Designing crop rotations in organic and low-input agriculture: Evaluation of pre-crop effects

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Abstract

In this overview, the preceding effects of crop pairs are classified by establishing schematic diagrams for use in crop rotation planning in low external input or organic agricultural systems. Results from previous crop rotation trials and earlier diagrams cited in the literature were evaluated in order to classify the succession effects for more than 25 main crop species into four ranks: very favourable, practicable, not favourable and very unfavourable. Additional information about several cultivation remarks were annotated in small letters for every crop sequence. In a tabular overview, the crop species were arranged into three main categories according to the different duration of their pre-crop effects: I. N fixing, soil fertility increasing legumes and legume-grass mixtures; II. N depleting, intense soil fertility reducing non-legumes; III. modest soil fertility reducing non-legumes.

Keywords: crop rotation, pre-crop effects, classification, low-input and organic agriculture

Introduction

With the expansion of extensive or low-input agricultural farming systems, problems have emerged in the arrangement of crop husbandry subject to special production and cultivation limitations. This is true especially for organic agriculture, where strict standards regulate external inputs (see ANON., 1991, 1994) which are known to compensate for the negative effects of monoculture or pure crop rotation designs, as is usual in intensive conventional agriculture. One key-factor in successful crop production is the optimal succession of crops in the fields, which is, for example, importent for a high level of plant health, nutrient efficiency, yield and quality, and is created by a strengthening of the self-regulating power of the agricultural system (KOLBE, 1997a, b). Therefore, principles of optimal crop rotation planning, as already established by KÖNNECKE (1967) and other agronomists, are increasing in importance again.

Crop rotation systems with a standardized succession of crops, as, for example, proposed by BRINKMANN (1950) for the different German conditions, have long been the main adjustments in research and agricultural practice. But in the present situation, rotation systems with fixed crop sequences are often not useful in organic agriculture, so that crop successions are determined from year to year according to current economic relevance, marketing possibilities, weather conditions, working capacity and other very different requirements.

For this purpose, exact knowledge of the direct effects of preceding crop sequences is of increasing importance. Therefore, a new assessment of these crop rotation

effects is established for a high number of crop species and different production specializations, for use in low-input and organic agricultural crop rotation planning in the Middle European area.

Methods

In the past, crop rotation research was carried out intensively by different institutions. Taking into consideration the high input of money and working capacity, various efforts were made to summarize these manifold crop rotation results. At first, at the Institute for Agronomy and Crop Science of the University of Halle-Wittenberg, the previous and following crops were arranged in a schematic diagram. ANDREAE (1959), RÜBENSAM & RAUHE (1964) and KÖNNECKE (1967) classified these crop pairs of rotation sequences according to the following priorities: very good (1), possible or practicable (2), limited practicability (3), not practicable (4). Information was also given, for example, for the cultivation of cover crops, sowing time, occurence of diseases and pests. Subsequent schemes were based on those or were more or less the same in terms of the classification priorities and completeness (SAGASSER, 1957; SEIFFERT, 1965; ANON., 1978; STEINBRENNER & LISTE, 1981; KÄMPF, 1983; BAEUMER, 1992; ANON., 1993, 1995, VULLIOUD, 2005).

These previous works were used to establish a new diagram following the order ranks of BAEUMER (1992):

White	Dark-green	=	very favourable succession,
Light-grey	Light-green	=	favourable or practicable succession,
Dark grey	Yellow	=	unfavourable succession,
Black	Red	=	very unfavourable or impossible succession.

The classifications were completed by the addition of the following information, labeled with small letters:

- a = Causion in severe drought,
- b = Crossing vegetation periods (climatic marginale zones),
- c = Stimulation of particular diseases and pests, low self-compatibility,
- d = Stimulation of particular weeds,
- e = Preceding crop value is insufficiently used, luxury succession, possibly practicable with intercrop or catch crop,
- f = Succeeding crop quality reduction,
- g = Succeeding crop risk to lodging,
- h = Catch crop as underseed in preceding crop is practicable or favourable, especially on high nutrient leaching locations,
- i = Catch crop as stubble seed, winter catch crop or green manure cropping is practicable or favourable, especially on high nutrient leaching locations,
- k = Favourable on light soils,
- l = Organic manuring is favourable for succeeding crop,
- m = Succeeding crop as covering crop is very suitable,
- n = Succeeding crop as covering crop is of limited suitability,
- o = Favourable preceding crop for open sowing of main, green manuring and forage crops,
- p = Volunteer plant risk in the succeeding crop (seed multiplication),
- r = Before ploughing, (intensive) mechanical weed control is practicable,

as stubble cultivation in cereal sequences,

s = Unfavourable on light soils,

t = Spring crops are favourable in mountain areas.

