Role of Crop Rotation and Organic Manure in Sustainable Land Use

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Introduction

Several definitions of the term "sustainable agriculture" have been formulated during the last decade and a number of international conferences have dealt with this question (Stockholm 1972; UN 1984, 1987; Rio de Janeiro 1992; Martonvásár 1992; Gödöllő 1993; Keszthely 1995). It is clear that sustainable agriculture should be economically efficient, but at the same time it must comply with environmental and ecological requirements. In industrially developed countries modern agriculture depends on considerable inputs of energy of industrial origin (artificial fertilizers and other chemicals) and is generally characterized by a small variety of crops, or even by a monoculture. The phenomena accompanying intensive production in recent years (decreasing profitability, soil degradation, contamination of natural waters, etc.) raise the question of what direction further development should take. It will be necessary to evolve an integrated view of agricultural systems, in which development will be sustainable and will depend less on chemicals and industrial sources of energy, leading to a maintenance of or increase in the yield level and a reduction in costs and ecological risks. The strategy for further development can only be planned on the basis of reliable information on plant production and land use obtained from long-term trials (HUTCHINSON, 1990).

Crop rotation and biological diversification have long been recognized as the basis of successful plant production, but the exaggerated use of chemicals has pushed them into the background in farming practice in recent years. If sustainable agriculture is to be achieved, crop rotation will be a necessity. Natural resources can be mobilized by rotation to improve soil fertility, and chemicals can be replaced by integrated pest management.

The need for crop rotation was first observed and recorded by the ancient Egyptians, Romans and Greeks. In the first centuries B. C. and A.D. valuable works on soil quality, soil fertility and soil use were compiled by Varro (116-26 B.C.), Virgil (70-19 B.C.) and Pliny (62-113 A.D.). In later centuries in Europe special mention should be made of the work of Arthur Young (1741-1820), who developed and popularized the four-step Norfolk rotation based on his wide-ranging practical experience. This crop sequence is a perfect model not only from the agronomic, but also from the economical point of view, and is still the subject of crop rotation research today. In Hungary during the same period, Sámuel Tessedik, János Nagyváthy and Ference Pethe, who dealt with many aspects of agriculture, all stressed the importance of crop rotation. In Germany crop sequences were widely introduced by A. D. Thaer, who advocated the alternate cultivation of mono- and dicotyledonous crops. Based on his thorough knowledge of soil chemistry and soil biology, Theodor Roemer also emphasized the importance of crop rotation in sustaining soil fertility.

With the growth of the population and improvements in farm implements, the intensity of agricultural production also increased. Fallow systems were gradually replaced by crop rotation, a system in which the succession of crops to be grown on a given area in a given year were determined in advance. These systems can be characterized in terms of the sowing structure, and the proportion and order of the individual crops (KISMÁNYOKY, 1993; KEMENESY, 1961).

Now that market conditions are continually changing and the number of crop species has been reduced, it is impossible to determine the composition, ratio and succession of crops for years in advance. As a result, the crops grown in each field are chosen without much regard to what went before (COOK & ELLIS, 1987). Crop rotation is usually employed in contrast to continuous cropping, the practice of growing the same crop on the same land in consecutive years. The favourable effect of the forecrop, a factor in high yields which requires no investment, is unable to assert itself in continuous cropping systems. Although it cannot be disputed that large yields can be attained using high rates of fertilizers and chemicals, these also involve greater costs (KISMÁNYOKY, 1986) and in some cases loss of yield is still unavoidable (KÖNNECKE, 1969).

Crop rotation combined with other agronomic measures (fertilization, soil tillage, irrigation) may also maintain or improve soil fertility (NEMES, 1971; SIPOS, 1978; TISDALE & NELSON, 1966; FERTS, 1955), so it is closely linked with the concept of sustainable agriculture. The positive effect of crop rotation in pest management is also well known. An annual change in the crop checks the spread of epidemics and parasites as well as that of the weed species dominant in various crops (COOK & ELLIS, 1987; FRANCIS & CLEGG, 1990). GYŐRFFY (1993) states that the lower yields achieved in continuous cropping can be attributed to plant diseases in the case of wheat and to water management problems and the spread of herbicide resistant weeds in the case of maize.

The nutrient theory, based on the different nutrient uptakes of various crops, also helps to explain the importance of crop rotation. Each species requires different quantities and ratios of nutrients, while the nutrients taken up are returned to the soil in different forms and quantities. The nutrients themselves are found in various forms and at different depths in the soil, so their availability to the plants also differs (PESEK et al., 1989). Thus, by growing several crops the nutrient reserves of the soil are optimally utilized, making crop sequences a valuable tool in soil management.

