Chapter 6
Integrative Energy Crop Cultivation as a Way to a More Nature-Orientated Agriculture

Marianne Karpenstein-Machan

Abstract The vision of integrative energy cultivation concepts is to contribute to a more diverse and sustainable rural landscape, keep nature in balance and conserve ecosystems. Integrative cultivation concepts also harmonise utilisation/production with the protection of landscapes. An overview is given of the status quo of energy crop cultivation management on farms in Lower Saxony, Germany. This overview explains the opportunities, but also the many risks associated with current bioenergy cultivation practices. Examples are presented of ecological and economical optimisation of farmland use for the production of food, feed and energy. In addition, sustainable cultivation concepts are presented, which include several winter annuals, summer annuals, perennials and wild herbs found in cultivation concepts adapted to local climate and soil conditions. In the model farms, the ecological challenges regarding the current cultivation concepts are described and farm-specific examples of more sustainable concepts are described. Subsequently, the opportunities to implement integrative energy cultivation concepts in agricultural practice are evaluated.

Keywords Biogas • crop rotation • integrative cultivation concept • energy crops

6.1 Bioenergy Production in the Contradictory Contexts of Nature, Environment and Society

Landscapes provide many services, offering agriculture, forestry, biodiversity, local recreation, buildings and streets. In industrial societies, an increasing amount of land is used for homes, buildings, industry and mobility (streets). In Germany,

M. Karpenstein-Machan (✉)
Interdisciplinary Centre for Sustainable Development, University of Göttingen, Goldschmidtstrasse 1, 37077 Göttingen, Germany
e-mail: mkarpen@gwdg.de

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approximately 87 ha of soil are sealed for a settlement area and infrastructure implementation (Federal Statistic office 2012) every day. However, land is limited, especially for agriculture, which is needed for food, fodder and bioenergy production. Furthermore, with increasing intensity in agricultural production, more space is necessary for biodiversity protection to reduce intensive agriculture's negative effects. Over the past 5 years, bioenergy has gained importance in Germany. Triggered by the 2004 Renewable Energy Sources Act (EEG), the total area for energy crop cultivation has increased rapidly. In Lower Saxony, the total area for bioenergy has increased by 5 % since 2004 to a total area of 10 % of arable land (ML 2010). This can be considered a positive development, because bioenergy reduces the CO_2 output and contributes to climate protection (BMU/AGEE 2010); however, more conflicts have arisen between farmers, locals and nature conservation organisations due to their differing opinions of bioenergy (see the Chap. 10). The most frequent misgivings voiced by opponents of bioenergy are the increasing monoculture associated with maize and winter oilseed rape (Brassica napus L.) cultivation, the increasing use of pesticide, soil degradation and the reduction in fauna and flora.

The problems associated with energy crop cultivation could be avoided in sustainable bioenergy projects. Our work seeks to establish sustainable and integrative cultivation concepts for food, fodder and energy. The synergy effects between different utilisation options should therefore be identified and used. In the following sections, the bioenergy status quo in Lower Saxony is summarised, integrative concepts are described and examples are given. I start off by defining integrative cultivation.

6.2 Integrative Cultivation Concepts for Food, Fodder, Energy and Wildlife

Integrative cultivation can be defined as a scientific approach in which scientists working on concepts combine different landscape utilisation options to produce food, fodder and energy, as well as support wildlife (Karpenstein-Machan 1997, 2001, 2004, 2009a; Rode and Kanning 2010). Integrative cultivation concepts harmonise utilisation/production and landscape protection. The agricultural utilisation of farmland and landscape protection should no longer be seen as mutually exclusive. In the long term, only sustainable concepts are economically sound for society, due to the external costs of unsustainable systems.

Energy crop cultivation can act as a bridge between different landscape utilisation systems, such as grassland, cropland and forest, as well as between ecological and conventional agricultural systems. Furthermore, water and nature protection areas, as well as problematic locations (e.g., contaminated soils), do have a place in integrative concepts.

