Importance of Long-term Field Experiments in Sustainable Agriculture for Hungary

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Long-term field experiments (LTFE) are fundamental not only for agriculture, but for many other environmental questions that require public action if the quality of life here is to remain acceptable. Long-term is defined herein as decades to centuries. Fundamental means knowledge without which rational decisions about the management of our agriculture and environment cannot be made.

Theoretical approach and methodology for LTFE

There is a nearly universal acceptance of the fact that most long-term ecological research is inherently interdisciplinary in nature. The successful performance of long-term field experiments requires the special recognition of certain key elements in the work. The scientific questions and objectives must be clearly defined and stated because they must guide research for several generations of scientists, administrators and funding agencies.

The people involved in the LTFE must possess a shared philosophy, appropriate training, the acceptance of a team leadership, and mutual trust and respect. The site at which long-term field experiments are performed must be representative of the biological and ecological (soil, weather, type of cultivation, etc.) setting. Both the site and research programme must have solid financial support and continuity, and they must have a strong group of people associated with them. Of course, the actual application and implementation of long-term field experiments may vary from place to place and time to time.

Scientific creditability can only be achieved in long-term research if the methodology is appropriate, documentation and quality assurance are guaranteed, and uniform fertilizer application, cultivation, sampling techniques and procedures are used. A strong research history is also necessary and all data must be carefully recorded in situ. Accessibility and site security are also vital.

These circumstances can only be ensured at research stations with their own trained staff and equipment, and with the proper instruments for the implementation of field trials.

Scientists working within one country need to communicate, exchange data and discuss results with scientists working on the same topics in other parts of the world. Specific mechanisms should include exchange visits for joint research, sending scientists from one country to another for education and training, and the conduct of regular workshops and scientific conferences. The Hungarian Academy of Sciences has devoted considerable planning and resources to communications and coordination activities, providing the basis for the development of scientific cooperation in this field.

Why should long-term field experiments be done?

Every human use of the natural ecosystem results in the removal of material and embodied energy which are later not returned or broken down at the same place. This means that human uses change natural ecosystems through different forms of matter and energy transports, involving removal or supply. Long-term field experiments are vital in order to represent cumulative effects and unusual events caused by human use, agricultural practice, such as cultivation, manuring, etc.

Slow phenomena, or accumulative changes in soil properties may be captured only in long-term studies. Limited duration might miss important results, or worse, cause the results to be misinterpreted. Experiments in different years yield different results because of weather changes. Long-term experiments are one of the sure ways to determine slow processes.

The various experiments at Rothamsted, including both the classic and modern, symbolize the value of long-term studies in general. The original goals of several of these experiments have long since been fulfilled. However, they continue to be of value as demonstrations, and as sources of continuing insight into agricultural practice (JOHNSTON, 1989). In Hungary, most long-term field experiments are less than 30 years old, though this number has been increasing since the late 1980's, as the regional research stations and institutes were established in the late 1950's, and 1960's. The long-term field experiment network now has 25-28 year old experiments on 9 sites.

About the nature of LTFE

Long-term field experiments may incorporate historical data when appropriate. Usually there is a wealth of relatively unexploited data from existing LTFE. Without the timely analysis of the potentially rich resources of existing long-term data, we may be "reinventing the wheel". It is true that the existing

LTFE were mostly not intended to be long-term. But the value of the results of LTFE, whether those results are expected or not, is great.

Changes of unknown type include transient and indirect effects. This type of change is very common among the catalogue of anthropogenic effects. The most significant changes now facing society are anthropogenic ones (see for example the toxic heavy metal accumulation in the biosphere and the food chain). Changes in global climate are the other major class of environmental changes that are likely to be of unknown type. The magnitude and significance of such changes are only now beginning to be appreciated. The role of LTFE in documenting such changes and the ecological responses to them is clear.