At first, the crop successions were classified in terms of their yield effects. According to STEINBRENNER (1990) and others (SIMON, 1963; KÖNNECKE, 1967; ROSCHE, 1973; POMMER, 1994), the differences in yields can be calculated approximately, with 20 - 40 % between very favourable and very unfavourable crop successions. In the new scheme, the results concerning yield and additional cultivation effects from numerous crop rotation trials cited in several compendia (e.g. GLIEMEROTH, 1964; KLAPP, 1967; KÖNNECKE, 1967; BROUWER, 1972; BACHTHALER; 1979; BAEUMER, 1990), as well as the results concerning rotation effects on crop quality were taken into consideration (e. g. SEIFFERT, 1965; KREUZ, 1990; KREUZ & ZABEL, 1990; DACHLER, 1993).

Results from crop rotation trials, especially for organic agricultural systems, are very scarce. The results mentioned by SATTLER & VON WISTINGHAUSEN (1985), HESS, (1989), PREISSNER (1989), HERRMANN & PLAKOLM (1991), POMMER (2002), FREYER (2003), and others were also used to set correct succession ratings. In addition, the results of earlier examinations (before the year 1970) show better correspondence with the special conditions of organic agriculture, and could be more effectively used than the trial results and classification diagrams which were created later. Experiments and advices received from the use of first diagram versions (KOLBE, 1998a, b) were adapted into the diagram introduced here.

Classification of pre-crop effects

The classification of the most typical crop species preceding sequences are shown in Table 1/2. The preceding crops are arranged according to their vegetative duration, and therefore, for example, silage maize and grain maize are listed separately. Also, the succeeding crop species are grouped according to their specific cultivation requirements (e.g. in terms of vegetative duration, nutrients, quality, utilization).

Succsession of the same crop species

Successions of the same or genetically closely related crop species are generally classified as very unfavourable due to yield decline, negative allelopathy effects, stimulation of diseases, pests and weeds, or have to be seen as luxury successions. Spring wheat, winter rye and maize can be seen as exceptions, where the negative effects of self successions do not appear to be as strong. Even self sequences of different legume species are often not negatively related, but due to insufficient use of the preceding legume crop, a succeeding legume is recorded as not practicable (luxury succession) (Table 1/2).

Succsession of forage crops and grain legumes

Winter rye, winter and spring barley, oats and winter rape seed are favourable preceding crops for main green manuring and forage crops, sown as covering crops, or as open sowings after root and tuber crop cultivation. Favourable preceding crops

for grain legumes are winter and spring cereals except wheat, and maize, root and tuber crops.

Succsession of cereals

Good preceding crops for all winter cereals and spring wheat are legumes and grasses, early and medium-early potatoes, winter rape seed and sunflowers. Maize, feeding and sugar beets and late potatoes can be successfully used when the vegetative duration is long enough. On the other hand, winter and spring wheat and barley cereals in particular, are to be seen as very unfavourable preceding crops, especially for wheat, dinkel and triticale. Rye, barley and oats can follow after winter and summar wheat, dinkel, durum wheat, rye and triticale. Cereals like dinkel, rye, barley and oats have very high lodging problems especially when growing after multi-annual legumes (Table 1/2).

The spring cereals are best cultivated after preceding crops of maize, beets and potatoes, and in addition, cultivation after rape, sunflowers and even legumes seem to be possible. Exceptions have to be put forward for cereals grown for utilization by brewers and distilleries. These cereals should not be directly cultivated after legumes. The same is true for sugar beets, early and medium-early potatoes, where reductions of the product quality can often occur, especially when cultivated on heavy soils. Good preceding crops for malting barley and wheat are maize, beets and potatoes, as well as sunflowers. Preceding wheat and rye species seem to be also possible.