Integrative cultivation's vision is to contribute to a more diverse agricultural landscape, to keep nature in balance and conserve rare ecosystems. Integrative cultivation's vision for bioenergy includes the cultivation of locally adapted biomasses and the transformation of energy into locally scaled energy plants (decentralised concepts).

6.3 Examples of Integrative Cultivation

Figure 6.1 shows an integrative cultivation model with food, feed and energy crops. This can be a model for a farm, but also for a greater area, for instance a community area. Annual crops for food, feed and energy are cultivated in conventional ways. They are rotated in crop rotations (the minimum crop rotation length should be 3 years) and form the basis of high agricultural production. These annual crops are surrounded by herbicide-free buffer strips (flower strips). Such flower strips should increase the flora and fauna biodiversity and stabilise the agro-ecosystem, both of which should reduce the pesticide use on the annual crops. Flower strips can be harvested after flowering and utilised in the biogas plant, or remain there until the grain harvest. Maize and winter triticale/winter rye mixtures, which are typical biogas production crops, undergo the food and feed crop rotation together with winter cereals, sugar beet and field grass. Contrary to food production, pesticide use

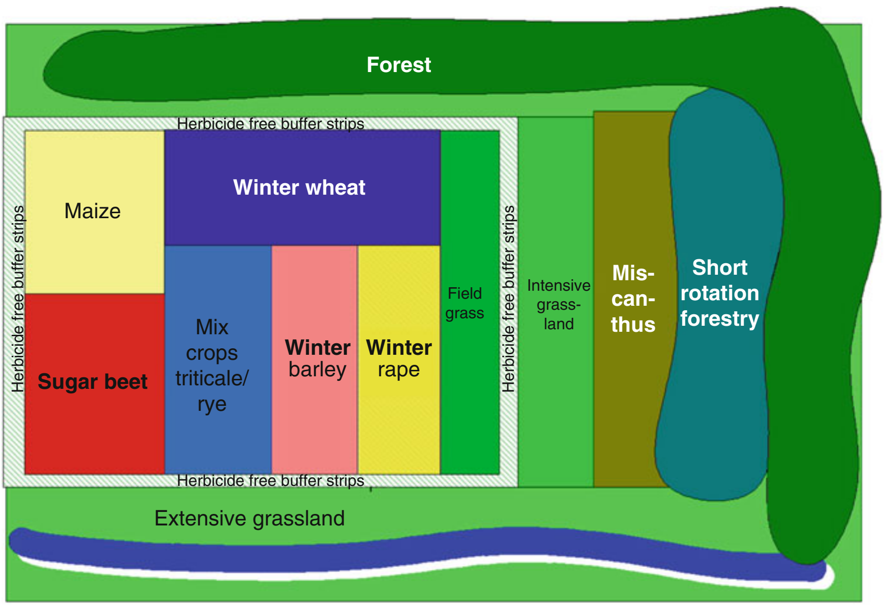

Fig. 6.1 Model of an integrated cultivation concept with food, feed and energy (Modified from Karpenstein-Machan 2004)

on biogas crops can be reduced, due to their lower sensitivity to diseases and premature harvest time (Karpenstein-Machan 2000a, 2002). In this way, the mixture of energy crops and food crops in one crop rotation leads to higher diversity and reduces pesticide use.

In this example, intensive grassland culture forms the transition between annual and perennial crops. Ecologically sensitive soils, which tend to leach nitrate and erosive hills, are better suited to perennial crops. These crops cover the soil all year round, which prevents leaching problems. In addition, extensive grassland builds a buffer that prevents erosion as well as pesticide and nutrient contamination of the river. Furthermore, permanent grassland can absorb the water from floods and does not form a barrier to run-off water. However, extensive grassland with nature protection status must fulfil certain harvest time and frequency requirements. A late harvest after flowering ensures wild flower reproduction. The removal of chopped biomasses from grassland is important since it prevents nutrient accumulation. Biomass from extensive grassland has a low fodder quality, due to advanced plant lignification. In special biogas plants, this biomass can be utilised for biogas production (dry fermentation). Low-input woody perennials, such as miscanthus or the newly discovered perennial for biogas use (see Sect. 6.6.6), and short-rotation forestry act as transition zone between open landscape and dense forest.

