The Importance of Long-term Experimentation in Sustainable Agricultural Development

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In the past few years many European countries were (and nowadays are) undergoing changes in agricultural practice. The changes have occurred in a wide range; in the EC current policy seeks to avoid the over-production of cereals via different political and economical means, while in the Central and Eastern European countries the driving force of the changes is the damaged economy together with the restructuralization of the agricultural sector. LÁNG (1994) summarized the new factors that have influenced Hungarian agriculture in the early 90's:

- profound changes in the country's economy,
- privatization, changes in ownership and former market,
- expressed decrease in general consumption.

In the Hungarian economy the role of agricultural production is a long-term basic and traditional constituent. The land resources in Hungary are relatively favourable, the indicators related to land resources are good, both in respect of arable land per capita (≈ 0.47 hectare) and of their utilization. As a result of research carried out for several decades, precise scientific knowledge is available on the properties as well as on the nutrition status and supplying capacity of Hungarian soils.

Sustainability

An actual question nowadays is how can the land be cultivated and agricultural goods be gained under the conditions of sustainable development. Sustainable development or sustainability is currently of great concern to the media, politicians as well as scientists. BARNETT (1994) gave a short definition of sustainability as follows: it is essentially the ability to maintain agricultural production (output) in quantity and quality year after year without degradation; particularly in relation to environmental concerns. There is another important statement according to the definition of the Burtland Report (in LÁNG, 1994), which is: "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Sustainability is not equal with low-input and/or biofarming.

However, if we would like to know whether agriculture in Hungary nowadays is sustainable or not from the viewpoint of soil fertility, we have to use nutrient balance approaches. The phosphorus balance of Hungarian agricultural soils became positive in the 60's, while that of nitrogen and potassium in the 70's, but from the early 90's nutrient balance studies reveal negative values again (CSATHÓ, 1994a; KÁDÁR, 1994; NÉMETH, 1995).

The Possible Role of Long-term Experiments in Sustainability

The basis of human life is to use the natural ecosystem to meet the growing demands of mankind. This process results in the removal of nature bound materials and embodied energy. Later, most of them are not returned to, or modified, or broken up at the place of origin. The driving forces of these changes are fortunately slow release, so these positive and negative changes may be detected only in long-term experiments. Long-term field experiments are suitable to follow the cumulative effects, the usual and unusual events caused by human use, especially agricultural practice (such as cultivation, application of manure, fertilizers and pesticides, etc.).

From soil fertility and plant nutrition point of view long-term experiments provide useful information and tools to follow the longevity of the supplying capacity of soils. They also serve as fundamental, basic constituents and data bank for environmental policy.

While most of the long-term experiments have been successfully maintained over a long period, this is partly because crop yield can be used to indicate the sustainability of a particular system, i. e. the crop integrates across all factors affecting its growth. On the other hand, crop yield does not necessarily give an advanced warning of factors that will lead to non-sustainability (POULTON & JOHNSTON, 1994).

The arising questions of sustainability lead researchers to investigate and evaluate long-term experiments from this respect, as well. BARNETT (1994) has reported from a study in which such questions were discussed like: how are the long-term experiments to be differentiated in terms of their defining characteristics of crop type, soil features, costs of operation, cultural practices, etc. These questions were posed by the Rockefeller Foundation in New York, who commissioned six long-term experimental sites to conduct major research studies with the brief to produce

- an operational definition of sustainability,
- a statistical/economical way of measuring is based on their experiences with their long-term experiments.

During this study, at one of the six sites (Rothamsted) a substantial database was developed with yield and culture variables augmented by extensive economic information stretching back to the middle of the last century using experimental plots from three of the "Classicals". The study included environmental approaches as well (nitrate leaching, soil erosion). Armed with an appropriate measure BARNETT et al. (1994) adopted the stance that an agricultural system is sustainable if, in statistical terms and in the long run

- output values exceed input costs,
- the measure of relative value is non-decreasing over time.

The evaluation of long-term field experimental data helps in answering important questions arising in soil fertility and plant nutrition studies. Some of these questions were designated by KÁDÁR (1994):

- How can the productivity of our soils be sustained?
- What are the optimal values for nutrient concentration in soil, plant tissues and crops for assessing the nutrient status?
- Long-lasting effects and side-effects of treatment, interactions among nutrients, varieties, irrigation, pest control, etc.
- Effect of treatments on soil physical and chemical properties, such as pH, humus, available nutrient content, salt accumulation, as well as soil biological activities, etc.