LTFE may record unforeseen events and may give the necessary perspective into the sort and distribution of rare events in the past. Modelling can give an insight into suspected trends resulting from future periodic or unique events. Soil and plant samples should be archived for future analyses not now considered important, and for calibration with new techniques that may become available. The interpretation and extrapolation of the results of LTFE to other sites requires a variety of safeguards using soil and plant analyses as tools.

Questions to be answered in LTFE

Instead of setting up new studies to answer each question as it arises (the answer usually comes after the question has gone) the approach being considered is to make use of sites which are already well-established, with existing data. The questions are basically what is happening, where is it happening, what are the consequences, are there thresholds and is it reversible?

We know what today's problems are but what are the questions that will be asked in a few years' time and for which we should now be doing long-term research and monitoring? Although we cannot predict specifically, we can identify generic subjects: management effects, chemical pollutants, climate changes, etc. Apart from responding that "more research is needed" or that "it all depends on the conditions" most scientists will turn to their favourite site (LTFE) and, using their favourite methods, will measure the important new parameters.

Experience has shown that the range of pollutants and their effects are extremely variable and complex but the pressure to define cause and effect is great. In considering pollutant problems such as heavy metals the common questions concern the rate of deposition, transformation and retention of the element within the soil-plant system, its transfer through biological pathways and its toxicology. In other words, questions of element dynamics. The consequences are relevant to long-term research because the response times are often measured in decades. The response of soil processes, particularly nutrient release, are essentially long-term, a good example being the detection of enhanced heavy metal release from acidifying soil.

The short-term natural variation, e.g. year-to-year changes in crop responses, need to be separated from long-term trends. Is the nitrate concentration high because of increased fertilizer use or because of particular climate conditions? Trends are often induced in response to events occurring years or decades previously and a knowledge of site history is therefore particularly important (HEAL, 1989).

Data base management

The value of creating permanent plots, adequately documenting procedures, and creating a user-friendly data base cannot be over-emphasized. With few exceptions data bases have not outlived the investigators that collected them. Those that have survived have become ecological treasures. Most field experiments are three years or shorter in duration. Even these short-term studies, if adequately documented and site referenced, could be subsequently resampled for similar or other questions.

We can find a variety of new questions for old data sets. These data can be quickly reanalyzed, even in the absence of the individual responsible for the original data set. One cannot be serious about measuring decade-to-century level phenomena without making a serious time and financial commitment to documentation. In a partly slowly-changing ecosystem such as soil the proper data base management is vital; this will make the "invisible present" visible.

Changes in soil and fertilizer responses are time-dependent

LTFE make visible processes and events often invisible in most short-term experiments. As MAGNUSON (1983) stated: "Because we are unable to directly sense these slow changes and because we are even more limited in our abilities to interpret cause and effect relations for these slow changes, processes acting over decades are hidden and reside in the invisible present." This is the time scale of acid deposition, the introduction of synthetic chemicals, air borne pollution and climate changes made by man.

In the absence of long-term studies, serious misjudgments can occur not only in our understanding of events, but also in our attempts to manage our environment. An example of nitrogen additions to plots in an old field trial at Nyírlugos makes this clear. On this sandy acid brown forest soil poor in humus and nutrients, in the first decade (1963-1972) nitrogen alone increased the potato and rye yield substantially. In the second decade (1973-1982), yields on N plots declined dramatically to the N-control levels; phosphorus and, in part, potassium additions were needed to maintain or increase the yield of different crops (Table 1).

Table 1

Effect of fertilization on the grain yield of cereals. Acid brown forest sandy soil. Nyírlugos, 1964-1982, t/ha (LÁNG, 1973; SZEMES & KÁDÁR, 1990)