The effects of crop sequences have been studied in long-term experiments in Keszthely at the Department of Agronomy of the Georgikon Faculty of the Pannon University. These trials were set up in the early sixties by Géza Láng, Ernő Kemenesy and András Kováts to furnish answers to the questions raised by economists, scientists and farmers. The work presented in this publication is supported by the National Scientific Research Fund (OTKA T 016469).

Materials and Methods

Data were processed from long-term trials set up more than three decades ago at the Georgikon Faculty of Pannon University in Keszthely, West Hungary. The starting dates of the trials, the forecrop structure and other important information are given in Tables 1 and 2. The two- and three-factorial trials were set up in a randomized complete block design with split plots or split-split plots, using mineral and organic fertilizer treatments in three or four replications. The gross size of the plots ranged from 50 to 100 m². The tables include the winter wheat and maize yields obtained in unfertilized control plots and in fertilized treatments (NPK mineral fertilizers, farmyard manure, green manure and straw) which gave the highest yields over the average of many years. The soil was a Ramann-type brown forest soil (Eutric Cambisol) containing 41% sand, 32% silt and 27% clay. The available phosphorus content of this sandy loam soil was low (AL-P_2O_5: 60-80 mg kg^{-1}), the potassium content medium (AL-K_2O: 140-160 mg kg^{-1}) and the humus content fairly low (1.6-1.7%), with a pH(KCl) value of 7.3. The long-term annual mean precipitation was 715 mm, but the distribution was often unfavourable. The average number of rainy days is 161, with a mean annual temperature of 10.8 °C.

Results

Winter wheat

Under continuous cropping conditions the grain yield of winter wheat was only 2.3 t ha^{-1} in the unfertilized treatment, while in the optimum NPK treatment it was almost double this, reaching a value of 4.2 t ha^{-1}. The yields of the crop sequences will be compared to these data.

In the wheat-maize biculture the grain yield was even lower than in continuous cropping, presumably as a consequence of the greater water and nutrient consumption of the maize forecrop. The yield could be significantly increased by fertilization. In the fertilized treatments of the four-year biculture, wheat proved to be a worse forecrop for wheat than maize (132%).

Table 1

Wheat yields in different crop rotations

Crop rotations	Proportion in the crop rotation (%)	Yield, t ha^{-1}				Relative yield (%)			
		Fertilized		Unfertilized		Fertilized		Unfertilized	
1. Continuous crop. 1976-1990	100	4.25		2.29		100		100	
2. Biculture W-W-M-M 1972-1996	50	WW 4.79	MW 5.62	WW 1.73	MW 1.91	WW 112.7	MW 132.2	WW 75	MW 83.4
3. M-W-B 1984-1994	30	4.71		2.10_{PK}		110.8		91.7	
4. M-W-B (Gm) 1984-1994	30	4.86		3.13_{PK}		114.3		136.6	
5. M#W-B 1984-1994	30	5.14		2.75_{PK}		120.9		120.9	
6. W-M-M-P 1966-1996	25	6.37		3.13		149.9		136.7	
7. 2 yr A-W-M-W 1963-1996 x	40	AW 4.60	MW 5.12	AW 2.65	MW 2.35	AW 108.2	MW 120.4	WW 115.7	MW 102.6
8. 2 yr A-W-M#-W 1963-1996 x	40	AW 4.57	MW 4.97	-		AW 107.5	MW 116.9	-	
9. M-S-W-Ov-W 1963-1996 x	40	SW 4.21	OvW 4.65	SW 2.12	OvW 2.37	SW 99	OvW 109.4	SW 92.5	OvW 103.4
10. M#S-W-Ov-W 1963-1996 x	40	SW 4.33	Ov 4.68	-		SW 101.8	OvW 110.1	-	

W: winter wheat; M: maize; B: winter barley; Gm: green manure; P: peas; A: alfalfa; S: Sudan grass; Ov: oats and vetch; #: farmyard manure; x: 1963-1986 potatoes, 1986-1996 maize; +: straw incorporation (N supplement); PK: phosphorus and potassium fertilizers

In the maize - winter wheat - winter barley triculture, where the proportion of wheat was 30%, the yields in fertilized plots were 10% higher than for the monoculture. When N fertilizer was omitted the yields were lower than in the monoculture, despite the addition of P and K. This indicates the importance of the natural N-supplying ability of the soil, which became depleted when maize was the forecrop.

When green manure was applied to the triculture (in the form of oil radish applied to the stubble of winter barley) it had a positive effect, which could not, however, be regarded as a forecrop effect, but as the joint result of green manure and the N supplementation (30 kg N ha^{-1}) to the barley straw. The yield-increasing effect of green manure + straw + N supplement was 36.6%.

When farmyard manure was added to the triculture under maize it increased the yield by 20.9% both in the unfertilized and fertilized treatments as compared to the monoculture.