Instead of always setting up new studies to try to answer each problem as it comes into the interest of scientists, policy makers or the public, the use of sites which have already been well-established with existing data is more relevant.

Before discussing the above mentioned questions, it may be worthwhile to summarize the necessary management of long-term agricultural field experiments. It comes from their nature that long-term field experiments must remain in their original place for many years. Supposing that this can be realized, it ensures the application of treatments, methods of cultivation and harvest as far as possible from year to year. However, during the experimental years, management will include some changes needed for a number of reasons; mainly to address newly emerging issues.

One of the reasons of the changes can be the decreasing pH value (strong acidity) due to unsatisfactory lime management in fertilizer treatments, while a newly emerging issue could be the appearance of environmental side-effects.

A basic requirement before the start is the uniformity of the site (homogeneous soil, lack of shading and slope). If, at the beginning the plots are large enough, it allows subsequent modification of the whole experiment (or some of the plots) - in case it becomes necessary. This is one of the methods which gives a good possibility (i. e. dividing into sub-plots) to find answers to new scientific questions addressed through the lifetime of the experiments. LEIGH et al. (1994) summarized the ways long-term experiments can be changed avoiding their breakdown, with examples from the "Rothamsted Experiments":

(i) Minimum changes to treatments or husbandry to ensure longevity. In one of the Park Grass experiments liming became necessary via dividing the original plots.

(ii) Retain the major objectives but incorporate innovations in agricultural practice. The Broadbalk experiment provides a very good example for this: the cultivar changed periodically, harvesting has changed, use of herbicides has been introduced on most of the plots (keeping control from this point of view), crop rotation started in 1968, larger N rates were introduced at two occasions (1968 and 1985),

(iii) Change the objectives and continue the experiment in a different form. The experiment on Exhaustion Land has undergone many changes in objectives; its history reflects flexibility, as each change has been made to address agricultural questions current at that time.

(iv) Change the experiment to obtain more information in the short-term but sacrificing longevity. This occurred at Agdell which started in 1848 and after various intervals and changes the experiment stopped in 1990, because it was impossible to return to a larger plot design after many subdivisions.

How Can the Productivity of Our Soils be Sustained?

Within other advantages long-term experiments provide ideal opportunities to study nutrient cycling in agricultural lands. As it was mentioned earlier it is difficult to accurately measure minor changes in different parameters over a short period. This is partly because of the variability of the yields, the heterogeneity of the soil and the large quantities of nutrients usually present in it. Accurate nutrient balances can only be calculated by comparing inputs and outputs over long periods. In the following some examples from long-term field experiments are presented to show these evaluation processes.

Nagyhörcsök Experimental Station (Hungary)

To understand residual effects of the applied fertilizer a P-exhaustion long-term fertilizer experiment was established in autumn 1972 on a loamy calcareous chernozem soil with initial doses of 0, 18, 53, 106, 211 and 317 kg P/ha (CSATHÓ & KÁDÁR, 1992; KÁDÁR, 1994). The main findings of the 16-year-study were:

- the soil P-test values sharply decreased in the first four years,

- on this soil - originally poorly supplied with P - the 317 kg P/ha initial rate provided satisfactory cereal yield levels for 8 years, while 211 kg P/ha for 6 years and 106 kg P/ha for 4 years, respectively,

- the effectiveness of the initial, previously added ("old" P doses) decreased by 50% in every 5-6 year interval compared with the effect of the superphosphate P ("fresh") applied every second year,
- it seems possible to recover approx. 50% of the applied P with time-decreasing yields.

Exhaustion Land Experiment, Rothamsted (UK)

The long-term rate of decline of plant-available P and K in the soil of plots within the Exhaustion Land Experiment, Rothamsted were evaluated by POWLSON (1994). After continuous spring barley cropping for over 70 years without any inputs of P and K fertilizers, the initial soil available P and K contents have decreased by 13% (P) and 25% (K), respectively. This type of information is necessary when considering the sustainability of reduced input agricultural systems and for calculating the amounts of nutrients needed to maintain a given level of productivity (POWLSON, 1994).

