK-PK)
< 1.0	4	28	0.74	143	1.88	57	1.50
1.01-2.00	19	38	1.56	105	2.26	63	1.34
2.01-3.00	22	43	2.73	119	3.02	82	0.78
3.01-4.00	17	45	3.61	86	2.91	76	0.79
> 4.01	4	47	4.48	79	3.78	81	0.89
Mean (total)	66	41	2.60	105	2.75	74	0.99

* upper limit of plasticity, according to Arany; ** The N amount needed for maximum economic yield (~ 95% of maximum yield)

age farmyard manure application reached 89% of the surpluses gained by the equivalent NPK mineral fertilizer application. Surpluses were affected, however also by the yearly amounts of the applied nutrients which did not reach the optimum level on the average of whole rotations (Table 5).

The connection between the soil organic matter (OM) content of control plots and the comparative effects of FYM and FER, resp., can be described by hyperbolic functions (Figure 2).

It was found that the higher the soil OM content of the control plots was, the lower the advantage of equivalent nutrients applied in the form of mineral fertilizers was over FYM.

A similar correlation was established between the AL- (ammonium lactate) (EGNER et al., 1960) soluble K contents and differences or ratio of the responses to farmyard manure (FYM) and fertilizer (FER), respectively.

Soils with higher clay and OM contents have a higher natural nutrient supplying capacity, and as a consequence, nutrient deficiencies are less expressed in such soils after the 3rd-5th year of previous FYM application (ÁRENDÁS & CSATHÓ, 1996).

The effect of soil OM contents on responses to N fertilization in the dataset of Hungarian field trials with winter wheat

The correlation between soil OM content and responses to N application was examined on the dataset of Hungarian field trials with winter wheat, carried out between 1960 and 1990 (Table 6).

Evaluating the results of the Hungarian 1- to 10-year-old nitrogen field trials with winter wheat, the following conclusions were drawn:

a) As a result of N application, surpluses in winter wheat varied between 0.8 and 1.5 t/ha, depending on the soil OM groups (Table 6);

b) The soil OM values indicated the natural N-supplying power of the different soils quite adequately, i.e. on soils with higher OM contents responses of wheat to N application were diminished;

c) As an effect of increasing soil OM content, the amount of N needed for maximum economic yields (~0.95 x maximum yields) of winter wheat decreased significantly (CSATHÓ et al., 1996).

Conclusions

Although the application of mineral fertilizers was superior to the equivalent amount of NPK given in the form of farmyard manure, the latter also has an important role in maintaining and increasing the fertility of Hungarian soils.

Responses to N application and optimal N doses strongly depend both on soil OM contents.

The new N supply categories for Hungarian soils - expressed in OM contents, and based on the evaluation of the dataset of long-term field trials - are sometimes lower than those in former fertilizer advisory systems (CSATHÓ et al., 1996). The use of the new OM content categories can help in establishing a new, environmentally friendly N fertilizer advisory system (NÉMETH et al, 1997).

Summary

The paper presents the changes in national N balances for agricultural soils during the last 60 years, and changes in the ratios of organic and mineral input N sources.

Synthesis of the results found in literature of Hungarian long-term field trials with farmyard manure and mineral fertilizer application, set up on the principle of nutrient equivalencies are also presented in the paper.

It was found that in the experiments, grouped according to their soil texture - with the exception of extremely clayey soils -, annual fertilization was more favourable in all cases than periodic manure application. The correlation between the changes in the organic matter (OM) content in the ploughed layer of control plots of the long-term field trials' soils, and differences or ratios of the responses to farmyard manure (FYM) and fertilizer (FER), resp., could both be described by hyperbolic functions.

The evaluation of the dataset of the Hungarian N-fertilization field trials with winter wheat between 1960 - 1990 has shown that N was the most effective mineral nutrient in increasing the yields of the above-mentioned crop.

Related to the soil organic matter (OM) content groups, the responses of winter wheat to N application varied between 0.8 and 1.5 t/ha. As an effect of increasing soil OM content, the amount of N needed for maximum economic yields (~0.95 x maximum yields) diminished significantly.

As a result of the present evaluation, new N supply categories were elaborated for the economic, sustainable N nutrition of winter wheat.

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