The aims of crop rotations in organic farming systems (Kahnt *et al.* 1997)

* maintenance and improvement of **soil fertility**,
* maintenance and improvement of **soil organic matter**,
* maximisation of **symbiotic N-fixation** through cultivation of forage and grain legumes,
* production of **sufficient feed** and **straw** for animal husbandry,
* optimised use of **pre-crop effect** through crops with high gross margin,
* mobilisation of **nutrients** through crops with high root density and root depth,
* control and reduction of **pest and diseases**,
* control of **weed competition** combined with gentle soil cultivation,
* improvement of **time management** for crop husbandry specific labour, and
* maintenance and improvement of **economic situation** of the farm.

Source: Kahnt, G., Keller, E.R. and Köpke, U. 1997. Ökologischer Landbau.
In: Hanius, H. Heyland, K.U. and Keller, E.R. (eds.) *Handbuch des Pflanzenbaus*, Eugen Ulmer Verlag. 1: 625-702.

Crop rotation terminology (Wijnands 1999)

crop rotation	Carefully designed sequence of crops in which succession is highly advantageous.
cropping plan	The partitioning of crops over the available area in a given year, often represented as the percentage of the area for each crop **(space)**.
crop sequence	The succession of crops in time on one field in particular **(time)**.
crop frequency	The frequency of growing the same crop on the same field, usually expressed as once in a number of years. For example: 1 out of 3, 1:3, meaning once every three years.
crop rotation block	One year of the crop rotation succession and the crop(s) in that specific crop rotation year.

Source: Wijnands, F.G. 1999. Crop rotation in organic farming - theory and practice.
In: Olesen, J.E., Eltun, R., Gooding, M.J., Jensen, E.S.& Köpke, U. (eds.)
Designing and Testing Crop Rotations for Organic Farming -
Proceedings from an International Workshop. Danish Research Centre for Organic Farming, Tjele, pp. 21-35.

Crop rotation terminology (Wijnands 1999) [cont'd]

agro-ecological layout of the farm	The layout of the farm over the available space, the partitioning of the area in fields, their shape and size, the spatial crop rotation and the ecological infrastructure of the farm.
ecological infrastructure	The network of natural and specifically managed areas on the farm to provide habitats and (transport) corridors for flora and fauna.
field adjacency	The proximity in space of the fields composing the crop rotation.
adjacency of subsequent blocks	The proximity, in both time and space, of the same crop or between crops belonging to the same group. An attempt is made to avoid cultivating a crop on a field adjacent to one in which the same crop has been cultivated the previous year.

Source: Wijnands, F.G. 1999. Crop rotation in organic farming - theory and practice.
In: Olesen, J.E., Eltun, R., Gooding, M.J., Jensen, E.S.& Köpke, U. (eds.)
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Examples for proportions (%) of typical crop groups (Freyer 2003)

Farm structure	Legumes	Cereals	Root crops	Cover crops
Mixed farm (milk cows)	30 – 50[1]	30 – 50	5 – 15	20 – 50
Mixed farm (various animals)	25 – 40[2]	40 – 60	10 – 20	20 – 50
Mixed farm (pigs)	20 – 35[3]	50 – 60	15 – 25	40 – 60
Arable farm	25 – 30[4]	40 – 60	20 – 30	40 – 60

[1] Mainly forage legumes;
[2] forage legumes (>50 %), grain legumes;
[3] grain legumes, forage legumes, propagation of cover seeds, set-aside;
[4] grain legumes, forage legumes, propagation of cover seeds, set-aside.

Source: Freyer, B. (2003): Fruchtfolgen. Eugen Ulmer Verlag, Stuttgart.

Types of crop rotations (Freyer 2003).

F = forage legumes, G = grain legumes, N = non-legumes, C = cover crops, U = undersowings.

Fields	Year							F	G	C / U
No	1	2	3	4	5	6	7	%	%	%
4	F	N	N+C	N+U				25	0	50
	F	N	G	N+U				25	25	25
	F	F	N	N+U				50	0	25
5	F	N	N+C	G	N+U			20	20	40
	F	F	N	N+C	N+U			40	0	40
	F	F	N+U	N+C	N+U			40	0	60
6	F	F	N	N+C	N+C	N+U		33	0	50
	F	F	N	N+C	G	N+U		33	17	33
	F	F	F	N	N	N+U		50	0	17
7	F	N	N+C	N+C	N	G	N+U	15	15	42
	F	F	N	N+C	N+C	N	N+U	28	0	42
	F	F	N	N+C	N+C	N+C	N+U	28	0	57
	F	F	F	N	N	N+C	N+U	42	0	28

Source: Freyer, B. (2003): Fruchtfolgen. Eugen Ulmer Verlag, Stuttgart.

