# Effect of Crop Rotation on the Sustainability of Yield and Soil Organic Matter Content

J. LAZÁNYI

Research Centre of the Debrecen Agricultural University,
Nyíregyháza (Hungary)

The problem of agriculture is as old as agriculture itself. The core of the problem has always been soil erosion, the loss of fertile soil. In our time, when the energy input into agricultural production has increased, a new problem has been added and has exacerbated the old problem. The growing human population increases global demands due to both population growth and increased consumption. In the year 2020 agricultural production must be increased by 90 to 140 percent for cereals, meat and vegetable oil (FARRELL et al., 1984). Just to maintain the current level of per capita consumption, grain production should be 56% higher than the 1985 levels (WOLF, 1987).

Historical and recent experience in agriculture suggests that these gains are not likely to be achieved without negative effects on natural systems, environmental quality and rural communities. Chemical and energy subsidies have to be efficiently assimilated within an agroecosystem to increase production (FRANCIS & HILDEBRAND, 1989; EHRLICH, 1985; MAGLEBY et al., 1985). Agriculture in developed countries has moved progressively from traditional practices relying on the natural soil fertility and regenerative powers to practices depending on high levels of inorganic fertilizers, the intensive use of chemicals for pest control, and crops produced mainly under a monoculture.

Concern about sustainability can be dated from the First Earth Day in 1969; and has been given very different definitions (LARSON et al., 1982; CARTER, 1989; LOCKERETZ, 1988; RUTTAN, 1988; HAMILTON, 1989). According to YORK (1989) sustainable agriculture is a farming practice which avoids or at least minimizes the use of non-renewable production inputs such as fertilizers, pesticides and herbicides.

LOWRANCE et al. (1984) defined sustainable agriculture that does not deplete soil or people. The idea of sustainable agriculture is popular among people interested in alternative systems of agriculture which minimize the potential negative effects of feeding a growing population (LOWRANCE et al., 1986). DOUGLASS (1984) identified three different views of sustainability. The first view - called *sustainability of food sufficiency* - seeks to maximize food production within the constraints of profitability. The second view - *sustainability of stewardship* - defines sustainability as controlling the environmental damage caused by agriculture. The third view - *sustainability as community* - defines sustainability in terms of maintaining and reconstructing the rural value of ecosystems.

Studies on the sustainability of agricultural production and the connections between agriculture and environmental quality have been initiated in developed countries, but in less developed countries, with an inadequate food supply, the difficulties are even more serious. The Agency for International Development, dealing with agriculture and resource management in developing countries, can address these problems on a global scale. The aim of the presented work is to examine the sustainability of production in the Westsik crop rotation experiment and to draw attention to the importance of long-term experiments in the study of soil organic matter.

## Description of the Westsik Crop Rotation Experiment

The experiment, which was established in 1929, contains 46 plots, each of which measures 0.27 hectares, separated by narrow paths. Table 1 lists the 15 treatments together with the symbols used to distinguish them, the amount of organic matter applied and also the sequence of crops grown. At the beginning, Westsik introduced certain changes in the number of crops in the rotation and adjusted blocks F-13, F-14 and F-15 in 1932. During the first 10 years he also tested leguminous crops suitable for growing under the adverse soil conditions of the Nyírség region.

The rate of fertilizers applied was increased in 1951 after 7 complete cycles and in 1972 after 14 complete cycles, while the manure treatments were kept unchanged. Vilmos Westsik maintained strict control of all operations on the plots, and to ensure the validity of the results he made great efforts to keep down weeds. The results were reviewed from time to time in several massive papers discussing the yield results and some measurements on quality (WESTSIK 1941, 1951).

Yield data are divided into five sections and three time periods. The first covers the control treatments, where fallow and organic manure were applied without fertilizers. The second group shows the effects of different straw manure treatments. The third group is used to study forage production and farmyard manure treatments. One is used to compare different ways of utilizing the lupin main crop and a further to study the method of production and application of lupin green manure as a second crop.

The F-1 block received no fertilizers or organic material treatment except the rye stubble, potato roots and straw incorporated into the soil. The fallow in this block was a green one and the plant material was ploughed into the soil.