Nagyhörcsök and Őrbottyán Experimental Stations (Hungary)

Long-term nitrogen fertilization experiments were set up with identical treatments in two different growing areas, on a calcareous sandy soil (Őrbottyán) and a calcareous chernozem soil (Nagyhörcsök), with the aim to create differences in mineral-N content in the soil profiles in order to study how these differences affect the N supplying capacity of the soil and whether they may be regarded as nitrogen supply categories for crop production (NÉMETH, 1995, 1996a). In the first three years of the experiments four rates of fertilizer-N were applied. In the 4th year the original plots were divided into 5 smaller ones onto which 5 spring fertilizer levels were applied and winter oil-seed rape was the indicator plant. In the following three years the basic 4 N fertilizer treatments were given. In the 8th year a division of the plots was carried out again, similarly to that in the 4th year and winter wheat was used as indicator plant. The effects of residual-N and freshly applied fertilizer-N on the yields of winter oil-seed rape and winter wheat were compared. The results indicate that under certain environmental conditions nitrogen (in the form of nitrate, resulting from N fertilization and N transformation processes in previous years), may accumulate in the soil profile to such an extent that it must be taken into consideration when determining fertilizer rates. The calibration experiments show the dependence of yield on the mineral-N content, as well as on spring N application. Under these specific conditions the optimum N fertilizer rates were 50-100 and 0-50 kg N/ha on the calcareous sandy and calcareous chernozem soil, respectively. This is important not only for economic management and environmental protection, but it affects yield quality, too. The calculations can be performed reliably through the measurement and calibration of the mineral-N content of soil.

What are the Optimal Values for Nutrient Concentrations in Soils for Assessing the Nutrient Status?

The results of long-term experiments serve as the basis for developing processes of environment-friendly fertilizer recommendation systems. If there are a sufficient number of long-term experiments, scientists are free to group and classify the results into different supply categories.

Hungarian long-term experimental dataset

This type of study has been carried out by CSATHÓ (1994b) and CSATHÓ et al. (1996a), establishing a database from the results of Hungarian long-term field trials to investigate the effect of potassium fertilization, as well as to develop a more precise K-supplying category system for potassium recommendations. The available soil-K data were classified according to the soil texture of the experimental sites. Some of the authors' conclusions can be summarized as follows:

- The AL- (ammonium lactate) - soluble K content of the soil (which is the commonly used solvent in Hungarian soil analysis practice) indicated the natural K-supplying power of the different soils adequately.
- Responses to potassium fertilization were eliminated when soil K test values exceeded 160-170 and 200 mg/kg in the case of winter wheat and maize cultivation, respectively.
- On the basis of the long-term experimental dataset new AL-soluble K supply categories were elaborated both for winter wheat and maize, according to their special responses to K fertilization.

Environment-friendly fertilizer recommendation system in Hungary

Most experts agree that this type of fertilizer recommendation system is capable of fulfilling the demand of the growing population as well as keeping the environment in good condition for the next generations. Experts also agree that fertilizer application could not be replaced widely with organic farming solely.

An environment-friendly fertilizer recommendation system has to be sensitive enough to follow the effects of different conditions, i. e. great spatial variability of soil characteristics, mosaic-like soil cover, climate, crop rotation practices, soil nutrient supply, etc. The main reason why the basic features of a computerized fertilizer recommendation system were developed in RISSAC was to characterize the soil fertility levels in the different regions in Hungary under diverse agricultural practices and environmental conditions. The elaboration of the system was based on long-term experimental background (CSATHÓ et al., 1996b, 1997; NÉMETH, 1995, 1996b; VÁRALLYAY et al., 1992).

Long-lasting Effects and Side-effects of Treatments

Long-term fertilization experiments provide good tools for the evaluation of long-term effects of different treatments. The long-term effects can be nutritional (changes in the nutrient contents of soils) and environmental (mainly unfavourable side-effects).

Long-term changes in the nutrient content of experimental soils

Broadbalk wheat experiments (UK) - POWLSON (1994) reported how the total N content of soil has changed in selected plots of the experiment. The results show that the total N content of soil in the plot receiving no N fertilizer since 1843 has been almost constant for well over 100 years, indicating that the inputs and outputs of N are in balance. The soils of manured plots were enriched with high amounts of total N during this period. There is more information available from N balances of this experiment in JENKINSON (1977).