Treatment	1963	1965	1967	1969	1971	1973	1975	1977	1979
	Potato, variety Gülbaba					Potato, variety Desirée			
Control	8.5	6.8	8.4	10.7	10.1	6.0	5.9	14.4	3.6
N	12.8	15.1	13.3	14.4	14.5	11.6	12.4	15.6	9.0
NP	13.5	18.5	15.2	17.2	17.4	15.6	15.5	19.4	10.9
NK	13.4	16.7	15.4	17.0	16.4	14.8	12.5	22.4	10.8
NPK	13.7	19.3	16.3	19.0	18.4	21.0	18.2	26.9	12.7
NPKMg	13.6	19.3	16.9	20.4	19.3	19.1	17.0	28.1	12.6
$LSD_{5\%}$	0.9	1.1	1.0	1.0	1.0	0.9	1.0	2.6	2.4
Mean	12.4	14.0	14.5	16.2	16.3	14.8	13.9	22.6	11.1

Treatment	1964	1966	1968	1970	1972	1974	1976	1978	1980
	Rye, variety Kisvárda					Wheat, variety Mv 4			
Control	1.6	1.6	1.3	1.3	1.4	1.7	1.6	1.2	0.3
N	2.2	2.8	2.7	2.2	2.8	1.7	1.8	2.1	0.7
NP	2.2	3.3	2.9	2.3	3.1	2.9	2.6	2.4	1.1
NK	2.2	2.9	2.6	2.1	2.8	1.6	1.6	2.6	0.8
NPK	2.2	3.0	2.9	2.4	3.1	3.3	2.9	3.4	1.1
NPKMg	2.2	3.0	2.9	2.5	3.3	2.2	2.8	3.3	1.1
$LSD_{5\%}$	0.2	0.2	0.2	0.2	0.2	0.2	0.2	1.3	0.4
Mean	2.1	2.6	2.3	2.1	2.5	2.6	2.2	2.8	1.1

Fertilization: 90-160 kg N; 80-160 kg K_2O; 40-80 kg P_2O_5; 15-30 kg Mg per ha and year

During the third decade (1982-1992) nitrogen addition alone led to yield losses compared to the control. To maintain or especially increase the yield of different crops, phosphorus, potassium, calcium and sometimes magnesium additions were needed. The main point is that the response to nutrients (elements) or fertilization is time-dependent. This time series displays features invisible in one- or two-year experiments. Clearly, a short-term experiment, even though its results would be repeatable and statistically significant, does not fully reflect the changes induced by fertilization (Table 2).

Soil scientists have initiated long-term studies, mainly dealing with crop rotations and fertilization, that have provided valuable material to those working to synthesize and predict in today's environment. Soils have variables that operate at slow, intermediate and fast rates, so it is important to recognize the nature of the variable studied. Variables such as soluble salts or nutrients may be highly dynamic, varying over a season (nitrate) or less dynamic, reaching a tentative equilibrium in a few years (P-fixation), whereas organic matter levels have a time-dimension of decades to centuries, with clay weathering having a scale of millenia in semi-arid climates (ANDERSON, 1977).

The sustainability of soil fertility is the question of greatest concern in Hungary. LTFE and the practice of the past few decades have shown that soil fertility and yields could be sustained or increased over time even in continuous maize rotations, provided that adequate manure or chemical fertilizer was applied. On less buffered and slightly acidic soils in the Nyírség region, detailed evaluations indicated that chemical fertilizers had increased acidity and easily extractable forms of manganese, with exchangeable calcium and magnesium decreasing.

After 26 years of fertilization in the Nyírség LTFE, it was found that in P-plots the total Sr content of soil and sunflower plants was generally doubled. The P-fertilizer composition depends on the origin of the raw material and the technology used in its production. The Russian Kola-phosphate used for superphosphate production in Hungary contains nearly an order of magnitude more Sr and less Cd than N-African phosphates. Superphosphate may contain 1-2 % Sr, so build-up P-fertilization leads to Sr accumulation in the ploughed layer of fertilized soils and crops. At the same time the total Cd content remained the same.