*Table 1*

**Organic manure and fertilizer treatments in the Westsik crop rotation experiment**

| Crop rota-tion | Organic matter treatments | t/ha/ 3 years | Series I. | Series II. | Series III. | Series IV. | Fertilizer input (kg/ha/3yr) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | N | $P_2O_5$ | $K_2O$ |
| F1 | Fallow | | Fallow | Rye | Potato | | | | |
| F2 | Green manure | NM | Lupin | Rye | Potato | | 36 | 94 | 84 |
| F3 | Root manure | NM | Lupin | Rye | Potato | | 36 | 94 | 84 |
| F4 | Mulch | 3.48 | Rye | Potato | Rye | | 90 | 62 | 56 |
| F5 | Straw manure | 11.3 | Rye | Potato | Rye | | 90 | 62 | 56 |
| F6 | Straw manure | 26.1 | Rye | Potato | Rye | | 90 | 62 | 56 |
| F7 | Straw manure | 26.1 | Rye | Potato | Rye | | | | |
| F8 | Root and green manure | NM | Lupin | Rye+ lupin | Potato | Rye | 72 | 94 | 56 |
| F9 | Green fodder | NM | Lupin | Rye | Potato | | 72 | 62 | 56 |
| F10 | Farmyard manure | 26.1 | Fodder | Rye | Potato | | | | |
| F11 | Farmyard manure | 26.1 | Fodder | Rye | Potato | | 36 | 94 | 84 |
| F12 | Green manure S. C. | NM | Rye + lupin | Rye | Potato | | 36 | 94 | 84 |
| F13 | Green manure S. C. | NM | Rye + lupin | Rye | Potato | | 72 | 94 | 84 |
| F14 | Green manure S. C. | NM | Rye + lupin | Rye | Potato | | 72 | 94 | 84 |
| F15 | Green manure S. C. | NM | Rye + lupin | Rye | Potato | | | | |

*Remarks:* NM = not measured; S. C. = second crop.

The F-2 block represents a green manure treatment, where lupin was grown as the main crop and incorporated into the soil 4-5 weeks after flowering. The phosphorus and potassium fertilizers in this treatment were distributed before the lupin.

The F-3 block represents a lupin root manure treatment, where lupin was grown for grain and the total organic material, except the grain, was incorporated into the soil.

Blocks F-4 to F-7 represent straw manure treatments. In the F-4 block rye straw was applied as a mulch. In blocks F-6 and F-7 straw manure was fermented without nitrogen and in block F-5 with nitrogen addition. The straw manure was incorporated into the soil 4-6 weeks before sowing the rye.

F-8 is the only 4 series crop rotation block where lupin occurred twice in 4 years, once as a main crop produced for grain and once as a second crop produced after rye and before potato for green manure.

In the F-9 block lupin was grown as a forage crop and harvested 2-3 weeks after flowering.

Blocks F-10 and F-11 represented farmyard manure treatments without and with supplementary fertilizers, respectively.

In the F-12 block lupin was grown after a forage crop (rye) sown early in May. This block was also evaluated with farmyard manure treatments.

Blocks F-13, F-14 and F-15 represent green manure treatments, where lupin was grown as a second crop after rye before potato. F-15 received no supplementary fertilizers. The difference between blocks F-13 and F-14 can be found in the time of incorporation of the green manure.

## Results

One of the main practical objects of the Westsik crop rotation experiment was to measure the long-term effects of different organic manures and inorganic fertilizers on the yield of rye and potato. In individual years yields are affected by unpredictable factors, such as weather conditions at critical stages or attacks by pests and diseases (Figure 1). The decline of yields between 1960-1975 was the direct effect of weed competition, as labour was not available at that time for hand hoeing. To smooth out the effects of such factors the yields in this summary are averages over 21 years. They estimate the results likely to be obtained from specific schemes of manuring over a period of years.

When considering 63-year averages, rye yielded better in treatments where lupin green manure and higher rates of phosphorus and potassium fertilizers we reapplied (F-8, F-2). In F-11, farmyard manure supplemented with phosphorus and potassium fertilizers also resulted in a high yield. In straw manure treatments rye yielded less than the main average (AVG) of the experiment. The lowest rye yield was measured in series F-1, F-15 and F-7; i.e. in control treatments, where no fertilizers were applied.