N fertilizer experiments (Nagyhörcsök and Őrbottyán, Hungary) - In long-term N fertilizer experiments established with identical N treatments in two different growing areas in Hungary it was found that the residual effects of nitrogen fertilization could be detected by measuring the nitrate-N content of the soils, as well (NÉMETH, 1995, 1996a). The nitrate-N concentration varied between 6.0-11.3 and 11.3-41.8 mg/kg in the calcareous sandy soil (Őrbottyán) and calcareous chernozem soil (Nagyhörcsök), respectively in the upper 1 m soil layers.

Environmental side-effects

From the point of view of agricultural production N fertilization is one of the major sources - mainly in the form of nitrate - that may influence the quality of the environment, and especially the quality of subsurface waters via leaching.

Brimstone experiment (UK) - In this experiment the impacts of drainage and cultivation treatments on the losses of nitrate were studied. The results show that nitrate leaching was always greatest when soil was bare during winter. Any form of crop cover (such as straw incorporation, grass ley, reduced tillage and cover crops) during this period of year decreased the amount of leached nitrate by causing the retention of N in the soil-crop system in organic forms. It could also be concluded that after various winter cover treatments, however, some of the retained N was mineralized and increased nitrate leaching in subsequent years. These results emphasize the importance of continuing experiments on nutrient dynamics for a number of years in order to reveal the true impact of a particular management strategy (POWLSON, 1994).

Crop rotation experiment (Nagyhörcsök, Hungary) - The soil of this site is a migration type (calcareous chernozem) with a relatively deep humus layer. The soil moisture regime is also migration type; the annual precipitation is not enough to leach soluble salts through the soil profile down to the groundwater table (which is at the depth of 13-15 m). It can be stated that nitrate-N accumulation in the subsoil was proportional to the N rate (NÉMETH, 1993, 1995). Nitrate-N distribution in the profiles of various nitrogen treatments in the 12th and 17th years of the experiments are shown in Figure 1.

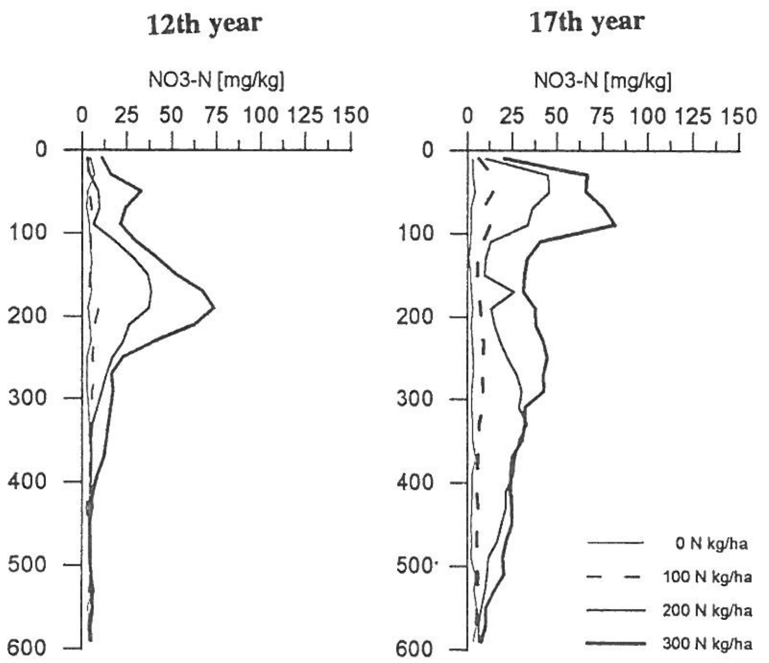

Figure 1
Nitrate-N accumulation in the soil profile in a long-term experiment conducted at Nagyhörcsök (1985, 1990)

In both years significant nitrate-N accumulation was found in the deeper soil layers of intensively fertilized plots (i. e. 200 and 300 kg N/ha/year). These curves differed significantly from each other, while practically no difference was measured between the nitrate-N content of unfertilized plots and of the plots receiving 100 kg N/ha/year. The effects of overfertilization on the residual nitrate-N form could be detected down to 350-400 cm. The evaluation of experimental datasets from this trial showed that it is possible to improve nitrogen management practices to match the expectations for securing stable and sufficient yields and for protecting the environment as well (NÉMETH, 1995). It was also proved that after the appropriate use of N the amount of residual nitrogen was as low as in the unfertilized plots, and no nitrate-N accumulation was detected under the root zone. The conclusion drawn from this study was that the harmful effect of fertilization can be avoided when N fertilizers are applied at the recommended rates; taking into account the N demand of the crops for the expected yield, and the specific environmental conditions.

