Results of Sustainable Land Use in a Crop Rotation Experiment

J. LAZÁNYI, A. MÁRTON, E. VASS and A. HADHÁZI

Research Centre of Debrecen Agricultural University, Nyíregyháza (Hungary)

Agricultural research and production have been characterized by the excessive application of fertilizers over the past 50 years. Crop production uses more and more fertilizers to obtain higher yields, while environmental pollution causes very serious problems. The situation is especially bad on sandy soil where the organic matter and pH have decreased to a great extent and deflation causes serious damage. The crop rotation experiment established by Vilmos Westsik in 1929 offers a solution to these problems. The experiment, consisting of 15 treatments, makes it possible to study the sustainability of land use under different applications of green, straw and farmyard manure.

Description of the Westsik Crop Rotation Experiment

Location: Agricultural Research Centre, Nyíregyháza
Initiation date: 1929
Purpose:
Original: To maintain and improve the fertility level of sandy soil
Present: To study the effects of different cropping systems on the fertility of the soil.
Soil type: Sandy soil with low pH.
Climatic type: continental

Mean air temperature (January)	4.3 °C
Mean air temperature (July)	15.4 °C
Annual mean temperature	9.6 °C
Average annual precipitation (1929-90) (min. 353 mm; max. 846 mm)	568 mm

Wind direction: N, NE.

Experimental design: Non-randomized, non-replicated. All crops are present each year (Table 1).
- Cropping systems: 3 course in series 1-7 and 9-15
  4 course in series 8
- Plot size: 2700 m^2. Total size of experiment: 12.42 ha.

Table 1

Organic matter and fertilizer application in the Westsik Crop Rotation Experiemnt (Fertilizers kg/ha)

Series	Organic matter	t/ha	Crop 1	N	P_2O_5	K_2O
1.	Fallow	NM	Fallow	-	-	-
2.	Green manure	NM	Lupin	-	62	56
3.	Lupin root	NM	Lupin (G)	-	62	56
4.	Rye straw	3.5	Rye	88	47	56
5.	Straw manure+N	11.3	Rye	88	47	56
6.	Straw manure	26.1	Rye	88	47	56
7.	Straw manure	26.1	Rye	-	-	-
8.	Green manure	NM	Lupin (G)	-	31	28
9.	Green forage	NM	Lupin (F)	-	62	56
10.	Farmyard man.	26.1	Forages	-	-	-
11.	Farmyard man.	26.1	Forages	-	62	56
12.	Green manure	NM	Rye+LSC	-	62	56
13.	Green manure	NM	Rye+LSC	44	31	28
14.	Green manure	NM	Rye+LSC	44	31	28
15.	Green manure	NM	Rye+LSC	-	-	-
1/A	None	-	Rye	88	47	56

Series	Crop 2	N	P_2O_5	K_2O	Crop 3	N	P_2O_5	K_2O
1.	Rye	-	-	-	Potato	-	-	-
2.	Rye	-	31	28	Potato	44	-	-
3.	Rye	-	31	28	Potato	44	-	-
4.	Potato	44	31	28	Rye	-	-	-
5.	Potato	44	31	28	Rye	-	-	-
6.	Potato	44	31	28	Rye	-	-	-
7.	Potato	-	-	-	Rye	-	-	-
8.	Rye+LSC	44	31	28	Potato	-	31	28
9.	Rye	44	31	28	Potato	44	-	-
10.	Rye	-	-	-	Potato	-	-	-
11.	Rye	-	31	28	Potato	44	-	-
12.	Rye	-	31	28	Potato	44	-	-
13.	Potato	-	31	28	Rye	44	31	28
14.	Potato	-	31	28	Rye	44	31	28
15.	Potato	-	-	-	Rye	-	-	-
I/A	Rye	88	31	28	Potato	88	31	56

Crop 4 in series 8 is Rye: N = 44; P_2O_5 = 0; K_2O = 0. (G): grain; (F): forage: (LSC): lupin second crop; NM: not measured

Surroundings: The experiment is situated on two sandy hills. There is a country road on the East side of the experiment and also a ditch with a row of trees. A canal is found on the West side.

Changes in the experiment: only slight revisions have been made to the experiment.