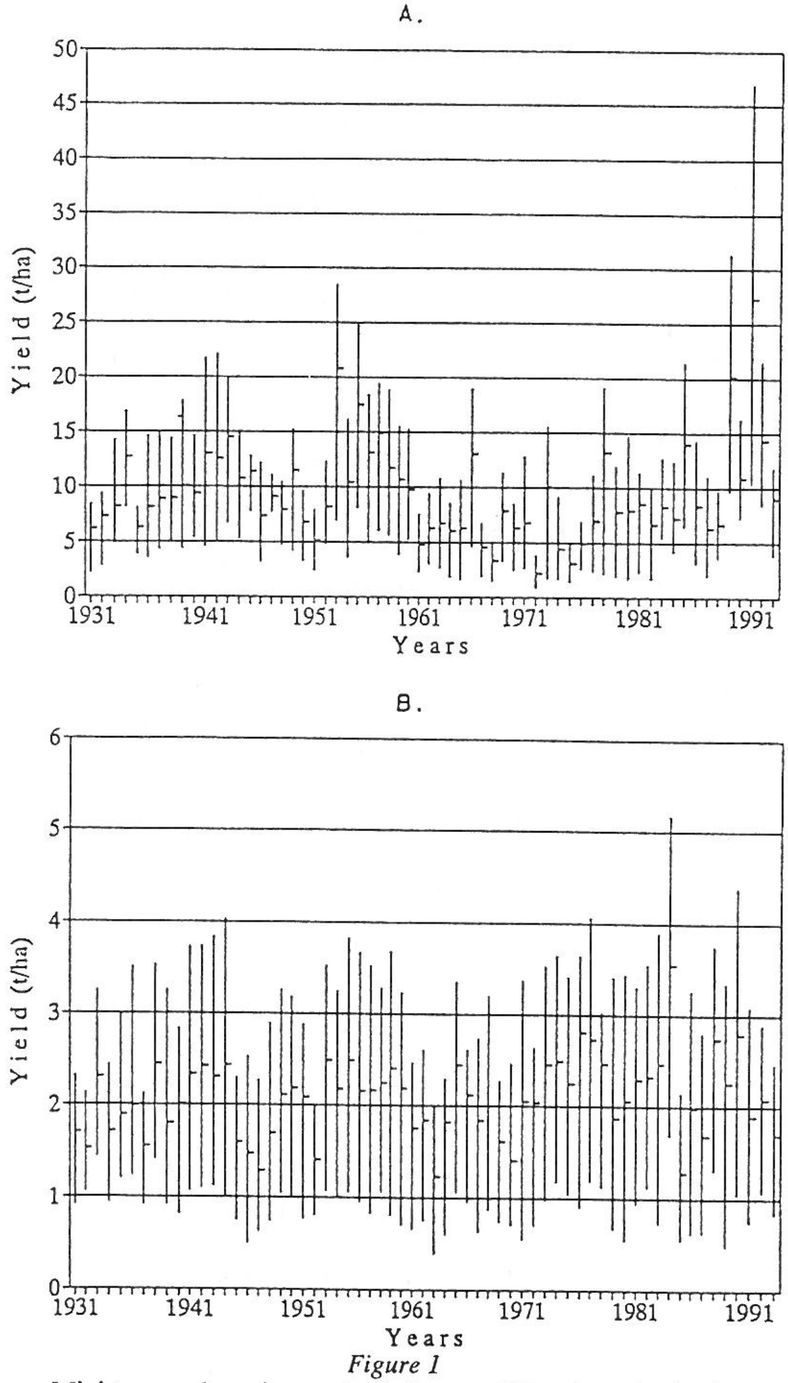


*Figure 1*

Minimum and maximum yield of potato (A) and rye (B) in the Westsik crop rotation experiment

Concerning the yield of rye, an increasing tendency can be found in series F-6, F-8 and F-11, where straw, green and farmyard manure were applied and supplemented with fertilizers. Fallow (F-1), straw manure (F-7) and lupin as a second crop without fertilizer addition (F-15) resulted in poor yields and a decreasing tendency over time.

The soil organic matter (SOM) content increased in treatments where farmyard and straw manure were applied (series F-6, F-7, F-10, F-11). As soil organic matter changes only slowly with time under Hungarian conditions, it is not surprising that data from the Westsik experiment show little difference in organic matter content within the treatments. SOM declined steadily in the fallow treatment and after more than 60 years it has not yet reached an equilibrium. In the straw manure treatments the SOM content increased as a result of improved organic matter management but the effect of rye straw mulch in treatment F-4 is surprisingly small. In all treatments the SOM content in the green manure treatment is low, highlighting the importance of the quality and quantity of organic material. Soil organic matter continuously declined in the second crop green manure treatment (F-15). Yield and soil organic matter tended to increase with fertilizer application, where the cropping sequence had been in favour of building up humus.

The amount of humus in the soil tends to move towards an equilibrium value which depends on the farming system practised and on the soil and climatic conditions. The carbon content of unfertilized soil decreased, while in fertilized treatments it increased. In the lupin green manure treatment the annual losses of carbon were balanced by annual gains. Where 26.1 t/ha farmyard manure and 26.1 t/ha straw manure were applied every third year the organic matter content increased but equilibrium has not yet been reached.

Correlations between the organic matter content of the soil and the yields of cultivated plants are shown in Figure 2.

In the control treatments rye yielded 1 t/ha less than in fertilized treatments, where the soil organic matter has a very small effect on yield. Soil organic matter increased the potato yield both in the fertilized and control treatments.