Succseccion of root and tuber crops, maize, rape seed and sunflowers

Silage and grain maize especially, but also feeding beets, rape seed and potatoes, have high nutrient requirements. Therefore, maize and feeding beets are best cultivated after legumes, grasses, wheat, rye, barley and other (late) root and tuber crops. The potatoes are also successfully grown after those cereals and after maize. The highest tuber yields are usually recorded after annual cultivated legumes, but special problems of tuber quality can occur when cultivating in high nutrient supply after multi-annual legumes. In addition, potatoes, maize and rape seed compete with the rotation position of baking wheat cultivation for the rison of their high nutrient requirement. Winter rape seed is often not easily integrated into the crop rotation due to its very early sowing time and particular disease problems. Favourable preceding crops seem to be annual and multi-annual legumes, pea, winter and spring barley and early potatoes.

Integration of catch crops and manuring

In climatic locations, where periods of severe drought often occur, the preceding multi-annual legumes and grasses are limited by the cultivation of the succeeding crops like rape seed, cereals and feeding beets. The nutrient requirements for sunflowers and especially for spring barley are relatively low, so that legumes and grasses, and, to some extent also potatoes and winter rape, are not favourable

preceding crops. Sunflowers are best grown after rye, triticale, winter barley and maize, especially when a catch crop is followed by the preceding crop (Table 1/2).

In locations with high precipitations, a catch crop as underseed or stubble seed is also favourably cultivated after nearly all cereals, when cereals and especially when spring crops follow. Catch crops should also be grown in the preceding crops maize, early potatoes, rape and sunflowers. If no catch crop is planned and winter cereals follow as following crops, the wheat and in particular the rye, barley and oat preceding crops are suitable for special mechanical weed control arrangements as stubble cultivation.

Organic manure applications can be preferably integrated into the crop rotation when the nutrient requirements of high-demanding crop species is not satisfied. This is true for baking wheat, which should be cultivated after grass, maize, root and tuber corps, rape seed and sunflowers. In addition, when cropping after cereals and further root and tuber species, also maize, feeding beets, potatoes and rape seed make frofit from organic manuring (Table 1/2).

Design of crop sequences

Field forage growing, green manuring and grain legumes

In Table 3, the succession of crops throughout rotations is shown, classified according to their nutrient and quality requirements as well as in terms of heavy and light soils. On both soil types the crop rotation begins with legumes and legume-grass mixtures for use as forage, green manuring or seed multiplication. Favourable species are lucerne and clover, which should be cultivated multi-annually, usually when growing for two years they obtain maximal values in DM, N yields and soil fertility of the whole rotation (top 1, Table 3).

Three or more years of use lead to gappy crops and minor yields in most soil and climatic conditions, excapt when cultivating in the main distribution areas of the lucerne and clover species and in locations with higher precipitation amounts. Only in special conditions (e.g. on soils of high fertility, without problems of particular weeds) is one-year or 1.5 years legume cultivation sufficient. The same is true whith one-year grain legume cultivation. In these cases the legume nitrogen harvest and soil fertility is not so high as after multi-annual cultivation systems.

High-demanding non-legumes

The following one to two years are characterized by cultivation of non-legume crop species with high nutrient and special quality requirements, because of the favourable preceding crop value (see SCHMIDT, 1997; BECKMANN et al., 2002; top 2, Table 3). Therefore, in most cases, wheat species, maize, rape seed or root and tuber species follow on heavy soils, and root and tuber species, maize, triticale, rye or winter barley may preferably follow on light soils.

The next year of cultivation is charakterized by choosing non-legume species with relatively high nutritional requirements, as shown as lower rankings in Table 3, top 2:

winter barley, winter rey or grasses on hevy soils, and winter rey, winter barley, oats, dikel or grasses on light soils. If the fertility is not too high, brewers´ crops and sugar beets are also favourable on this rotation position (see top 3 in Table 3). If the fertility is already too low, special organic fertilizer applications are useful when organic manures from livestock farming are available, or green manuring from catch crop growing is possible in stockless farming systems, or mineral nitrogen fertilization is possible in conventional agriculture. If the rotation position is judged to be unfavourable after some years experience (especially without livestock farming), the crop species have to be succeeded in a better rotation position, or an additional cultivation of legume species in form of grain legumes or annual forage legumes has to be added into the rotation (see top 1, Table 3).

