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IMPACT OF FERTILIZERS ON THE QUALITY OF GROUND WATER MONITORING IN FIELD EXPERIMENT CONDITIONS

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ABSTRACT

On the Bohemian-Moravian Highlands a test was carried out in the period 1977 - 1979 on an area of 30.5 ha of arable land which have been sown three times in succession with spring barley to investigate the relationship between the quantity of applied fertilizer, the cereal yield and ground water quality.

A close relationship has been proved among the nitrate contents of ground water and the quantity, manner, sort and frequency of applied fertilizers. The importance of division of the nitrogen fertilizer doses into three applications was stated from the standpoint of qualitative ground water protection, the optimal result being achieved when the first dose had been applied at sowing time in the form of ammonium sulphate. Excessive fertilizer doses gave rise not only to high nitrate waste into ground water but also to a reduction of sorts and quantities of macroorganisms in the soil. The investigation is continuing with particular emphasis on nitrogen distribution in the unsaturated zone when changing agricultural crops in the usual sowing regime.

INTRODUCTION

Owing to the application of constantly increasing quantities of fertilizers in arable land, ground water non-point pollution has become a world wide problem. There is a possibility of ecological hazard of the subsurface water mass, the restitution of which evidently would not be immediate and what is more it could cause social and economic consequences for a long time to come.

Up to now, the impact of agricultural activities on ground water quality has become the subject of investigation and of subsequent practical measures in only few countries. Investigations carried out on extensive experimental agricultural areas are an important contribution to the solution of such a demanding task which may be simply called "optimal production of digestible albumens from arable land with minimal impact on ground water".

RESULTS

Geological, pedological and hydrogeological characteristics

The investigation area covering 30.5 ha was divided into 7 plots marked from I to VII and the plots separated from each other by 25 m wide unfertilized strips (Fig. 1.). The altitude above sea level i from 490 to 520 m, the natural surface declination from 3 to 5%. The area is marked with considerably differing precipitation and temperature between the winter and summer periods.

The basement is geologically formed by monotonous series of moldanubic crystallinic of the Bohemian Massive (biotic paragneiss), weathered exceptionally up to 10 m in depth. Weathered material may be designated as partially replaced sandy-clay eluvium.

Soils. The origin of the brown acid soils was genetically affected by gneiss weathering under relatively higher precipitation and lower temperature. The soil thickness varies from 30 to 120 cm with an expressive low percentage of clay fraction (low water cohesity) and with a high percentage of sand fractions (higher permeability). The sorption capacity of the cultivated layer varies from 17.4 to 18.1% and drops to from 7.6 to 11.9% towards the basement. The sorption saturation (77.9 to 38.2) and soil acidity (6.9 to 4.0%) in the soil profile goes down in a similar way. The soil generally has little capacity of nutrient binding on the bio-organic-mineral complex.

Hydrogeologically, the area is uncomplicated. There is a shallow aquifer with free water level in the eluvio-diluvial deposits. In accordance with their thickness, the water level varies from 1.0 to 6.8 m under the surface. The test field is situated between the local watershed line and the edge of the erosive base of the local river. It obtains its moisture solely from the total registered precipitation on this field. The water level gradient goes from SE to NW. The hydraulic gradient I varies from $5.6 \cdot 10^{-2}$ to $8.9 \cdot 10^{-2}$, the transmissivity T varies from $1.5 \cdot 10^{-6}$ to $4.6 \cdot 10^{-6}$ $m^2.sec^{-1}$, k varies from $2.5 \cdot 10^{-7}$ to $10.5 \cdot 10^{-7}$ $m.sec^{-1}$.