## Discussion

When the experiment was started in 1929, the soil was in a poor state of fertility as it had already been used to grow rye and potato without manure for many years. The territory was suitable for testing different methods of organic manure application. The yield of rye in the fallow block was very small and the effect of lupin main crop and farmyard manure was equally important at the beginning. A few years later another important result emerged and Westsik was able to distinguish between the effects of the organic manure treatments applied.

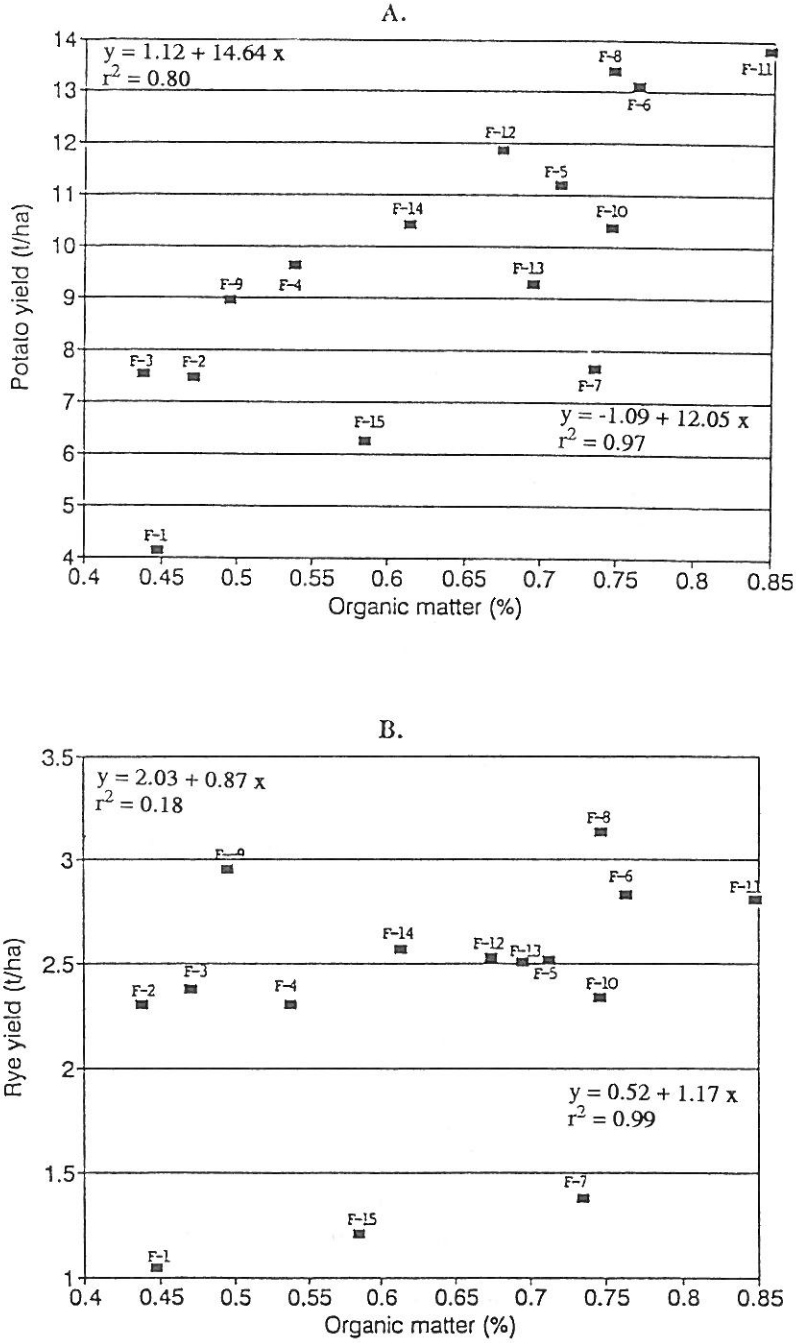


*Figure 2*

Crop yield as a function of soil organic matter content.
A. Potato yield. B. Rye yield.

The importance of lupin on sandy soil with a low pH content was confirmed but there were signs that plots treated with straw manure required additional nitrogen to produce a full crop. Vilmos Westsik realized that rye can be grown with much better results in these treatments than in the traditional fallow system and went on developing an appropriate, sustainable cropping system in which the ratio of leguminous crops was increased or inorganic fertilizers were used to maintain the fertility of the soil.

The soil fertility in the Westsik crop rotation experiment is strongly linked to soil organic matter (SOM) through its influence on soil physical properties and plant nutrient supply. Long-term experiments are used to study the effect of fertilizers and additional organic matter on SOM (RASMUSSEN et al., 1980; SAUERBECK, 1982; KOFOED et al., 1984; ODELL et al., 1984; MCGILL et al., 1986; BALESDENT et al., 1988; PAUSTIAN et al., 1992). The results of these long-term experiments have contributed substantially to our knowledge on the behaviour of organic matter in the soil.