Interval of crops due to incompatibilities or biotic factors (Müller 1988)

Crop	Year	Incomp-atibility	Viruses	Fungi	Nemat-odes	Insects
Winter wheat	2			#	#	
Winter barley	1 – 2			#		#
Spring barley	0 – 1				#	
Oats	3 – 5				#	
Winter rye	0 – 1			#		
Potatoes	3 – 4				#	
Sugar beets	4			#	#	
Rape	3			#	#	
Field peas	4	#		#		
Flax	6	#		#		
Faba beans, lupins	3		#	#		
Lucerne	4 – 5	#		#		
Red clover	6	#		#		
White or yellow clover	2 – 3	#		#		
Grass-clover	3 – 4	#		#		
Cabbage spec.	3 – 4			#	#	
Celeriac	3			#		
Leek	2 – 3			(#)	#	
Carrots	3 – 4			(#)	#	
Onions	4 – 5			#	#	

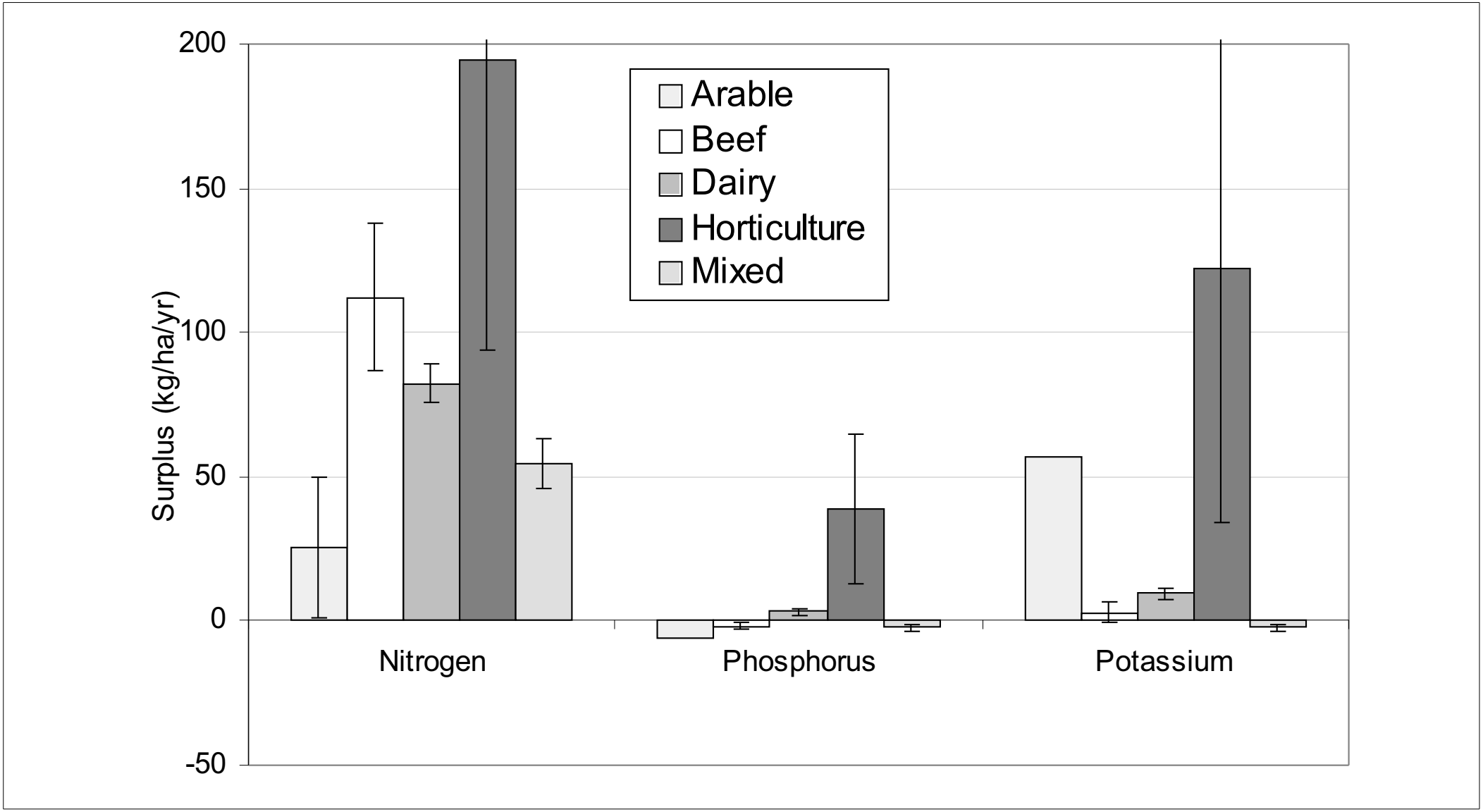
Source: Müller, P. (ed.) 1988. *Ackerbau*. VEB Deutscher Landwirtschaftsverlag, Berlin.