Long-term Experimental Datasets as the Basis of Modelling Studies

JENKINSON et al. (1994) found that models of organic carbon and nitrogen turnovers in soil have three main functions:

i) to bring disparate data into a comprehensible whole;

ii) to formulate hypotheses in a way that can be tested, and

iii) within strictly specified limits, to predict future events from past experience.

Models for organic carbon turnover in surface soils

The Rothamsted model (JENKINSON et al., 1994) - The five-compartment model has two input compartments: decomposable plant material (DPM) and resistant plant material (RPM), both of which decompose microbial biomass (BIO) and humified organic matter (HUM). The model allows for the effects of temperature, soil moisture content, plant cover, and clay content on the decomposition processes. It works in monthly intervals, using mean monthly air temperatures and soil moisture (from the rainfall and evaporation of the preceding month). The developed model was fitted, tuned and tested against data from long-term experiments at Rothamsted.

CERES Model application at Nagyhörcsök

A long-term crop-rotation experiment with various N fertilizer applications, conducted in Nagyhörcsök, from 1968 to 1988 provided an excellent dataset for testing crop simulation models. It was mentioned above that under these environmental circumstances a (big) part of the residual nitrogen was able to accumulate in the deeper soil layers. This accumulated nitrate in the sub-soil became the basis for testing the simulated leaching using the CERES-Wheat and CERES-Maize crop simulation models (KOVÁCS & NÉMETH, 1995; KOVÁCS et al., 1995). The characterization of these models was given by KOVÁCS (1995). The simulation study shows that the measured and simulated nitrogen use by plants and nitrate loss by leaching was within acceptable limits most of the time. The simulation gave the same results as were measured and discussed above: when 150 kg/ha/year or less nitrogen was applied, the leaching was minimized and was about the same as in the case no fertilizer was added. This was also proved with nitrogen balance studies as well. Figure 2 shows the observed and modelled nitrogen balances of 0, 150 and 250 kg/ha/ /year N fertilizer treatments, respectively. It can be seen that below 150 kg N/ha/year application rate long-term nitrogen balances are negative.

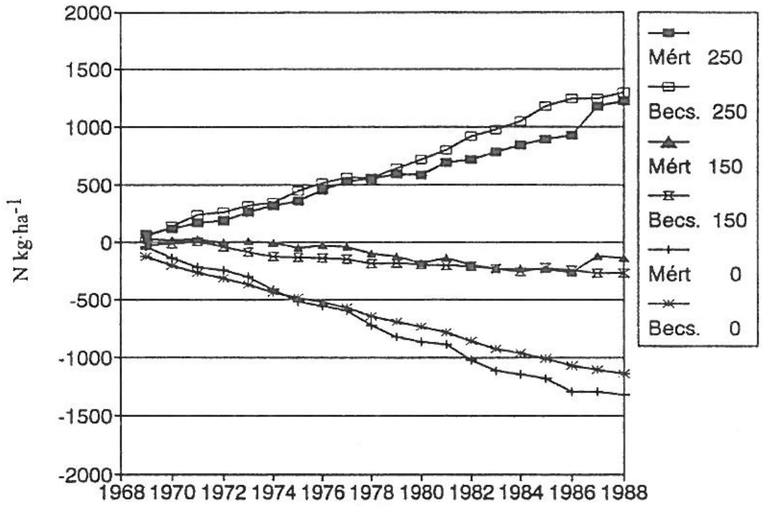

Figure 2
Observed (MÉRT) and modelled (BECS) nitrogen balances of 0, 150 and 250 kg/ha/year N fertilizer treatments

Summary

The sustainability of the agricultural system under different managements can be demonstrated by using results from long-term experiments. The examples from different well-known long-term experiments from the UK and Hungary proved that this type of experimental background can serve as irreplaceable tools for investigating

- the effects of the changing environment;
- the fate and behaviour of elements and various compounds in the soil-plant system,

and is able to give reliable information and predictions on the influences of certain professional, society or policy induced changes in agriculture and environment.

The above mentioned results and the possible utilization of the information received from them only cover one part of the importance of long-term experimental networks, they also fall under the national (and overall) history of mankind.

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