In the Westsik crop rotation experiment the organic matter treatment encompassed a wide range of organic matter inputs: a) fallow (none); b) lupin roots only; c) lupin green manure main crop; d) lupin green manure second crop; e) rye straw; f) rye straw manure fermented with or, g) without N fertilizer; and h) farmyard manure. In this experiment the type of organic matter addition was the most important factor determining the organic matter level and also yield trends of different crops.

Organic material with a higher lignin content, i.e. rye straw manure, resulted in a higher accumulation of SOM than lupin green manure. The addition of straw manure resulted in an 8.5% higher total soil organic matter content compared to farmyard manure. Many long-term experiments have also found differences in soil organic matter with respect to the type of organic matter added. The ability of farmyard manure to maintain and/or increase soil organic matter is known (JENKINSON & RAYNER, 1977). ANDERSON & DOMSCH (1989) reported that differences in the ratio of microbial biomass carbon to total soil organic matter could be related to the type of organic matter applied. They also suggested a higher overall yield efficiency of microorganisms in a mixed rotation.

Lupin as a leguminous crop appeared to have a very positive effect in the Westsik crop rotation experiment (WESTSIK, 1941, 1951). However, in some studies little or no influence of residue quality on soil organic matter content was found. JENKINSON (1977) as well as JENKINSON & JOHNSTON (1977) found 15% greater first year decomposition of straw under unfertilized vs. fertilized barley. POWLSON et al. (1987, 1992) found similar differences in decomposition in unplanted vs. planted soil. Another mechanism by which mineral nitrogen availability might affect soil organic matter levels would be influenced by microbial efficiency. To analyze the interaction of these factors, including the indirect effects due to feedback between plant growth and soil processes, modelling will be essential.

The amount of SOM depends on: a) the input of organic material and its rate of oxidation; b) the rate at which existing soil organic matter decomposes; c) soil texture; d) climate. The first two factors are dependent on the farming system practised. All four factors interact so that humus levels tend towards equilibrium values. In temperate zone these changes are too slow to evaluate in field experiments or in practice.

Soil organic matter increased when a large amount of farmyard manure was applied, although recent calculations have shown that much organic matter was lost from these plots by mineralization (LAZÁNYI, 1993).

Fertilizers combined with organic material increased yields and soil fertility. The result clearly indicated a benefit from the fertilizer applied. Most of this benefit was ascribed to the higher nutrient level and availability. Only a small part of it can be attributed to the higher drought tolerance of crops in the green manure and lupin green forage treatments. The yield results showed some benefits for lupin green manure compared to farmyard manure, which can also be explained by the extra nitrogen supplied by this crop. These benefits from extra organic matter began to be measured when crops with higher yield potential were introduced and agrochemicals became available to protect this yield potential through the control of pests and diseases (Tables 2 and 3).

It is of great interest that there have been benefits from ploughing in rye straw, especially now, when there is a ban on the field burning of straw. The soil in Nyíregyháza contains only 0.6% organic matter and this may be one reason of the benefit observed when the straw or straw manure incorporation is followed by nitrogen treatments to adjust the C/N ratio.

The soil of the F-6 and F-11 treatments now contains about 50% more organic matter than the soil of the fallow treatment. The increase represents 10.3 per cent of the total organic matter applied as straw and farmyard manure. These results confirm the data obtained in the Broadbalk and Hoosfield experiments by JENKINSON & JOHNSTON (1977) and JOHNSTON (1986). During the past years the organic matter content has decreased in the F-1 and F-15 treatments. A large loss of organic material occurred before the experiment was set up, as the equilibrium value specific to a forest system on similar soil and under similar climatic conditions is 1.5% soil organic matter.

Lupin green manure increased soil organic matter only a little. The higher equilibrium compared to fallow comes from the extra organic material of lupin ploughed into the soil. The amount of green manure incorporated into the soil was not measured and depended on the climatic conditions. According to the estimation of Vilmos Westsik, lupin yielded well in 3 out of 10 years (60 t/ha), corresponding to 12 t/ha dry matter. In some treatments lupin was harvested for grain and forage, thus reducing the organic matter input. In these treatments (F-3, F-9) the soil organic matter content was similar to that of F-2 where lupin was used as green manure.