Future research needs. An example of food chain studies

Because of the lack of exact long-term field experiments, a false picture may be drawn about the behaviour of little-known harmful elements and heavy metals. Based on the results of experiments carried out in nutrient solutions or pots, it is commonly accepted, for example, that Cd can be toxic at a concentration of over 10 ppm both for soil and plants, whereas the real problem is (as shown by field studies) that Cd is able to accumulate in the edible vegetative

Table 2

Effect of fertilization and liming on the yield of different crops. Acid brown forest sandy soil. Nyírlugos, 1982-1992 (t/ha)

	Winter wheat	Sunflower	Spring barley	Tobacco	Winter wheat		Triticale	
Treatment	1982	1984	1987	1988	1989	1990	1991	1992
Control	1.6	0.8	0.7	1.2	2.3	0.5	0.8	0.4
N	2.7	0.6	0.4	0.9	3.3	1.1	1.6	0.4
NP	3.5	1.0	0.8	1.8	3.6	1.1	4.0	0.8
NK	2.6	0.8	0.5	1.0	3.2	1.0	2.0	0.4
NPK	3.5	1.4	0.9	1.8	4.0	1.3	3.6	0.8
NPKCa	3.9	1.8	0.9	1.9	2.9	1.0	3.9	0.8
NPKMg	3.9	2.3	0.9	1.9	4.7	1.2	4.5	0.9
NPKCaMg	4.2	2.6	1.0	2.2	4.9	1.5	4.9	1.0
$LSD_{5\%}$	1.0	0.6	0.4	0.4	1.1	0.6	1.5	0.4
Mean	3.3	1.4	0.7	1.6	3.6	1.1	3.2	0.7

1988 - dry tobacco leaves

parts of crops without damaging them. This accumulation, however, may contribute to the Cd-load of grazing animals and man.

The fate of these elements must be followed in the food chain, in the soil-plant-animal system. Only the results of complex research work can be really useful. An attempt must be made to examine the phenomena in their complexity, in the way they appear in nature. The interdisciplinary cooperation now developing may provide an opportunity for a more detailed and comprehensive understanding of these problems.

Table 3

Treatments in the field experiments. Calcareous chernozem soil (Nagyhörcsök, 1991)

Element used	Applied in spring 1991, kg/ha				Chemical used
	0	1	2	3	
Al	0	90	270	810	$AlCl_3$
As	30	90	270	810	As_2O_3
Ba	0	90	270	810	$BaCl_2$
Cd	30	90	270	810	$CdSO_4$
Cr	0	90	270	810	K_2CrO_4
Cu	0	90	270	810	$CuSO_4$
Hg	30	90	270	810	$HgCl_2$
Mo	0	90	270	810	$(NH_4)_6Mo_7O_{24}$
Ni	0	90	270	810	$NiSO_4$
Pb	0	90	270	810	$Pb(NO_3)_2$
Se	30	90	270	810	Na_2SeO_3
Sr	0	90	270	810	$SrSO_4$
Zn	0	90	270	810	$ZnSO_4$

With the support of the Ministry for Environmental Protection and Land Development a food chain study was initiated based on LTFE with toxic and heavy metals. The soil of the site (Nagyhörcsök Experimental Station) is a loamy calcareous chernozem with 25% clay, developed on loess. In its ploughed layer it contains 3% humus and 3-5% $CaCO_3$. To ensure a sufficient macronutrient supply for the whole experiment, 100 kg/ha N, P_2O_5 and K_2O are given yearly. The 13 selected microelements were applied in early spring 1991 at 4 levels each. The 13 x 4 = 52 treatments were arranged in a split-plot design with 2 replications. Each plot had an area of 21 m². Maize was grown in 1991, carrot in 1992 and potato in 1993. The treatments and the chemicals applied in the experiment are presented in Table 3.

The purpose of this work was to evaluate the movement of some important contaminants in the soil-plant-animal system. The research programme had the following goals for investigation:

- Behaviour of elements studied in the soil (fixation, availability, leaching, volatilization, transformation).
- Effect of these elements on soil life (soil biological activity, recording of macro and micro organisms in the soil).
- Absorption of these elements by plant roots and their transport within the plants (root, shoot, leaves, stalks, grain).
- Effect of these elements on the quantity and quality of the crop, and on crop resistance to plant diseases and weediness.
- Effect of these elements on animals. The plant material derived from the field experiment is fed to animals in feeding experiments conducted by the Institute for Animal Feeding of the University of Veterinary Science.