1929 Establishment of series 1-12
1932 Establishment of series 13-15
1941 Change in course in series 8
1951 Change in fertilizer rates in series 2, 3, 9, 10 and 11
1961 Series 1 was divided into two, one of which was fertilized
1971 Change in fertilizer rates in series 4, 5 and 6.

Measurements recorded:

- *Yield data:* (i) grain and straw for rye; (ii) grain for lupin; (iii) tubers for potato; (iv) green yield and dry matter for forage.
- *Inputs:* Fertilizers and other chemicals are recorded (source and amounts)
- *Field operation:* Recorded in a field notebook
- *Soil characteristics:* Complete set of pH values and extractable nutrients in 1954, 1968, 1971, 1979, 1986, 1989, 1991.
- *Plant characteristics:* Complete set of plant yield analysis, root measurements, macro- and microelements for certain years.
- *Meteorological data:* Rainfall and mean temperature data are available since 1930. More detailed meteorological data are available for the town of Nyíregyháza, 800 m from the experiment.
- *Economic data:* Partly recorded. Inputs and yield data are known.
- *Ecological monitoring:* A few data are available on emergence, weeds and insects.

Results

Over a 60-year average, rye yielded better in treatments where lupin green manure and higher rates of P and K fertilizers were applied, i.e. in series S-8 and S-2. S-11, where farmyard manure was supplemented with P and K fertilizers, also resulted in high yields. The lowest rye yields were measured in series S-1, S-15 and S-7, i.e. in the control plots, where no fertilizers were added. The highest yield for potato was measured in series S-8, where lupin occurs twice: once as a main crop produced for grain, and as a second crop produced after rye and before potato. Similarly good results were obtained in series S-11, where farmyard manure was applied (Table 2).

As regards soil characteristics, the highest pH values were recorded in series S-11 and S-10, given farmyard manure, and in series S-7, where straw manure was applied. The soil organic matter content increased in treatments where farmyard and straw manure were applied; i.e. in series S-6, S-7, S-10 and S-11. An evaluation of the average yields for potato and of their deviations from the 10-year averages indicates that there was a great decrease in potato yields in the sixties. Concerning the treatments, the best series were S-6, S-8 and S-11, where a continuous increase in relative yield could be established, resulting

Table 2
Average yields and certain soil parameters as measured in 1979 in all the series of the crop rotation experiment

Series	60-year averages		Soil parameters			
	Potato yield kg/ha	Rye yield kg/ha	pH	Organic matter, %	P_2O_5 mg/100g	K_2O mg/100g
S-1	4070	1013	3.9	0.42	5.2	4.7
S-2	8458	2503	3.8	0.50	12.2	8.7
S-3	7729	2192	4.1	0.54	13.2	8.8
S-4	8246	1978	4.3	0.60	9.0	11.5
S-5	9437	2123	4.4	0.65	9.9	11.0
S-6	10984	2416	4.9	0.84	10.2	14.6
S-7	7292	1428	5.6	0.81	8.0	13.9
S-8	11605	2608	4.8	0.69	10.3	10.6
S-9	8615	2464	4.7	0.49	12.1	11.9
S-10	9247	2022	5.4	0.73	15.2	27.8
S-11	11208	2505	5.5	0.79	17.5	24.0
S-12	10530	2492	4.2	0.65	11.3	11.1
S-13	10333	2112	4.1	0.66	12.3	11.8
S-14	9793	2191	4.0	0.62	10.7	10.6
S-15	8046	1360	4.2	0.67	3.4	7.7

from continuously improving soil characteristics. A significant decrease in relative yield could be found in series S-1, S-7 and S-15, where no fertilizers were applied (Table 3).

Concerning the yield of rye, an increasing tendency can be observed in series S-6, S-8 and S-11, where straw, green and farmyard manure were applied and supplemented with fertilizers. Fallow (S-1), straw manure (S-7) and lupin second crop without fertilizer addition resulted in poor yields, with a decreasing tendency over time (Table 3).

Discussion and Conclusions

Sustainable land use focuses on mantaining soil fertility, which arises from complex interactions between the biological, chemical and physical properties of the soil. As many aspects of these properties change only slowly over time, long-term experiments are required to measure and evaluate such processes.