The largest gain occurred in treatments F-6 and F-11, where 4.2 t/ha organic matter was applied. An appreciable increase in soil organic matter can

*Table 2*

**Rye yield in the Westsik crop rotation experiment**

| Years | F1 | F2 | F3 | F4 | F5 | F6 | F7 | F8 | F9 | F10 | F11 | F12 | F13 | F14 | F15 | Avg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Yield, t/ha* | | | | | | | | | | | | | | | | |
| 1931-51 | 0.99 | 2.73 | 2.15 | 1.59 | 1.88 | 2.04 | 1.39 | 2.14 | 1.96 | 1.95 | 2.32 | 2.61 | 1.92 | 1.90 | 1.62 | 1.95 |
| 1952-72 | 0.81 | 2.39 | 2.00 | 1.82 | 1.97 | 2.22 | 1.34 | 2.71 | 2.48 | 1.78 | 2.53 | 2.38 | 2.19 | 2.07 | 1.41 | 2.01 |
| 1973-93 | 1.04 | 2.30 | 2.38 | 2.31 | 2.52 | 2.83 | 1.38 | 3.13 | 2.95 | 2.34 | 2.81 | 2.53 | 2.51 | 2.57 | 1.21 | 2.32 |
| 1931-93 | 0.95 | 2.48 | 2.18 | 1.93 | 2.13 | 2.38 | 1.37 | 2.67 | 2.46 | 2.02 | 2.55 | 2.51 | 2.21 | 2.18 | 1.38 | 2.09 |
| *Deviation from treatment average, t/ha* | | | | | | | | | | | | | | | | |
| 1931-51 | -0.95 | 0.79 | 0.21 | -0.36 | -0.07 | 0.10 | -0.56 | 0.20 | 0.02 | 0.00 | 0.37 | 0.66 | -0.02 | -0.05 | -0.33 | 0.00 |
| 1952-72 | -1.20 | 0.39 | 0.00 | -0.18 | -0.04 | 0.21 | -0.66 | 0.70 | 0.47 | -0.22 | 0.52 | 0.38 | 0.18 | 0.06 | -0.60 | 0.00 |
| 1973-93 | -1.28 | -0.02 | 0.06 | -0.01 | 0.20 | 0.51 | -0.94 | 0.81 | 0.63 | 0.02 | 0.49 | 0.21 | 0.19 | 0.25 | -1.11 | 0.00 |
| 1931-93 | -1.15 | 0.38 | 0.08 | -0.17 | 0.04 | 0.29 | -0.72 | 0.58 | 0.37 | -0.07 | 0.46 | 0.41 | 0.12 | 0.09 | -0.71 | 0.00 |
| *Percentage deviation from treatment average, %* | | | | | | | | | | | | | | | | |
| 1931-51 | -49.0 | 40.4 | 10.6 | -18.6 | -3.6 | 5.0 | -28.6 | 10.1 | 0.8 | 0.0 | 19.1 | 34.2 | -1.1 | -2.3 | -16.8 | 0.0 |
| 1952-72 | -59.6 | 19.2 | -0.1 | -9.2 | -2.1 | 10.4 | -33.0 | 35.0 | 23.5 | -11.2 | 26.1 | 18.8 | 9.0 | 3.1 | -29.9 | 0.0 |
| 1973-93 | -55.0 | -0.7 | 2.5 | -0.6 | 8.5 | 21.9 | -40.6 | 35.0 | 27.2 | 0.9 | 21.1 | 9.1 | 8.0 | 10.6 | -47.9 | 0.0 |
| 1931-93 | -54.7 | 18.2 | 4.0 | -7.9 | 1.8 | 13.9 | -34.6 | 27.5 | 17.7 | -3.4 | 21.9 | 19.8 | 5.6 | 4.3 | -34.0 | 0.0 |