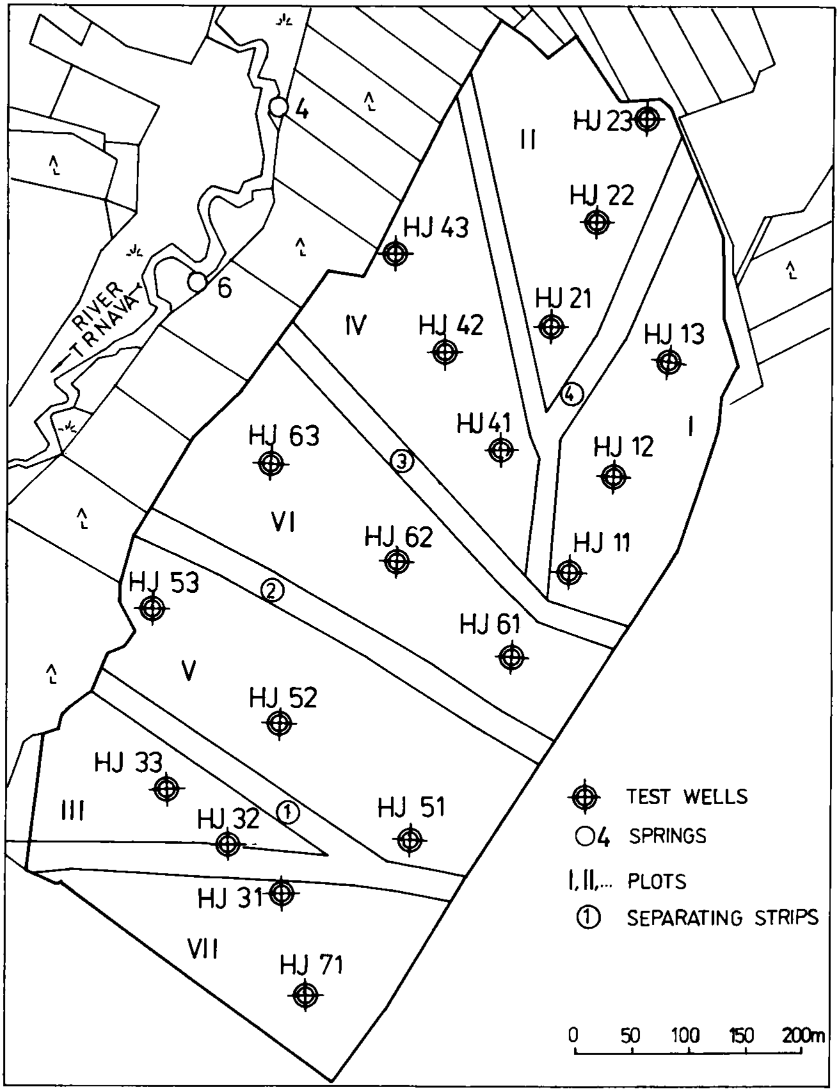


Fig. 1. Scheme of the test field

Relationship between rainfall und run-off

Precipitation is predominantly during the vegetation season when its distribution was monitored in detail and the quantity of storm precipitation was evaluated, too (Table 1). The year 1977 was extremely rich in precipitation. The difference between 1978 and 1979 in precipitation is without significance (2.7 mm), but the difference in barley yields in the same period is remarkable. Reduction

TABLE 1

Monthly precipitation totals (mm) in vegetation seasons 1977 - 1979

Year	Months IV	V	VI	VII	VIII	IX	X	Vegetation season total
1977	45.5	39.9	74.3	118.5	149.5	61.9	29.8	519.4
1978	34.2	67.2	31.3	87.4	103.5	64.0	48.7	436.3
1979	51.3	31.8	116.3	83.2	41.7	88.2	21.1	433.6

TABLE 2

Rainfall and run-off data

Hydrological year	Run-off per unit	Precipitation (mm)	Evapotranspiration (mm)	Specific run-off				N flow in kg/ha/year
				total	base	subsurface	surface	
1977	mm	784	568.50	215.50	19.30	129.74	66.46	43.70
	l/sec/km^2	-	-	6.83	0.62	4.10	2.11	
	%	100	72.50	27.50	9.10[x]	60.00[x]	30.90[x]	
1978	mm	579	481.25	97.75	17.28	73.27	7.20	22.70
	l/sec/km^2	-	-	3.10	0.55	2.32	0.23	
	%	100	83.10	16.90	17.75[x]	74.85[x]	7.40[x]	
1979	mm	666	385.20	280.82	50.46	154.00	76.36	44.80
	l/sec/km^2	-	-	8.90	1.60	4.88	2.42	
	%	100	57.80	42.20	18.00[x]	54.80[x]	27.20[x]	

x = % of the total run-off - hydrological data (ref. 1) in yields in 1979 (1.2 t/ha) was evidently due to unfavourable distribution of precipitation in May and in the first half of June (less then 50% of 1978) and due to higher temperature in the same period (plus 1.3 to 2.4°C). The relationship between rainfall and run-off of the test field may be found in table 2.