Low-demanding non-legumes

At last the crop rotation position two or three years after legume cultivation is characterized by a relatively low soil fertility, especially in terms of nitrogen (top 3, Table 3). Crop species with low nutrient requirements (especially spring barley) or crops with special quality requirements (brewery, distillery, sugar production) are preferably cultivated in this crop rotation position. Other crops with higher nutrient requirements (oats, rye, potatoes, feeding beets, barley), have to be fertilized with stable manure, slurry or green manure. Finally, the following (multi-annual) main legumes (see top 1, Table 3) are established already as underseeds, for example, in barley, oats, rye or sunflowers. In this position, a successful legume cropping is possible, because legume content of the mixtures and symbiotic N fixation will be supported by low soil available nitrogen contents (SCHMIDTKE & RAUBER, 2000; BECKMANN et al., 2002).

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Table 1: Classification of pre-crop effects (black and white; legend see Methods)

Succeeding crop / Preceeding crop	Lucerne, Clover, Legume-grass mixtures (multi-annual)	Lucerne, Clover, Leg.-grass m., Serradella (annual)	Field bean [s]	Pea, Lentil	Lupin, Vetch, Soya bean	Grasses (annual – multi-annual)	Winter wheat [s] (baking a. fodder quality)	Spring a. Durum wheat [s] (baking a. fodder quality)	Wheat (malting quality)	Dinkel	Triticale [t]	Winter rye [t]	Winter barley (fodder quality)	Spring barley (fodder quality) [t]	Spring barley (malting quality)	Oats	Silage a. Grain maize	Feeding beets	Sugar beets [s]	Early potatoes (food quality)	Medium-early potatoes (food quality)	Late potatoes (processing quality)	Winter rape seed [t]	Sunflowers
Lucerne, Clover, Legume-grass mixtures (multi-annual)	c e	c e	c e		c e	e	a	i	f	a g	a g k	a g k	a g k	e g i	e f g	a g i k	i k	a i k	f	e f	f i k	f i k	a b	e
Lucerne, Clover, Leg.-grass m., Serradella (annual)	c e	c e	e	e	e	e n		i	f	g		b k	b k	e g i k	e f g	i k	i	e i k	f	f	f i k	i k	b	e
Field bean [s]	c e	e	c	c	e	b m	h	h	f h	g h	b h	b	b	e g h	f h	e h	h	h	f h	e h	h	h	b	e
Pea, Lentil	c e	e	c	c	e	n	i	h i	f i	g i	i	i		i	f i	i	i	e i	e f i	e i	e i k	e i k	c	e i
Blue lupin, White lupin, Vetch	c e	e	e	e	c e	b n		i	f	g k	k	k	b k	g i k	f i	i k	i k	e i k	f i	e i k	e i k	i k	b	e i
Yellow lupin	c e	e	e	e	c e	b						k	b k	i k	f i	i k	i k	e i k	i	e k	e i k	i k	b	i
Soya bean	c e	e	e	e	c e	b	b			b	b	b	b	g	g					e			b c	c e
Grasses (annual – multi-annual)	e						a b l	a i l	b	a b	a b l	a b l	a b l	i	i	i	i l	i l	f i	e f i l	e f i l	f i k l	a b l	
Winter wheat [s]			d i	d i	d i	i n	c d p	c i	c d p	c d h p	d h l p r	c h p r	c d p r	c i	c i	i	i l	i l	i	h l	i l	i l	b	i
Spring a. Durum wheat [s]			i	i	i	i n	c	c i	c	c i r	i l r	c i r	c h	c d i	c d i	c d i	i l	i l	i	h l	i l	i l	b	i
Winter rye, Triticale [t]	m	m	c h i	h i	h i	m	c d h p r	c h i l	c d h p r	c d h p r	c d h i p r	c d h p	c d h p r	h i	h i k	h i l	h i l	h i l	h i	h l	h i l	h i l	b l	h i
Winter barley, Dinkel	m	m	h i	h i	h i	m	c d h p r	c h i l	c d h p r	c d h i p r	c d h i p r	c d h i p r	c d p	c h i	c h i	h i l	h i l	h i l	h i	h i l	h i l	h i l	h l	h i
Spring barley [t]	m	m	d h i	d h i	d h	m	c h r	c h i	c h r	c h r	c h r	c h l r	c r	c h i	c h i	c h i	h i l	h i l	h i	h i l	h i l	h i l	h l	h i
Oats	n	n	c d h i	h i	d h	n	f h l r	c h i l	h r	h l r	h l	h l	b h l	c h i	c h i	c h i	h i l	h i l	h i	h i l	h i l	h i l	b l	h i
Silage maize	n	n	h	h	h	m	c f h l	c h l	c h	b h	b h l	b h	b	h	h k	h	c d h l	h l	h	h l	h l	h l	b	h
Grain maize	n	n	h	h	h	n	b c f h l	c h l	b c h	b h	b h	b	b	h	h k	h	c d h l	h l	h	h l	h l	h l	b	h
Sugar [s] a. Feeding beets	e o	e o	e	e		e o	b f l	l	b	b	b	b	b			l	l	c	c	e l	d e l	d e l	b	e
Early potatoes	o	o	e i	e i	e i	o	e i l	e i	e i	e i	e i	e i	i	e i	e i	e i	e i l	e i	e i	c d	c d	c d	i l	e i
Medium-early potatoes	e o	e o	e i	e i	e i	e o	i l	e i l	i	i	i	i	b	e i	e i	e i	e i l	e i	e i	c d	c d	c d	b	e i
Late potatoes	e o	e o	e	e	e	e o	l	l				b	b			l	l	l		c d	c d	c d	b	e
Winter rape seed [t]	e n o	e n o	e h i	e h i	e h i	e m	h i l	e h i	h i	h i	h i	h i		e h i	e	e h i	e h i l	c	c	e h i	e h i	e h i	c	h i
Sunflowers	h n	h n	h	h	h	h n	f h l	f h l p	h	b h l	b h l	b l	b l	h p	h p	h l p	h l	h l	h	h l	h l	h l	b	c