*Table 3*

**Potato yield in the Westsik crop rotation experiment**

| Years | F1 | F2 | F3 | F4 | F5 | F6 | F7 | F8 | F9 | F10 | F11 | F12 | F13 | F14 | F15 | Avg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Yield, t/ha*** | | | | | | | | | | | | | | | | |
| 1931-51 | 4.49 | 9.71 | 7.72 | 8.23 | 9.16 | 10.79 | 8.11 | 11.38 | 8.10 | 9.68 | 9.30 | 10.92 | 12.56 | 11.31 | 9.56 | 9.40 |
| 1952-72 | 3.67 | 9.10 | 8.70 | 8.05 | 9.27 | 10.72 | 7.49 | 12.04 | 9.58 | 9.21 | 11.94 | 11.08 | 9.62 | 9.15 | 7.53 | 9.14 |
| 1973-93 | 4.13 | 7.53 | 7.47 | 9.64 | 11.19 | 13.11 | 7.66 | 13.41 | 8.97 | 10.37 | 13.81 | 11.87 | 9.27 | 10.44 | 6.25 | 9.67 |
| 1931-93 | 4.08 | 8.73 | 7.97 | 8.68 | 9.91 | 11.58 | 7.73 | 12.31 | 8.91 | 9.77 | 11.69 | 11.30 | 10.45 | 10.28 | 7.66 | 9.40 |
| ***Deviation from treatment average, t/ha*** | | | | | | | | | | | | | | | | |
| 1931-51 | -4.91 | 0.31 | -1.68 | -1.17 | -0.24 | 1.39 | -1.29 | 1.98 | -1.30 | 0.28 | -0.10 | 1.52 | 3.16 | 1.91 | 0.16 | 0.00 |
| 1952-72 | -5.47 | -0.04 | -0.45 | -1.09 | 0.12 | 1.57 | -1.65 | 2.89 | 0.43 | 0.07 | 2.80 | 1.94 | 0.48 | 0.01 | -1.61 | 0.00 |
| 1973-93 | -5.54 | -2.15 | -2.20 | -0.04 | 1.51 | 3.44 | -2.02 | 3.73 | -0.71 | 0.70 | 4.14 | 2.20 | -0.41 | 0.76 | -3.43 | 0.00 |
| 1931-93 | -5.32 | -0.67 | -1.43 | -0.73 | 0.51 | 2.17 | -1.67 | 2.90 | -0.50 | 0.37 | 2.28 | 1.90 | 1.05 | 0.88 | -1.74 | 0.00 |
| ***Percentage deviation from treatment average, %*** | | | | | | | | | | | | | | | | |
| 1931-51 | -52.3 | 3.3 | -17.9 | -12.4 | -2.5 | 14.8 | -13.7 | 21.1 | -13.9 | 3.0 | -1.1 | 16.1 | 33.6 | 20.3 | 1.7 | 0.0 |
| 1952-72 | -59.8 | -0.5 | -4.9 | -11.9 | 1.3 | 17.2 | -18.1 | 31.7 | 4.7 | 0.7 | 30.6 | 21.2 | 5.2 | 0.1 | -17.6 | 0.0 |
| 1973-93 | -57.3 | -22.2 | -22.8 | -0.4 | 15.6 | 35.5 | -20.9 | 38.6 | -7.3 | 7.2 | 42.8 | 22.7 | -4.2 | 7.9 | -35.4 | 0.0 |
| 1931-93 | -56.6 | -7.1 | -15.2 | -7.7 | 5.4 | 23.1 | -17.7 | 30.9 | -5.3 | 3.9 | 24.3 | 20.2 | 11.1 | 9.4 | -18.6 | 0.0 |

only be achieved by adding large quantities of organic material to the soil; however, only 10.3 % of the organic matter added as straw or farmyard manure is still in the soil after 63 years. The increase in soil organic matter per tonnes of organic matter added per hectare was approximately 0.0105, 0.015. The higher equilibrium in this treatment can only be maintained by the permanent application of organic manure.

The addition of fertilizers increased both yield and roots. The increased soil organic matter content in these treatments comes from the extra roots and stubble ploughed in each year. In these plots the annual losses of carbon have been balanced by annual gains for the past 63 years. High yielding varieties of rye and potato benefit from the better soil physical conditions associated with a higher level of soil organic matter. Some of the benefit of extra soil organic matter may be related to enhanced soil water and ion retention capacity. The amount of organic matter retained in the soil is dependent on the quantity and quality of organic material added.

The effect of organic manure in the Westsik crop rotation experiment was measured by yield. Responses to NPK fertilizers were larger in treatments where farmyard manure and lupin green manure were applied. Further research is required to decide how much of the effect of the organic matter is due to

1) the supply of nutrients, especially nitrogen, at that time and in those parts of the soil profile where it may be of benefit to the crop,

2) an improvement in soil structure, allowing roots to develop rapidly through the soil to take up water and nutrients, and

3) increased retention of water.

## References

ANDERSON, T. H. & DOMSCH, K. H., 1989. Ratios of microbial biomass carbon to total organic carbon in arable soils. Soil Biol. Biochem. **21**. 471-479.

BALESDENT, J., WAGNER, G. H. & MARIOTTI, A., 1988. Soil organic matter turnover in long-term field experiments as revealed by carbon-13 natural abundance. Soil Sci. Soc. Am. J. **52**. 118-124.

CARTER, H. O., 1989. Agricultural sustainability: An overview and research assessment. Calif. Agric. 16-17.

DOUGLASS, G. K., 1984. The meanings of agricultural sustainability. In: Agricultural Sustainability in a Changing World Order. (Ed.: DOUGLASS, G. K.) 1-29. Westview Press. Colorado.

EHRLICH, A. H., 1985. The human population. Size and dynamics. Amer. Zoology. **25**. 395-406.

FARRELL, K. R., SQUANDERSON, F. H. & VO, T. T., 1984. Feeding a Hungry World. Report No. 76. Resources For the Future. Washington, D. C.