Favourable and unfavourable rotational pairs (Baeumer 1992).

1 = very unfavourable, **2** = unfavourable, **3** = possible, **4** = favourable, **5** = very favourable.

Preceding crops	Succeeding crops: Grass-clover (perennial)	Winter rape	Sugar beet	Potatoes	Sunflower	Faba beans	Field peas	Maize (grain & silage)	Winter wheat	Winter barley	Winter rye	Spring barley	Oats
Grass-clover (perennial)	1	5	1	4	1	1	1	5	5	4	4	2	2
Winter rape	3	1	1	4	2	3	3	4	5	4	4	1	1
Sugar beet	3	1	1	4	2	2	2	5	5	1	1	4	3
Potatoes	3	5	5	2	2	2	2	5	5	5	5	4	3
Sunflower	3	1	4	4	1	4	4	4	5	5	5	4	4
Faba beans	2	1	2	5	1	1	1	5	5	4	4	3	3
Field peas	2	4	4	4	1	1	1	4	5	5	5	3	3
Maize (grain & silage)	3	1	5	5	5	5	5	3	4	2	2	4	4
Winter wheat	4	2	5	5	5	5	5	5	1	3	3	3	4
Winter barley	5	5	5	5	5	4	4	4	1	2	2	2	3
Winter rye	5	5	5	5	5	4	4	4	1	1	2	2	3
Spring barley	5	4	4	4	4	4	4	4	3	1	2	2	1
Oats	5	4	5	4	4	4	4	4	4	4	4	2	1

Source: Baeumer, K. 1992. *Allgemeiner Pflanzenbau*. Eugen Ulmer Verlag, Stuttgart.



Average farm-scale nutrient budget surpluses (average input minus output) for nitrogen, phosphorus and potassium on various organic farm types in temperate countries (adapted from Watson *et al.* 2002)

Factors for increased NO3 leaching

- Breakdown of grass-clover in early autumn combined
  with mild climatic conditons and enough soil moisture,
- high quantities of nitrate in the soil solution
  after harvest of grain legumes,
- harvest of root and tuber crops
  combined with intensive turning of the top soil,
- incorporation of high quantities of quickly degradable biomass
  of young cover crops,
- continuous mechanical weeding
  for the regulation of thistles or couch grass,
- amendment of organic fertilizers at times of limited N offtake
  (i.e. early stages of winter wheat)
  or in quantitites not suitable for the uptake by crops.

Phytosanitary effect of grass-clover against cereal eyespot (*Pseudocercosporella herpotrichoides)* (% infected plants) (Baeumer 1992).

Rotation (A)	%
Potatoes	
Oats	
Wheat	79.9
Sugar beets	
Oats	
Vetch	
Wheat	78.9

Rotation (B)	%
Potatoes	
Oats	
Wheat	44.7
Grass-clover	
Grass-clover	
Potatoes	
Wheat	6.6

Source: Baeumer, K. 1992. *Allgemeiner Pflanzenbau*. Eugen Ulmer Verlag, Stuttgart.

Effect of green manuring with oil raddish and different soil cultivations to weed infestation of spring barley after tillering in a wheat – barley – sequence (% weed occurence) (Baeumer 1992)

Soil cultivation	Turning[1)]	Non-Turning[2)]
Cover crop without oil raddish	100	408
wth oil raddish	90	207

[1)] Stubble plough (10 – 15 cm & 20 – 25 cm)
[2)] Rotary tiller or mould board plough

Methods of non-chemical weed management (after Köpke 2000)

Indirect methods	Direct methods
Crop rotation	***Mechanical***
* competition	* hand weeding
* complementarity	* various ploughs. chisel tines, discs, harrows, spring tines
* allelopathy	* rotary hoes
	* brush weeders
	* mulching
Farm hygiene	***Thermal***
* cleaning of seed supplies	* flame weeders
* cleaning machinery and tools	* steam weeders
	* infrared weeders
Soil cultivation	***Biological***
* tillage (turning/non-turning)	* grazing with livestock
* photobiology	* classical bio-control
	* 'bio-herbicides', microorganisms as weed pathogens
Improvement of competitiveness	
* seed quality	
* morphology and vigour of cultivars	
* drilling design. density, row distance, sowing direction	
* strategic fertilisation and irrigation	

Source: Köpke, U. 2000. Konzept der Unkrautregulierung im Ökologischen Landbau. In: Pallut, B (ed.) *Pflanzenschutz im Ökologischen Landbau – Probleme und Lösungsansätze – Drittes Fachgespräch am 2. Nov. 1999 in Kleinmachnow "Unkrautregulierung im Ökologischen Landbau"*. Berichte aus der Biologischen Bundesanstalt für Land- und Forstwirtschaft. 72: 57-70.