Table 2: Classification of pre-crop effects (coloured, legend see Methods)

Preceeding crop \ Succeeding crop	Lucerne, Clover, Legume-grass mixtures (multi-annual)	grass m., Serradella (annual)	Field bean [s]	Pea, Lentil	Lupin, Vetch, Soya bean	Grasses (annual – multi-annual)	Winter weat [s] (baking a. fodder quality)	Spring wheat [s] (baking a. fodder quality)	Wheat (malting quality)	Dinkel	Triticale [t]	Winter rye [t]	Winter barley (fodder quality)	Spring barley [t] (fodder quality)	Spring barley (malting quality)	Oats	Silage a. Grain maize	Feeding beets	Sugar beets [s]	Early potatoes (food quality)	Miedium-early potatoes (food quality)	Late potatoes (processing quality)	Winter rape seed [t]	Sunflowers
Lucerne, Clover, Legume-grass mixtures (multi-annual)	ce	ce	ce		ce	e	a	i	f	ag	agk	agk	agk	egi	efg	agik	ik	aik	f	ef	fik	fik	ab	e
Lucerne, Clover, Leg.-grass m.,Serradella (annual)	ce	ce	e	e	e	en		i	f	g		bk	bk	egik	efg	ik	i	eik	f	f	fik	ik	b	e
Field bean [s]	ce	e	c	c	e	bm	h	h	fh	gh	bh	b	b	egh	fh	eh	h	h	fh	eh	h	h	b	e
Pea, Lentil	ce	e	c	c	e	n	i	hi	fi	gi	i	i		i	fi	i	i	ei	efi	ei	eik	eik	c	ei
Blue lupin, White lupin, Vetch	ce	e	e	e	ce	bn		i	f	gk	k	k	bk	gik	fi	ik	ik	eik	fi	eik	eik	ik	b	ei
Yellow lupin	ce	e	e	e	ce	b						k	bk	ik	fi	ik	ik	eik	i	ek	eik	ik	b	
Soya bean	ce	e	e	e	ce	b	b			b	b	b	b	g	g					e			bc	ce
Grasses (annual – multi-annual)	e						abl	ail	b	ab	abl	abl	abl	i	i	i	il	il	fi	efil	efil	fikl	abl	
Winter wheat [s]			di	di	di	in	cdp	ci	cdp	cdhp	dhlpr	chpr	cdpr	ci	ci	i	il	il	i	hl	il	il	b	i
Spring a. Durum wheat [s]			i	i	i	in	c	ci	c	cir	ilr	cir	ch	cdi	cdi	cdi	il	il	i	hl	il	il	b	i
Winter rye, Triticale [t]	m	m	chi	hi	hi	m	cdhpr	chil	cdhpr	cdhpr	cdhpr	cdhp	cdhpr	hi	hik	hil	hil	hil	hi	hl	hil	hil	bl	hi
Winter barley, Dinkel	m	m	hi	hi	hi	m	cdhpr	chil	cdhpr	cdhipr	cdhipr	cdhipr	cdp	chi	chi	hil	hil	hil	hi	hil	hil	hil	hl	hi
Spring barley [t]	m	m	dhi	dhi	dh	m	chr	chi	chr	chr	chr	chlr	cr	chi	chi	chi	hil	hil	hi	hil	hil	hil	hl	hi
Oats	n	n	cdhi	hi	dh	n	fhlr	chil	hr	hlr	hl	hl	bhl	chi	chi	chi	hil	hil	hi	hil	hil	hil	bl	hi
Silage maize	n	n	h	h	h	m	cfhl	chl	ch	bh	bhl	bh	b	h	hk	h	cdhl	hl	h	hl	hl	hl	b	h
Grain maize	n	n	h	h	h	n	bcfhl	chl	bch	bh	bh	b	b	h	hk	h	cdhl	hl	h	hl	hl	hl	b	h