FRANCIS, C. A. & HILDEBRAND, P. E., 1989. Farming systems research, extension and the concept of sustainability. Symposium. University of Arkansas, Fayetteville.

HAMILTON, N. D., 1989. Sustainable Agriculture. The Role of the Alterney. Drake University. Des Moines, Iowa.

JENKINSON, D. S., 1977. Studies on the decomposition of plant material in soil. V. The effects of plant cover and soil type on the loss of carbon from C labelled rye-grass decomposing under field conditions. J. Soil Sci. **28.** 424.

JENKINSON, D. S. & JOHNSTON, A. E., 1977. Soil organic matter in the Hoosfield Continuous Barley Experiment. Rothamsted Experimental Station Report for 1975. Part 2. 87-101.

JENKINSON, D. S. & RAYNER, J. H., 1977. The turnover of soil organic matter in some of the Rothamsted classical experiments. Soil Sci. **123**. 298-305.

JOHNSTON, A. E., 1986. Soil organic matter, effects on soils and crops. Soil Use and Management. **2**. 97-105.

JOHNSTON, A. E., 1987. Effects of soil organic matter on yields of crops in long-term experiments at Rothamsted and Woburn. INTECOL Bulletin. 15. 9-16.

KOFOED, A. D., NEMMING, O. ASKOV, T., 1984. Fertilizers and manure on sandy and loamy soils. Ann. Agron. **27.** 583-610.

LARSON, W. E., PIERCE, F. J. & DAVDY, R. H., 1982. Our agricultural resources: Management for conservation. In: Future Agricultural Technology and Resource Conservation. (Eds.: ENGLISH et al.). 40-59. Iowa State University Press.

LAZÁNYI, J., 1993. Results of sustainable land use in a crop rotation experiment. Agrokémia és Talajtan. **42.** 101-108.

LOCKERETZ, W. 1988. Open questions in sustainable agriculture. American Journal of Alternative Agriculture. **3.** 174-181.

LOWRANCE, R., HENDRIX, P. F. & ODUM, E. P., 1986. A hierarchical approach to sustainable agriculture. American Journal of Alternative Agriculture. **1.** 169-173.

LOWRANCE, R. et al., 1984. Riparian forests as nutrient filters in agricultural water-sheds. Bio Science. **34.** 374-377.

MAGLEBY, R., COLACICCO, D. & THIGPEN, J., 1985. Trends in conservation tillage. J. Soil Water Conservation. **40.** 274-276.

McGILL, W. B. et al., 1986. Dynamics of soil microbial biomass and water-soluble organic C in Breton L after 50 years of cropping to two rotations. Can. J. Soil Sci. **66.** 1-19.

ODELL, R. T., MELSTED, S. W. & WALKER, W. M., 1984. Changes in organic carbon and nitrogen of Morrow plot soils under different treatments, 1904-1973. Soil Sci. **137.** 160-171.

PAUSTIAN, K., PARTON, W. J. & PERSSON, J., 1992. Modeling soil organic matter in organic-amended and nitrogen-fertilized long-term plots. Soil Sci. Soc. Am. J. **56.** 476-488.

POWLSON, D. S., BROOKES, P. C. & CHRISTENSEN, B. T., 1987. The measurement of soil microbial biomass provides an early indication of changes in total soil organic matter due to straw incorporation. Soil Biology and Biochemistry. **19.** 159-164.

POWLSON, D. S. et al., 1992. Influence of soil type, crop management and weather on the recovery of N-labelled fertilizer applied to winter wheat in spring. Journal of Agricultural Science, Cambridge. **118.** 83-100.

RASMUSSEN, P. E. et al., 1980. Crop residue influences on soil carbon and nitrogen in a wheat fallow system. Soil Sci. Soc. Am. J. **44.** 596-600.

RUTTAN, V. W., 1988. Sustainability is not enough. Am. J. Alt. Agr. **3.** 128-130.

SAUERBECK, D. R., 1982. Influence of crop rotation, manurial treatment and soil tillage on the organic matter content of German soils. In: Soil Degradation. (Eds.: BOELS, D. et al.). 163-178. Balkema. Rotterdam. The Netherlands.

WESTSIK, V., 1941. [Results of crop rotation experiments at the Sandy Soil Research Farm.] (In Hung.) Klaffer Publ. House. Nyíregyháza.

WESTSIK, V., 1951. [Results of crop rotation experiments.] (In Hung.) Agric. Publ. House. Budapest.

WOLF, E. C., 1987. Raising agricultural productivity. In: State of the World. (Ed.: BROWN, L. R.). 139-156. W. W. Norton. New York.

YORK, E. T., 1989. Research for a sustainable agriculture. Amer. Soc. Agron. Spec. Publ. **46.** 61-68.