Basic system of a crop rotation (Herrmann & Plakolm 1991)

System	Properties of crops upon soil conditions
Legumes	**Soil structure improving**
(Legumes)	**(annuals and perennials)**
(Legumes)	
Non-legumes	**mainly degradative**
(Non-legumes)	**upon humus and soil structure**
(Non-legumes)	**(cereals or hoeing crops**
Legumes	**Soil structure improving**
(Legumes)	**(annuals and perennials)**
(Legumes)	
Non-legumes	**Mainly degradative**
(Non-legumes)	**upon humus and soil structure**
(Non-legumes)	**(cereals or hoeing crops**

Crop rotation examples for arable (stockless) farms
(Hermann & Plakolm 1991)

Example 1	Example 2	Example 3
Rotational fallow [1)]	***Legumes Seed propagation*** [2)]	***Field fodder*** [3)]
Potatoes	**Potatoes**	**Winter wheat**
Winter rye [*)]	**Winter wheat** [*)]	**Winter rye**
Sprint barley [*)]	**Oats** [*)]	**Carrots** [*)]
Field peas [*)]	***Faba beans***	***Pulses***
Spelt	**Winter wheat**	**Spelt** [*)]
Winter rye	**Winter rye**	**Oats**

1) Financed by extensification programmes
2) in case of missing support for green fallow: i.e. seed propagation of red clover, alfalfa, winter vetch
3) contract cultivation for neighbours
*) potential for cover crops

Crop rotation examples for cattle farms
(Hermann & Plakolm 1991)

Example 1 *High stocking rate*	Example 2 *Low stocking rate*	Example 3 *Low stocking rate*
Forage legumes [1)]	*Forage legumes*	*Forage legumes*
Forage legumes [1)]	*Forage legumes*	Winter wheat
Winter wheat [2)]	Potatoes	Winter rye
Barley/oats/field peas [3)]	Winter wheat	Field vegetables
Forage legumes [4)]	Winter rye	*Forage legumes*
Forage legumes [5)]	*Pulses* [6)]	Potatoes
Winter wheat	Winter wheat	Winter wheat
	Oats	Oats or spring barley

1) grass clover or alfalfa grass
2) other crops possible
3) Contract cultivation for neighbours
4) Landsberger mixture as winter cover crop followed by annual grass clover- or a mixtures of legumes and non-legumes for silage
5) Maize for silage or winter barley as total crop silage followed by a cover crop (by that there is problem for a sequence winter barley-winter wheat)
6) at wet sites: *faba beans*, at dry sites: *field peas*, at sufficient vegetation length and temperature sum: *soybean*

Crop rotation of farms with low stocking rate
(according to Herrmann & Plakolm 1991)

Main crops
Forage legumes
Winter wheat
Winter rye
Field vegetable
Forage legumes
Potatoes
Winter wheat
oats or spring barley

Crop rotation of farms with low stocking rate
(according to Herrmann & Plakolm 1991)

Main crops	Undersowing	Cover crops
Forage legumes		
Winter wheat	Clover	
Winter rye	Clover	and/or cover crop
Field vegetable		Grass clover (stubble crop)
Forage legumes		
Potatoes		
Winter wheat	Clover	and/or cover crop
oats or spring barley	Grass clover	Grass clover (stubble crop)

Crop rotation of pig farms
(according to Herrmann & Plakolm 1991)

	High stocking rate [1)]	Low stocking rate [2)]
1	Forage legumes	Green fallow
2	Winter wheat	Winter wheat
3	Spring barley/oats/peas *	Winter rye *
4	Faba beans	Carrots
5	Winter barley	Pulses
6	Triticale	Spelt *
7	Sunflower	Oats

1) Winter wheat and sunflowers only partially marketed
2) Feeding of sieving wastes and pulses
*) potential of cover crops

Stepwise conversion to organic farming
(according to Herrmann & Plakolm 1991)

	1990	1991	1992	1993	1994	1995
1	M / WW	WW / WB	GC	WW	O	FB
2	W-Ra / WB	WW / SB-O-P	WR	GC	GC	WW
3	WW	M	WW	FB	WW	WR
4	M	WW	FB	WW	WR	GC
5	WB	GC	WW	WR	GC	GC
6	WW	FB	WW	O	FB	WW
7	WW / M	WB / WW	M / GC	GC / FB	WW	O

Red: conventional cropping
Bleu: organic cropping

WW: Winter wheat, WB: Winter barley, M: Maize, Wra: winter rape
P: peas, H: oats, WR: winter rye, GC: grass clover, SB: spring, barley, FB: faba bean