Sugar [s] a. Feeding beets	eo	eo	e	e		eo	bfl	l	b	b	b	b	b			l	l	c	c	el	del	del	b	e
Early potatoes	o	o	ei	ei	ei	o	eil	ei	ei	ei	ei	ei	i	ei	ei	ei	eil	ei	ei	cd	cd	cd	il	ei
Medium-early potatoes	eo	eo	ei	ei	ei	eo	il	eil	i	i	i	i	b	ei	ei	ei	eil	ei	ei	cd	cd	cd	b	ei
Late potatoes	eo	eo	e	e	e	eo	l	l				b	b			l	l	l		cd	cd	cd	b	e
Winter rape seed [t]	eno	eno	ehi	ehi	ehi	em	hil	ehi	hi	hi	hi	hi		ehi	e	ehi	ehil	c	c	ehi	ehi	ehi	c	hi
Sunflowers	hn	hn	h	h	h	hn	fhl	fhlp	h	bhl	bhl	bl	bl	hp	hp	hlp	hl	hl	h	hl	hl	hl	b	c

Table 3: Design of crop sequences and suitability of crop species

Main crop sequence	Effect	Years of cultivation	Suitable crop species	
			Light soils (S - Sl)	**Medium and Heavy soils** (lS – T)
1a Field forage and green manuring legumes or:	Nitrogen supply by symbiotic N fixation, organic matter increasing, soil structure supporting crop species, Weed control	(1) – 2 – (3)	Clover species (red clover), Lucerne Serradella Legume mixtures Legume-grass mixtures	Lucerne Ret clover (further clover species) Legume mixtures Legume-grass mixtures
1b Grain legumes		1	Pea Lupine	Field bean Pea
2 High-demanding non-legumes	Nitrogen demanding, soil structure and organic matter depleting crop species (grain, root and tuber crops)	1 – (2)	Potatoes (+) Maize (+) Feeding beets (+) Winter rape seed (+) Triticale (+) Winter rye (+) Winter barley (+) Oats (+) Dinkel Grasses (+)	Winter wheat (+) Spring wheat (+) Maize (+) Winter rape seed (+) Potatoes (+) Feeding beets (+) Triticale (+) Winter barley Winter rye Grasses
3 Low-demanding non-legumes	Organic matter and soil structure depleting grain, root and tuber crop species	1 – (2)	Potatoes + Spring barley (+) Dinkel (+) Winter rye + Oats + Sunflowers (+)	Potatoes + Sugar beets Malting wheat Triticale + Winter barley + Winter rye + Dinkel (+) Spring barley (+) Oats (+) Sunflowers

Manuring: + = (organic) manuring is favourable; (+) = (organic) manuring in the 2. year, in cereals late manuring in the 1. year after legume cultivation is practicable or favourable; Years of cultivation: 1 – (2) = crop rotation component with one, or at best with two years of cultivation
Suitability: ■ = high; □ = low