Title
Do long-term experiments provide the key to sustainable soil productivity?

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Introduction

Long-term experiments started before sustainability became the hot issue it is at present. As a consequence the designs of these experiments were not directed, at least not explicitly, towards solutions of sustainability questions. Nevertheless, long-term experiments may provide, often after re-interpretation, important and sometimes surprising insights in the current research problems. The subject of sustainable agriculture does not only refer to continuing soil productivity, but also to the impacts of farming on the environment. In this paper, however, the discussion is narrowed down to the following questions: do agricultural practices inevitably threaten the sustainability of soil productivity; what is the role of plant nutrients in sustained productivity; what can we learn from the long-term experiments carried out for different purposes than the study of sustainability.

In this paper we try to analyze the outcomes of three long-term trials, carried out in different ecological settings in Kenya, Vietnam, and The Netherlands. For that purpose we apply two simple models, one on formation and decomposition of soil organic matter, and another on the residual effect of fertilizer P, and we make use of some rather recently introduced concepts with regard to soil fertility and required nutrient inputs, balanced plant nutrition, and optimum nutrient management. The general objective of the analysis is to arrive at general insights into the main requirements of sustainable soil productivity. The fact that the studied field trials could exist for a long time does already preclude situations, where processes like erosion, salting-up, acidification and the like, obviously make soil productivity unsustainable.

Methodologies for the analysis of long-term experiments

For calculations on decomposition and formation of soil organic matter we followed an approach that can be applied also when only elementary information is available (Hénin et Dupuis, 1945; Kortleven, 1963). The essential parameters to be assessed are the relative decomposition rate (k) of existing soil organic carbon (SOC), and the humification coefficient (h) of newly added organic materials.

The residual effect of fertilizer P was calculated with a slightly modified version of an equation developed earlier (Janssen and Wolf, 1988). The basic parameter that is needed is the recovery fraction of fertilizer P during the first season after application of P.

For the analysis of nutrients in soil-plant interactions, a framework was developed harboring concepts with regard to soil fertility, balanced plant nutrition, and optimum inputs of available nutrients. It can also be applied to evaluate the outcomes of long-term experiments. Benchmarks for the appraisal of soil fertility are saturated soil fertility (SSF) and ideal soil fertility (ISF). At SSF, the soil on its own is able to supply sufficient nutrients for a certain target yield. To maintain soil fertility, nutrient outputs must be compensated for by nutrient inputs. When no nutrients are lost by leaching, volatilization or erosion, the only nutrient outputs which have to be compensated for by nutrient inputs are the nutrients in the harvested components of a crop producing the target yield. The soil fertility level that can be maintained by such an input ('replacement input') was called ideal soil fertility (ISF). Additional criterions are balanced plant nutrition (optimum proportions among nutrients) and adequate soil structure stability (Janssen and De Willigen, 2006).

The most desirable management of the macronutrients (N, P and K) is formulated in relation to ISF and SSF. The three nutrients are considered simultaneously, which is facilitated by application of the concept of (cereal) crop nutrient equivalent (CNE), being the quantity of a nutrient that has the same effect on yield as 1 (k)g of nitrogen (N) (Janssen, 2009a). The quantities of N, P and K, expressed in kCNE, are added, and it is calculated what percentage each nutrient takes in the sum of the three. These percentages are plotted along the sides of a triangular diagram. The centre of the triangle represents optimum plant nutrition. Also the positions of ISF and the corresponding NPK input for a certain target yield can be indicated in the NPK triangle (Figure 1). From the places in the triangle of any other soil-input combination it is derived whether that combination is sustainable, and what changes may be recommended.