Test arrangement

The test was carried out in 1977 - 1979. The proprietor of the whole field (an agricultural cooperative) was responsible for sowing, fertilizer application, harvest, ploughing and for other agricultural activities. The investigating team directed and controlled the activities of the cooperative and at the same time carried out its own investigations.

First of all, on the whole test field 19 test wells were drilled and filled by screens (2 - 3 wells on each plot), of a diameter of 95 mm, made of polyethylene, the lower 5 m part being perforated. Each test well was equipped with a hand pump. The working cylinder with piston was situated at a depth of 7.5 m. An observation tube of 1" diameter was laid on the well wall to measure ground water level. Plot VII was meliorated. A limnigraph with a Thomson weir and a soil loss tank were situated at the drainage head. A field laboratory was set up at the site of the experiment.

Spring barley (Favorit) was sown in three consecutive years. From the agricultural standpoint, the test field was included in the cereal-potato soil type. The sorts of fertilizer employed for the test and quantities, manner and application time may be found on table 3. The dose of 70 kg N in pure nutrients per ha was fixed as basic, when 140 kg N/ha is the dose for simulation of excessive fertilizing. Superphosphate (300 kg/ha) was employed for phosphate fertilizing and potash for K fertilizing (48 kg K in pure nutrients per ha).

Data monitoring

Ground water (wells, drainage, springs) were sampled altogether 20 times a year for a complete chemical analysis with more frequent sampling during the vegetation period.

Precipitation - sampling for chemical analysis several times during the season (normal precipitation and storms).

Surface and subsurface water - sampled for chemical analysis 20 times a year at drainage head and in adjacent river.

TABLE 3

Summary of plots I - VII and employed fertilizer sorts, doses and application

Plot Nr.	Fertilizer sort	All-year doses of kg N/ha	Three applications in all cases : at
I	Ammonium sulphate	70	sowing, tillering, shooting
II	Ammonium sulphate	140	sowing, tillering, shooting
III	Ammonium nitrate + Ca	70	sowing, tillering, shooting
IV	Ammonium nitrate + Ca	140	sowing, tillering, shooting
V	Combination of ammonium sulphate, ammonium nitrate + Ca	70	sowing, tillering, by plane at earing
VI	As in case of plot V	140	as in case of plot V
VII x)	Ammonium nitrate + Ca	70	sowing, tillering, shooting

x) Meliorated plot

The soil was sampled 20 times a year, each time one day before water sampling. Chemical analysis (leachate), microaedaphon analysis (total number, microorganism activity and dynamics), macroaedaphon analysis (with particular regard to Lumbricus species) and catalaze analysis were carried out.

Plants - total quantitative analysis of biogenic elements in plants including total nitrogen. In barley, phenometry and phenology (growth and development monitoring), exact yield determination separately from each plot, segetal vegetation analysis.

Climatological measurements - complex measurements including precipitation at a special meteorological station built directly on the field.

Nitrate natural background in landscape with minimal agricultural pollution

The nitrate natural background of the investigated area was controlled by a test well situated at the edge of an extensive forest. The well was filled by a screen in a manner analogical with the wells on the test field. The NO_3 content during the vegetation season was 3.4 to 5.3 mg/l.

Orientation balance of nitrogen migration

One goal of the field test was to collect data for the individual balance items of the nitrogen small circulation cycle in one year with particular regard to nitrogen losses in ground water.