After a complex toxicological investigation of the experimental animals, the soil, plant and different animal organs are analysed in the same laboratory using the ICP technique. Plant and animal organs are digested in teflon bombs using cc. $HNO_3 + H_2O_2$ to determine their total element contents. Soil samples are extracted with ammonium acetate + EDTA to measure their available element content. The effect of Mo, Cd, Pb, Hg and Se on the available element contents in the ploughed layer and on the total element contents of carrots is presented in Table 4. The results of the feeding experiment, using fodder with contaminated carrot roots, are shown in Table 5. The main findings from this study are as follows:

1. Mo is very mobile in this calcareous soil and it accumulates to a great extent in plant tissues. Hare's organs absorb it weakly and it is excreted mainly with the faeces and partly through urine. The maximum concentration of 3.5 ppm is shown by the kidneys.

2. Cd is very mobile in soil, but it accumulates moderately in plant tissues. Hare's organs absorb it weakly, the maximum concentration found in the kidneys was 2.6 ppm. It is excreted basically with the faeces.

3. Pb is very mobile in soil, but it accumulated weakly in plant tissues. Hare's organs also absorb it weakly, the maximum concentration found in kidney was 4.7 ppm. It is excreted with the faeces.

4. Hg is also found in available form in soil and it accumulates moderately in carrot roots. It was absorbed to a great extent in hare's kidneys with a concentration higher than 50 ppm. The residue is excreted with the feaces.

5. Se is relatively mobile in soil and it accumulated intensively in the roots. Its maximum concentration was found in the liver and kidneys, however, Se was absorbed practically by every organ by an order of magnitude. Residue was excreted with the faeces and urine.

It can be seen that Se is capable of moving through the soil-plant-animal food chain unhindered. The other toxic element, Hg is able to accumulate dramatically in kidney causing the poisoning of the living organism.

Table 4

Effect of Mo, Cd, Pb, Hg and Se treatments on the available element content of soil in the ploughed layer and on the total element content of the carrot crop. Field experiment on calcareous chernozem soil, Nagyhörcsök, 1992 (mg/kg d.w.)

Soil and carrot crop	Applied in spring 1991, kg/ha				$LSD_{5\%}$
	0	90	270	810	
Molibdenum (Mo)					
In soil	0.1	21	26	104	46
In carrot canopy	0.1	117	270	434	33
In carrot root	0.0	21	54	99	12
Cadmium (Cd)					
In soil	0.1	60	172	456	124
In carrot canopy	0.1	2.9	6.6	11.2	4.2
In carrot root	0.0	3.1	5.4	5.8	1.8
Lead (Pb)					
In soil	5	29	56	158	81
In carrot canopy	0.8	3.1	5.3	7.8	2.0
In carrot root	0.9	3.6	4.1	4.1	1.2
Mercury (Hg)					
In soil	0.0	4	49	189	75
In carrot canopy	0.0	1.2	9.3	16.9	7.2
In carrot root	0.0	0.5	13.4	23.8	7.4
Selenium (Se)					
In soil	0.0	7	22	122	43
In carrot canopy	0.0	38	64	-	15
In carrot root	1.0	33	63	-	7

Remarks: -: No yield harvested because of phytotoxic effect. Soil data for ammonium acetate + EDTA soluble content by LAKANEN & ERVIÖ (1971). Plant data for total content using cc. HNO_3 + cc. H_2O_2 digestion.

Crop nutrient supply and sustainable agriculture

LTFE helps to answer many important questions arising in soil fertility and plant nutrition studies, such as:

- How can we sustain the productivity of our soils?
- What are the optima values for nutrient concentration in soils and crops for assessing the nutrient status?
- Long-lasting effects and side-effects of treatment, interactions among nutrients, varieties, irrigation etc.
- Effect of treatments on soil properties: such as pH, humus and available nutrient content, salt accumulation, biological activity, etc.