The most pronounced forecrop effect was observed in the four-crop rotation, where the proportion of wheat was 25% and its immediate forecrop was peas (49.9% in the fertilized treatment and 36.7% without fertilization). The highest absolute yield was also harvested in this sequence, being 6.37 t ha^{-1} in the fertilized treatment and 3.13 t ha^{-1} without fertilization over the average of 30 years.

In the five-year crop sequence which included 2 years of alfalfa and a 40% proportion of winter wheat the yield of winter wheat was lower than that expected from the literature. The results indicate that alfalfa is not always a good forecrop for winter wheat, presumably due to its high water consumption, but this did not involve a decline in the performance of the crop sequence as a whole.

Farmyard manure applied before maize in this five-year rotation did not increase the yield of winter wheat when mineral fertilizer was also applied. In the other five-year rotation, in which there were no legumes and the proportion of wheat was again 40%, sorghum (Sudan grass) proved to be an unfavourable forecrop for the whole sequence, while oats and vetch had a positive effect, but this only amounted to around 10%. The effect of farmyard manure was pushed into the background by mineral fertilizers.

Maize

The maize yield in the unfertilized plots was 2.1 t ha^{-1}, while this figure was trebled in the fertilized treatment.

In the wheat-maize biculture the effect of the forecrop was 20-30% without fertilization, while this effect was reduced by the application of fertilizers. Maize yielded better after wheat than after maize.

Table 2
Maize yields in different crop rotations

Crop rotations	Proportion in the crop rotation (%)	Yield, t ha^{-1}		Relative yield (%)	
		Fertilized	Unfertilized	Fertilized	Unfertilized
1. Continuous crop. 1976-1990	100	6.75	2.10	100	100
2. Biculture W-W-M-M 1972-1996	50	MM 7.45 / WM 8.43	MM 2.64 / WM 2.78	MM 110.3 / WM 124.9	MM 125.7 / WM 132.3
3. M-W-B 1984-1994	30	7.39	5.53_{PK}	109.4_{PK}	263.3_{PK}
4. M-W-B (Gm+) 1984-1994	30	7.45	6.19_{PK}	110.3_{PK}	294.7_{PK}
5. M#W-B 1984-1994	30	7.52	6.60_{PK}	111.4_{PK}	314.2_{PK}
6. 2yr A-W-M-W 1963-1996 x	20	8.30	6.72	122.9	320
7 2yr A-W-M#-W 1963-1996 x	20	8.63	-	127.8	-
8. M-S-W-Ov-W 1963-1996 x	20	8.92	6.33	132.1	301.4
9. M#S-W-Ov-W 1963-1996 x	20	9.06	-	134.2	-

W: winter wheat; M: maize; B: winter barley; Gm: green manure; P: peas; A: alfalfa; S: Sudan grass; Ov: oats and vetch; #: farmyard manure; x: 1963-1986 potatoes, 1986-1996 maize; +: straw incorporation (N supplement); PK: phosphorus and potassium fertilizers

In the maize - winter wheat - winter barley triculture the maize yields were no higher than in the diculture and a surplus due to farmyard manure could only be observed when no N fertilizer was applied.

The highest maize yield was harvested in the five-year rotation, in which the proportion of maize was only 20%. In unfertilized plots the yield was three-times that obtained in continuous cropping, while in the fertilized treatments this increase was more than four-fold. The positive effect of farmyard manure was clearly perceptible in this case. The yield-increasing effect of alfalfa, characteristic of legumes, could not be observed.

Summary

The role of crop rotation and organic manure in sustainable land use was studied in long-term fertilization experiments set up in the 60's and 70's.

It can be concluded from the long-term data that crop rotation is an important tool in the development of sustainable plant production systems. By exploiting natural resources the fertilizer rates can be reduced and the efficiency of fertilization increased. In the case of both winter wheat and maize the lowest yields were harvested under unfertilized continuous cropping conditions (2.29 and 2.10 t ha^{-1}). The yield of winter wheat can be doubled and that of maize trebled by fertilization. The highest yields were recorded in crop sequences where the proportions of wheat and maize were 20-25%. Without fertilization the forecrop effect was only pronounced in the case of wheat grown after peas, and this effect was increased by fertilization. This combination led to the highest absolute yield (6.37 t ha^{-1}). The effect of alfalfa as a N-fixing forecrop was not noticeable in the yield of wheat, though it increased the performance of the whole crop rotation. The highest maize yields were harvested when maize made up only 20% of the sequence and was treated with both mineral fertilizer and farmyard manure (9.06 t ha^{-1}). It should be emphasized that in the five-year rotation the maize yield was three times as high as in a monoculture even without fertilization, indicating that it responded sensitively to the effect of forecrops.

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