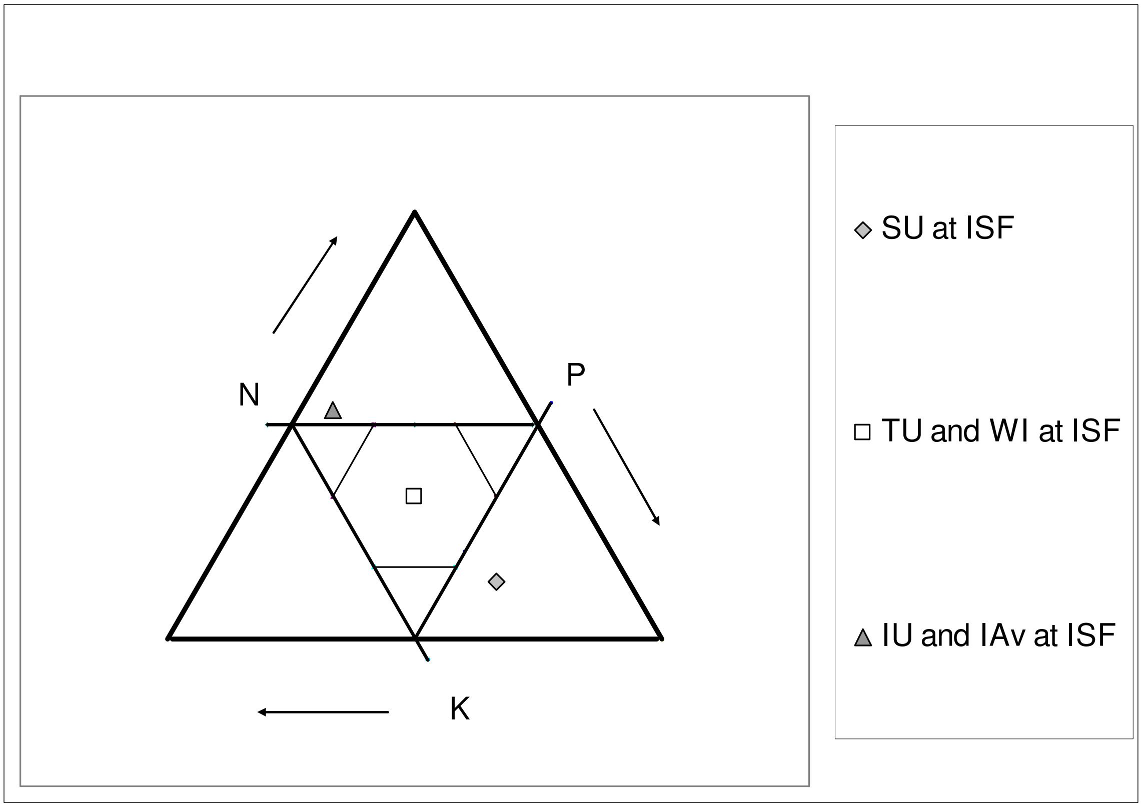

Figure 1. NPK triangle for Ideal Soil Fertility (ISF). At any point in the triangle the sum of N, P and K is 100%, when N, P and K are expressed in percentages of their kCNE sum. The arrows point to increasing portions of the concerning nutrient. The central point (TU) represents balanced nutrition. SU stands for uptake of nutrients from soil, IU for uptake of nutrients from input, and TU for target uptake (TU = SU + IU). WI stands for whole input, and IAv stands for input of available nutrients. Recovery fractions of input N, P and K were set at 0.8, 0.1 and 0.6, respectively. Slightly modified after Janssen, 2009b.

Analysis of the long-term experiments

Kabete, Nairobi, Kenya

Data on soil organic carbon (SOC) and maize grain yields between 1976 and 1991, presented by Swift et al. (1994), revealed that the relative mineralization rate (k) was 4 % per year, and the humification coefficient (h) was 0.25. The yield response to new SOC was 0.6 ton per g kg^{-1}, more than twice as great as the yield response to original 'old' SOC (0.25 ton per g kg^{-1}). The original SOC could be subdivided into an inert part of about 7.4 g kg^{-1} and an active part of which the relative mineralization rate (k) was about 8 % per year. It was estimated that annual applications of animal manure together with fertilizer N and P, at rates of 5.4 tons dry matter of manure, 65 kg N and 28 kg P, would be sufficient to keep maize yield at the original level of 4.8 t ha^{-1}. If no manure would be applied, a gradual increase of the annual fertilizer nutrient rates from 60 kg N and 26 kg P in year 1 to 192 kg N and 82 kg P in year 25 would keep the yield at the original level. The gradual increase is needed to compensate for the gradual decreasing contribution of the original SOC to soil productivity.

NPK experiment for rice monoculture in the Mekong River Delta of Viet Nam.

The results between 1986 and 1993 of a 2^3 NPK experiment with two crops of rice (wet and dry season) on a heavy (57% clay) soil in the Mekong delta in Vietnam (Pham Sy Tan et al., 1995) were analyzed to estimate soil supplies of available nutrients, and the first-year and residual crop response to fertilizer P. Estimated apparent recovery fractions of fertilizer N and K disclosed considerable losses of these nutrients. The soil proved extremely low in P. The crops responded strongly to P, and moderately to N when P was applied, but not to K. The response to P increased with time because of the residual effect of formerly applied P. The estimated apparent recovery fraction of fertilizer P was in the wet season more than two times as high as in the dry season. The measured cumulative responses to P could be explained by careful bookkeeping of the fate of applied fertilizer P, taking the different recovery fractions in the wet and dry season into account.

The average soil supplies of available N, P and K were 50, 4 and 54 kg ha^{-1} in the dry season, and 41, 2 and 46 kg ha^{-1} in the wet season. The higher values in the dry season may partly be a result of fresh sediments of the preceding flooding. The position in the NPK triangle showed that the Mekong soil was very low in P, and rather high in N and K compared to ideal soil fertility (ISF). The soil supply of available P decreased during the successive years in the wet season , but not in the dry season. The required inputs of N, P and K for a target rice grain yield of 6 t ha^{-1} were calculated, and proved to be higher than in the region usually was applied with fertilizers at the time of this long-term field trial. Once the soil will have reached steady-state soil fertility, the requirements for N and P will be closer to the local practice, but at that time also K has to be added for sustainable growing of rice.

<u>NPK factorial trial on a former sea bottom in the Netherlands</u>.