The original natural landscape ecosystem kept the nitrogen increase and decrease in equilibrium which may be expressed as follows:

I.	N	+	N	+	N	=	N	+	N	+	N
	from precipitation		from organic mass		fixation + nitrification		vegetation		denitrification		into water

nitrogen increase = nitrogen decrease

For further calculations which were concerned with the brown type soil and first yield without additional nitrogen fertilization, the quantity of nitrogen taken from the soil reserves was determined as 88 kg which corresponds to a yield of 2.2 t/ha. This value was set according to agricultural investigation results in this area (ref. 2) and to a statistical study of cereal yields of agricultural cooperatives.

Superiority of nitrogen increase over losses may be expressed as follows :

II.	88 kg N	=	N	+	N	+	N	-	N	-	N	-	N
			from precipitation		from organic mass		fixation + nitrif.		weeds		denitrification		losses into water

In further years, after the addition of 70 kg N in pure nutrients per ha, we get the left hand side of the equation :

88 kg + 70 kg = 158 kg N.

Individual balance equation items may be expressed by values of kg N/ha as follows :

III.	158 kg N at yield Ø 3.4 t/ha	=	15 kg N from precipit. 600 mm	+	30 kg N cca 1% of soil storage	+	189 kg N from macro- and microaedaphon	+	10 kg N fixation + nitrification	-
	1		2		3		4a + 4b		5	
		-	x kg N from denitrific.	-	37 kg N losses into groundwater	-	8 kg N into surface water	-	8 kg N into weeds	
			6		7		8		9	

158 = 244 - x - 53 x = 33

Denitrification processes can be quantified as 33 kg N/ha.

Explanatory notes to individual balance equation items :

1 - About 79 kg N a year get into crops at a yield of 3.4 t/ha. Thus the available nutrients are being built into crops with about 50% efficiency. Nutrient contents were determined in laboratories.

2 - 15 kg N are transported into the soil by 600 mm of precipitation.

Relation $NO_3 : NH_4 = 1 : 1$. One hectare area is supplied by storm precipitation with N concentration double of normal one.

3 - 30 kg N represent 2% of humus quantity on average from arable soil layer up to depth of 25 cm, determined in laboratories. Arable soil specific weight 1.5. Proper leachate determined by guess (order of magnitude).

4a- Macroaedaphon - 50 kg N from earthworms and their excrements and 80 kg N from other aedaphon on an average, i.e. a total of 130 kg N. Macroaedaphon values stated by weighing, laboratory analysis and qualified guess.

4b- Microaedaphon - total quantity 59 kg N. Data on microaedaphon correspond to guess of order of magnitude, the life period of bacteria and actinomyceta being very short (about 80 generations in a vegetation period). Up to now, it has been difficult to monitor the microorganism share which became food for other destruents and zoo-predators and the quantity of microorganisms accessible to plant roots with possible losses into ground water. Each year in May, the April quantity of soil biomass increases by about 100%. In June, the nutrient materials suitable for microorganisms being depleted, they begin to decrease to April values approximately. The difference between May and June may be taken as a sum which supplies soil with nitrogen after microorganism mineralization (1 to 3 weeks). Nitrogen forms about 10% of the weight of microorganisms. After the onset of frost (December and January) comes microorganism mass extinction and after mineralization their nitrogen may be considered one of the causes of nitrogen maximal wash out into ground water at the spring thaw. Macroaedaphon analysis and microaedaphon testing were carried out by the microbiological laboratory of the Technical University of Agriculture in Prague.

5 - Due to soil sandiness the air nitrogen main fixator Azotobacter Chroococcum fixes 0.5 kg N/ha only. Amylobacter and other fixator fixation is therefore evaluated very low. In spite of many determinations and tests the resulting sum of fixation and nitrification has been stated by qualified guess only.

6 - In the equation, denitrification is taken to be unknown. The computed value of 33 kg N is of course influenced by the sum of errors of individual balance items.

7 - Nitrogen losses into ground water were stated by regular chemical analyses in wells on the individual spots, in temporary springs

and from the adjacent Trnávka river. The unsaturated zone was not monitored for any particular purpose. For information only, the run-off from drainage heads was used for analysis. It contains 127 mg NO_3/l on an average.