Table 5

Effect of fodder carrots enriched with Mo, Cd, Pb, Hg and Se on the mineral composition of rabbit organs, hard excrement and urine

Feeding experiment at the Institute for Animal Feeding. Analysis at the Research Institute for Soil Science and Agricultural Chemistry, 1992

Carrot fodder/	Mo, ppm		Cd, ppm		Pb, ppm		Hg, ppm		Se, ppm	
Animal organs	Control	Treated	Control	Treated	Control	Treated	Control	Treated	Control	Treated
Fodder with carrots	0.53	39.00	0.14	2.30	1.58	4.01	0.00	30.00	0.00	36.20
Animal organs:										
1. Heart	0.06	1.23	0.00	0.00	0.39	0.00	0.00	0.00	0.58	19.4
2. Lung	0.03	1.21	0.01	0.03	0.64	0.51	0.00	0.00	0.73	14.7
3. Liver	1.26	1.88	0.12	0.72	1.72	1.85	0.00	3.53	1.74	65.0
4. Kidney	0.75	3.46	1.12	2.59	0.04	4.66	0.00	50.48	4.10	38.6
5. Milt	0.00	1.08	0.01	0.00	0.76	0.15	0.00	0.08	1.99	15.4
6. Testis	0.24	0.73	0.00	0.02	0.21	0.00	0.00	0.00	1.00	22.4
7. Fat tissue	0.00	0.06	0.00	0.00	0.14	0.06	0.00	0.00	0.00	0.6
8. Muscle	0.00	0.37	0.00	0.00	0.00	0.13	0.00	0.13	1.33	13.5
9. Bone	0.00	1.20	0.00	0.00	0.00	0.65	0.00	0.00	0.00	3.2
10. Hair	0.00	0.41	0.00	0.00	0.36	0.00	0.00	0.00	1.37	2.7
11. Faeces	0.42	25.34	0.46	9.07	3.02	9.38	0.00	32.06	0.00	11.7
12. Urine	0.42	6.60	0.00	0.01	0.04	0.05	0.00	0.02	0.06	3.2
$LSD_{5\%}$	1.41		0.38		1.14		11.04		2.21	
Mean	0.26	3.63	0.14	1.04	0.61	1.45	0.00	7.19	1.07	17.5
CV%	58		51		88		244		29	

However, if we would like to know whether nowadays agriculture in Hungary is sustainable or not, from the viewpoint of soil fertility, we have to use an other approach. We must analyze the nutrient balance of our agriculture. We have a positive P-balance from the 60s, and positive NK-balance from the 70s. In the 90s, nutrient balance sheets show a minus again, which means that soil fertility is not maintained.

When analyzing the NPK balances of Hungarian agriculture, it can be seen that the surplus appearing in the nutrient balance sheet is a consequence of intensive fertilization during the 70s and 80s. Hungary has a continental type of agriculture which focuses on plant production within land use and has a high rate of cereal production in monocultures. The product of the farms is overwhelmingly grain; about 60% of the arable land is covered by cereals and maize, which is produced exclusively for the market and will be sold (VÁRALLYAY et al., 1992).

These specialized farms do not have many livestock and do not produce large quantities of manure. The maintenance of soil fertility is based on the high rates of mineral fertilizers applied annually. Concerning the mineral nutrient cycling of these farms, it can be demonstrated that 60-80% of the nutrients taken up by the yield will leave the farms, so the cycle is an open one. In the 90s, the use of mineral fertilizers is decreasing, so the yields are also decreasing.

During the 70s and 80s, more NPK was used than the crops need. The nutrients not taken up by the crop, mainly P and K, accumulated in the soil, increasing both the total and the available nutrient content, as could be seen from soil analysis. What has happened to the P in the soil? How can a satisfactory P and K level be sustained in the soil? How long will it be possible to exploit the P-pool which was built up in the 70s and 80s? How long will P be in an available form in the soil? Is there any ageing, fixation or decline in the efficacy with time?