Between 1975 and 2003, an NPK factorial trial was carried out on soils on the former sea bottom in the Eastern Flevopolder in the Netherlands. The polder was reclaimed in 1957, but the experiment was set up in 1975. The aim was to examine how long it would take to deplete these fertile soils. A four-year rotation was followed with sugar-beet, spring barley, potatoes, and winter wheat, but sometimes other crops had to be planted. The experimental design was 2^3 NPK from 1975 to 1993, and a 3 N * 2^2 PK factorial between 1994 and 2002.

The yields obtained in the treatments without N application in proportion to the yields obtained in the treatments with N application (0N/+N), averaged per rotation cycle, decreased from an initial 65 % to 42 % in the last rotation cycle. The ratio of 0P/+P decreased from 101 to 90, while the ratio 0K/+K did not change at all. When no N was applied yields slightly decreased over time for all crops, except for sugar-beet. The good performance of sugar-beet was ascribed to continuous improvement of its yield potential as a result of breeding. The soil supply of N available to spring barley decreased by only 0.5% per year, whereas the supply of available N was 1.7% of total N in the topsoil. It was concluded that atmospheric N deposition and N mineralization in the subsoil must considerably have contributed to soil available N. A linear relationship was found between N uptake from the soil alone and the length of the growing period, irrespective the crop was spring barley, maize or sugar-beet. Soil fertility was in between ideal (ISF) and saturated fertility (SSF) for N, close to ISF for P, and above SSF for K. Sustainable crop production on this marine clay loam is easy because the soil is rich in P and K. Moreover, the groundwater table in the polder is maintained at such a depth that crop roots can reach it. Also the mineralization of subsoil organic N in the still further ripening clay soil and capillary rise of groundwater plus dissolved nutrients contribute to the excellent soil productivity, and to the complete recovery of fertilizer N by the crops. During the growing season no leaching occurs.

Discussion and Conclusions

Although the achievement to sustain the productivity of the soil is not as great as sometimes is suggested, it is self-evident that soil productivity is going down sooner or later when there are no inputs of nutrients. In many studies on sustainability the emphasis is on soil organic matter (SOM) and nitrogen (N). Decrease in SOM sounds alarming, but there are situations in which soil productivity is kept at the original or even higher level, also when soil organic matter decreases.

Lack of information on P, K and other nutrients, and on nutrient uptake has set hurdles to our analyses. Imbalanced crop nutrition is an often overlooked cause of nutrient losses. In retrospect, the choice of experimental treatments sometimes proves unfortunate. Nevertheless, the existing long-term experiments may provide the key to sustainable soil productivity, but the key often is hidden. Simple modeling exercises are helpful in discovering the key. We advocate daring quantitative approaches rather than descriptive analyses. Of course, testing of predicted results is essential.

Sustainable soil productivity is not only a matter of nutrient management. Improvement of the crops' production potential by breeding may increase yields even without changing nutrient management. Natural processes like flooding and capillary rise of groundwater contribute to nutrient input and nutrient use efficiency, and help to keep up soil fertility. In this study, sustainability threatening processes like erosion, salting-up, and acidification were left out of consideration, as they are hardly found in long-term field trials.

Some directly related references

Hénin, S. et M. Dupuis. 1945. Essai de bilan de la matière organique du sol. Ann. Agron. 15: 17 -29

Janssen, B.H., 2009a. Extending the QUEFTS model: optimum nutrient use efficiency, crop nutrient equivalents and NPK triangles. In preparation/submitted.

Janssen, B.H. 2009b. Steady-state soil fertility in NPK triangles as a guide to optimum nutrient management. In preparation/submitted.

Janssen, B.H. and P. De Willigen. 2006. Ideal and saturated soil fertility as bench marks in nutrient management. 1. Outline of the framework. Agriculture, Ecosystems and Environment 116: 132-146.

Janssen, B. and W. Menkveld. 1998. Long-term supply of N, P, and K on the marine loam soils of former sea bottom in the Netherlands. 16^{e} Congres Mondial de Science du Sol, Montpellier, France. Résumés Volume I: 288.

Janssen, B.H. and J. Wolf, 1988. A simple equation for calculating the residual effect of phosphorus fertilizers. Fertilizer Research 15: 79-87.

Kortleven, J. 1963. Kwantitatieve aspecten van humusopbouw en humusafbraak. Versl. Landbouwk. Onderz. Nr. 69.1. Wageningen, The Netherlands. 109 p.

Pham Sy Tan, Thach Ngoc Anh, Nguyen Van Luat, D.W. Puckridge. 1995. Yield trends of a long-term NPK experiment for intensive rice monoculture in the Mekong River Delta of Viet Nam. Field Crops Research 42: 101-109.

Swift M.J., P.D. Seward, P.G.H. Frost, J.N. Qureshi and F.N. Muchena. 1994 Long-term experiments in Africa: Developing a database for sustainable land use under global change. In: Leigh, R.A. and A.E. Johnston (eds) Long-term Experiments in Agricultural and Ecological Sciences. CAB International. Wallingford UK, pp. 229-251.