8 - Nitrogen losses into surface water. The run-off from the test area is minimal and nitrogen losses were quantified by guess. In the watershed where the test area lies the losses were monitored precisely.

9 - The weed vegetation was monitored as to its quantity and types up to the time of herbicide employment (between the second and third pair of proper leaves).

DISCUSSION OF RESULTS

On figs. 2. and 3. and on tables 4 and 5, the relationship among nitrogen fertilizing, yields and ground water pollution may be seen. The best results were obtained on plot V. The test carried out on plot VI proved that a further cereal yield increase (25%) is possible by fertilizing intensity elevation (100%) but at the cost of high pollution of ground water (NO_3 contents having risen by 220%). Greatly excessive fertilization may be found on plot IV which had an application of 140 kg N/ha in the form of calcium ammonium nitrate. With this fertilizer dose the yield decreases to 97.6% and the ground water pollution rapidly rises to 171.6 mg NO_3 per liter. This result is not favourable for agriculture and neither for water economy.

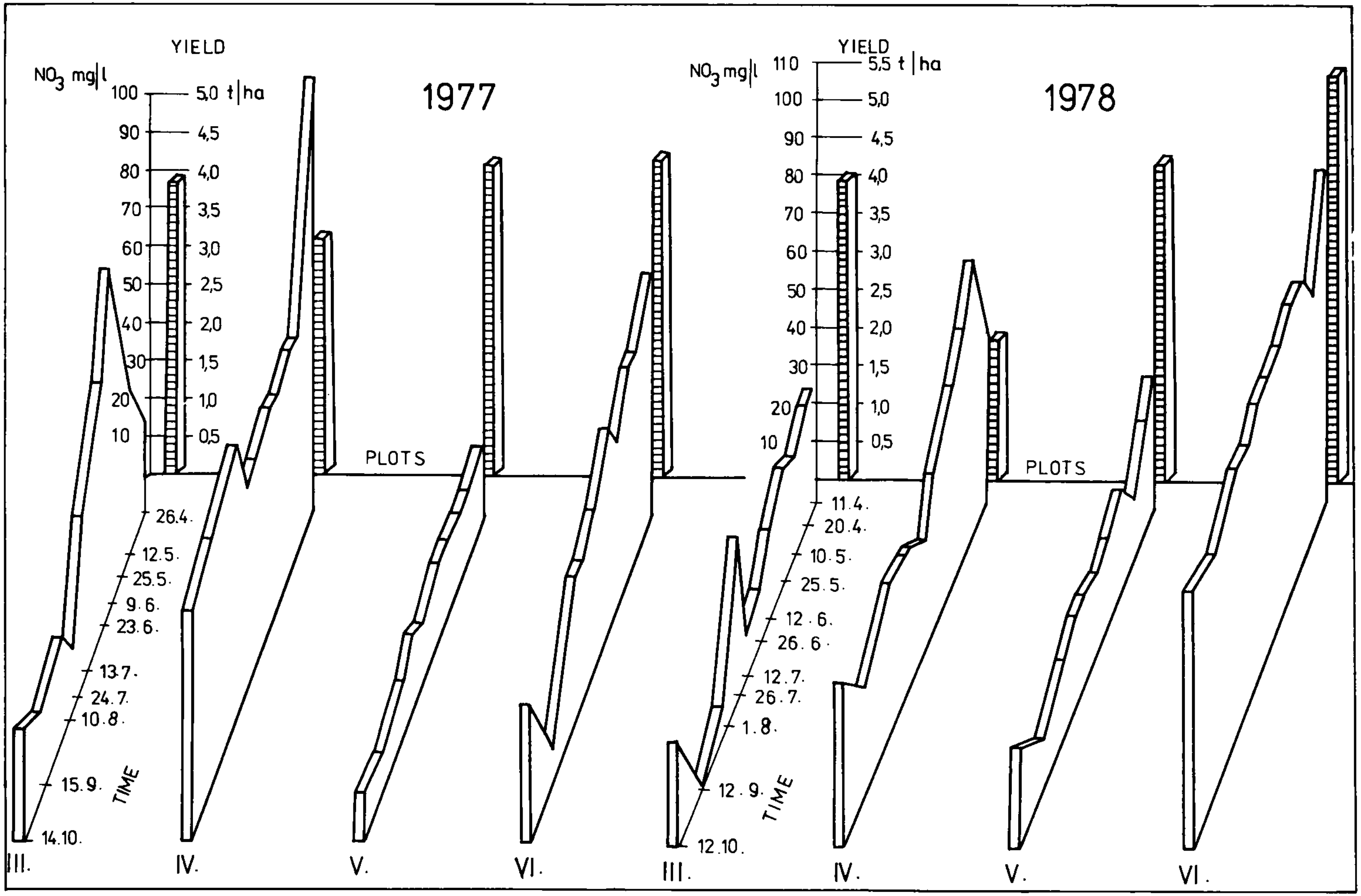
TABLE 4

N - NO_3 average concentrations in mg/l in ground water of individual plots

Fertilizer	non-veg.		veget.	non-veg.		veget.	non-veg.		veget.
		Ø 1977			Ø 1978			Ø 1979	
70 kg N in AS	33.6	37.1	40.6	38.7	45.4	52.0	61.3	61.6	61.9
70 kg N in CAN	40.7	47.7	54.7	55.7	46.6	37.5	47.1	50.7	54.3
70 kg N comb.	23.2	20.4	17.6	14.5	18.9	24.2	33.1	39.9	46.6
140 kg N in AS	27.7	43.8	59.8	59.8	53.9	47.9	78.3	72.7	67.0
140 kg N in CAN	55.8	65.4	74.9	63.6	54.9	46.2	52.0	45.1	38.2
140 kg N comb.	42.2	54.4	66.5	63.4	68.9	74.3	75.5	79.3	83.0

AS = Ammonium Sulphate CAN = Calcium Ammonium Nitrate
comb. = AS (1/3) + CAN (2/3)

A balance equation for the dose of 140 kg N/ha cannot be set up, because the linear relations between fertilizer increase and yield increase are no long valid.



Figs. 2., 3. Comparison of yields and nitrate content in groundwater on plots III - VI

TABLE 5

NO_3 and N average wash-out in relation to barley yields