The Westsik Crop Rotation Experiment, established in 1929, can be used to study the effects of organic manure treatment to develop models and to predict the likely effect of different cropping systems on soil properties and crop yields. Such experiments are costly to maintain, but their cost can be easily

Table 3

Average yields of potato and rye and their deviations from the 10-year average in the Westsik Crop Rotation Experiment

Years	Average yield, kg/ha	Deviation as a percentage														
		S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	S-9	S-10	S-11	S-12	S-13	S-14	S-15
Potato																
1931-1940	8687	-48	5	-19	-4	-14	4	-17	10	-18	20	-9	12	42	27	-
1941-1950	10564	-56	3	-15	-20	1	18	-17	30	-12	-12	3	18	29	18	3
1951-1960	12355	-59	4	-8	-16	3	14	-18	25	2	7	34	19	1	-2	-14
1961-1970	6354	-61	-8	-4	-10	-5	21	-13	36	6	-7	20	28	14	-6	-21
1971-1980	6930	-71	-32	-24	-2	22	45	-37	57	-1	-23	36	17	14	18	-24
1981-1990	9332	-71	-24	-21	1	19	53	-21	58	-6	-17	56	5	-14	-7	-22
Rye																
1931-1940	1887	-41	40	13	-23	-6	4	-16	3	-6	18	15	23	-6	-9	-16
1941-1950	2001	-57	39	4	-19	-7	3	-34	10	2	-18	21	43	16	12	-23
1951-1960	2164	-60	29	8	-16	-9	8	-32	29	26	-21	2-	22	5	9	-30
1961-1970	1803	-57	13	5	-1	7	17	-35	29	22	-3	13	13	10	11	-41
1971-1980	2325	-59	6	6	12	7	14	-49	34	27	-	16	16	1	10	-47
1981-1990	2373	-59	8	1	4	6	35	-45	41	26	1	17	4	5	6	-52

justified if they serve a number of different objectives and provide data for better agricultural practices.

In this respect the Westsik crop rotation experiment provides data of immediate value to farmers concerning the application of green, straw and farmyard manure. The experiment also provides a source of yield, plant and soil data sets for scientific research into the soil and plant processes which control soil fertility and into the sustainability of production without deterioration of the environment.

Long-term experiments such as the Westsik crop rotation experiment are essential for studying the carbon cycle and for calculating nutrient balances for nitrogen, phosphorus and potassium.

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. Numerous long-term experiments have been used to study the effect of fertilizers and additional organic matter on SOM (KOFOED & NEMMING, 1976; JENKINSON & RAYNER, 1977; RASMUSSEN et al., 1980; SAUERBECK, 1982; 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 of 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, i.e. : (i) fallow (none); (ii) lupin roots only; (iii) lupin green manure main crop; (iv) lupin green manure second crop; (v) rye straw; (vi) rye straw manure fermented with or (vii) without N fertilizer, and (viii) farmyard manure. In the present study the type of organic matter applied was the most important factor determining the organic matter level and yield trends of different crops.

Organic materials with a higher lignin content, e.g. 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 other long-term experiments have also found differences in soil organic matter due to the type of organic matter added.

The ability of farmyard manure to maintain and/or increase soil organic matter is well known (KOLENDBRANDER, 1974; JENKINSON & RAYNER, 1977). ANDERSON & DOMSCH (1989) reported that differences in the ratio of microbial biomass C 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, may have a very positive effect in the Westsik crop rotation experiment, as proposed by WESTSIK (1941, 1951a,b)

In some studies, however, residue quality was found to have little or no influence on soil organic matter content. LARSON et al. (1972) reported no differences in soil C contents after applying 8 t/ha/year of alfalfa, corn stalks, oat, brome straw and sawdust for 11 years.

In the present case, additional fertilizers increased the soil organic matter and crop yields. One possible explanation is that the greater plant growth in the fertilizer treatments resulted in a higher transpiration rate, drier soil and slower decomposition. For example, ANDRÉN (1988) found 15% greater first-year decomposition of straw under unfertilized barley as compared to fertilized barley. JENKINSON (1977) found similar differences in decomposition in unplanted and planted soil. Another mechanism by which mineral N 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 feedbacks between plant growth and soil processes, modelling will be essential.

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