Half-life of P fixation in a calcareous chernozem soil

A P exhaustion LTFE, with initial P doses of 0, 18, 53, 106, 211 and 317 kg/ha, was established in autumn 1972 on a light loamy calcareous chernozem soil containing about 3% humus, 5% $CaCO_3$, moderate supplies of N and K, and little P (Olsen-P = 6-8 ppm, AL-P =25-30 ppm). The design of the trial was a randomized block with 12 replications. The sequence of crops in the first 20 years was: winter wheat (8 years), millet, alfalfa (3 years), spring barley and winter wheat (7 years).

The main findings are as follows:

1. Soil P-test (Olsen and AL-) values sharply decreased in the first 4 years, after which an equilibrium was reached.

2. On this soil, originally poorly supplied with P, the 317 kg/ha initial P rate provided satisfactory yield levels of cereals for 8 years, 211 kg for 6 years, and 106 kg for 4 years. The residual effect of build-up P rates was measurable even 20 years after application.

3. The effectiveness of the initial "old" P doses previously added dropped by 50% every 5-6 years compared with "fresh" superphosphate-P, given every second year. This thus represents the half-life of the P remaining in this soil, which is not strongly fixing.

4. It seems possible to recover as much as 50% of the earlier applied P, but with decreasing yields.

The comparison of old and new P responses was made on the basis of equivalent P balances, i.e. the old P levels represented the amount of P left in the soil after plant uptake (KÁDÁR et al. 1993).

Future task: sustainable fertilization in Hungarian agriculture

Farmers and the fertilizer industry are facing a new set of conditions with regard to mineral fertilizers. Because of the economic situation supplies to farms will probably be limited in many local areas in the near future. Without government subsidies, most fertilizer prices have increased dramatically. The most immediate problem for discussion is the allocation and use of the limited supplies of commercial fertilizer that will be available. Fortunately, much of the research conducted in the past can be interpreted under conditions of limited as well as unlimited fertilizer availability:

1. Liming is one of the first conditions for soil fertility on acid soils in Hungary. Soils should be limed to an optimum pH. In maize-wheat-alfalfa cropping systems, the optimum soil pH is about 6.0.

2. Many farmers have livestock as a part of their farming practice and farmers with available farmyard manure should use it as part of their fertilizer programme. Although quite variable in its components, manure is usually credited with 5-6 kg N, 3-4 kg P_2O_5 and 5-10 kg K_2O per ton.

3. Soil analysis, which is an integral part of planning in any crop production system, becomes especially important with limited supplies of fertilizer. It can predict where fertilization can or should be avoided. About 40-60% of our fields are now "well" or "very well" supplied with P and K, so P and K fertilization should be avoided or minimized here for a few years. At "low" soil test levels, a high response is much more likely than at "high" soil test levels. Fertilizer placement, especially for phosphorus and potassium, is an area where improvements in fertilizer efficiency may be realized.

4. There are several ways in which farmers can minimize nitrogen fertilizer needs. The use of farmyard manure when available has already been mentioned. Growing legumes can also be useful. The nitrogen contribution from the pre-

ceding legume crop is approximately equivalent to 30-50 kg/ha N yearly. Soil testing can give a good indication of the nitrate pool of a field. Soil nitrate is credited with the N fertilizer equivalent and makes it possible to avoid leaching.

5. Some farmers will have to face the problem of whether to fertilize all fields with some fertilizer or some fields with near optimum amounts and others with little or none. Obviously much greater responses per kg of nutrients can be expected for example between zero and 50 kg/ha than between 150 and 200 kg. Although the cost of application to more hectares must be considered, a reduced amount of fertilizer over all fields would generally be more efficient than a high amount on a few fields.

These were just a few things farmers should consider in allocating limited fertilizer supplies to sustain soil fertility. The LTFE will provide data for ever sounder recommendations which are necessary for a sustained management of natural resources, such as soils.

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