1 ha surface	70 kg N in pure nutrients	140 kg N in pure nutrients
NO_3 mg/l contents in ground water	Ø 39.7	Ø 57.7
N mg/l contents in ground water	9	13
crops in tons/ha	Ø 3.40	Ø 3.32

Macroaedaphon reaction to different doses of fertilizers (70 and 140 kg N/ha) was remarkable. At lower fertilizer doses nitrogen supplies derive even from macroaedaphon bodies and excrements, on an average 130 kg/ha. However because of excessive fertilization, nitrogen supply of this origin decreases to 91 kg/ha. It means that doubled artificial nitrogen doses applied at economic expense to the field causes that the natural nitrogen supply from macroaedaphon decreases by one third.

An elevated nitrogen dose influences the microaedaphon of individual sorts but excessive fertilization does not influence negatively the sum of nitrogen due to the capacity of microaedaphon to replace the extinct populations by other sorts.

Some inaccuracies in several items of the balance equation for nitrogen migration and weather change influences in 1977 - 1979 have rather more generally than in detail permitted :

1. to detemine the nitrogen balance and migration in vegetation - soil - ground water system
2. to express the degree of ground water pollution with regard to the quantity, sort, manner and frequency of employed fertilizers.

CONCLUSIONS

In harmony with the results of different authors (refs. 3 - 5) increasing ground water pollution by nitrates, above all on areas used for cultivation of cereals has been proved. At the same time, the relationship between the degree of ground water pollution and the quantity of employed fertilizers is evident. Within the frame of the investigations, hydrochemical, geobotanical and other aspects have been studied and the results have been elaborated in detail in other reports.

The investigation is to continue up to 1984. Nitrogen distribution monitoring in unsaturated zone and field tests with model employment (one-dimensional vertical model) have been added. Simultaneously agricultural plant alternation within the current sowing regime has been introduced.

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