6.4 Bioenergy Status Quo in Lower Saxony

In Lower Saxony, the energy crop cultivation reached 7.3 % of the total agricultural area (arable land and grassland) and 10.6 % of the arable land in 2008 (ML 2010). Energy crop production includes production for biodiesel (share: 22 %), ethanol (share: 12 %) and biogas (share: 66 %). Generally, crop cultivation for biogas enjoys high priority in Lower Saxony, but this does differ depending on the district. In some districts, energy crops are cultivated on a 20 % share of the arable land, but provide 90 % of the biogas (i.e. the Celle district), while other districts have an energy crop share of under 5 % (district Göttingen). As energy crops, they mainly produce biodiesel with an 80 % share of the energy crop area. Problems arise in those districts where a high concentration of husbandry coincides with a high concentration of biogas plants. In districts high in husbandry, maize was the main crop even before the biogas boom. After the implementation of biogas plants, the farmers cultivated additional maize for these plants; consequently, the maize concentration in some districts comprises a 60 % share of the arable land (Karpenstein-Machan 2010). Figure 6.2 shows the maize cultivation shares (in percentage) of the arable land in the Lower Saxony districts.

The Ministry of Agriculture (ML 2010) calculates that, in 2012, 1,480 biogas plants with a 783 MW_{el} capacity will have been implemented in Lower Saxony. The produced electricity could cover the demand from approximately one million households. Further biogas plants, especially in critical districts, can create

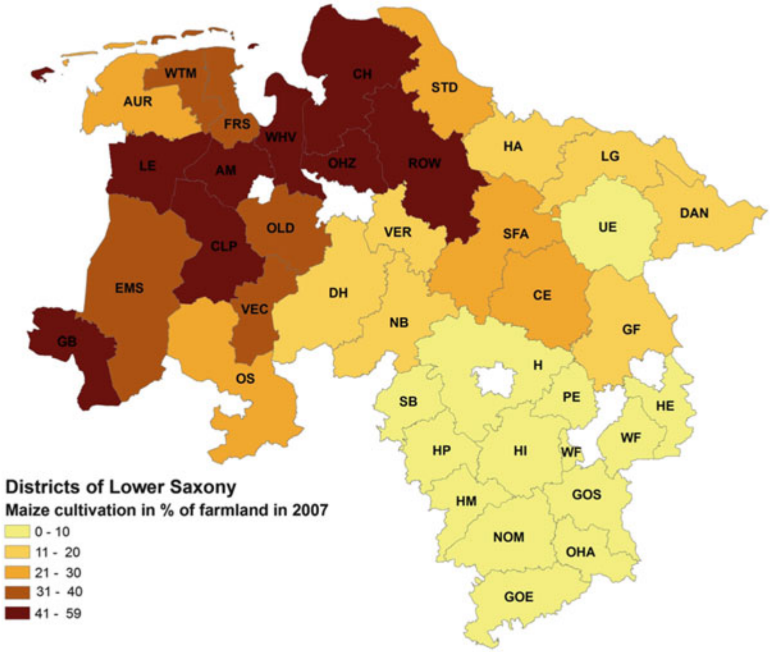

Fig. 6.2 Maize cultivation share (%) on arable land in districts of Lower Saxony (Status 2007)

environmental problems and problems with the local people. Therefore, scientists and experts from different disciplines should formulate new ecological standards for energy crop production, especially for biogas. Our work seeks to address antagonism to the energetical use of biomass and promote sustainable bioenergy development in Lower Saxony. More information about the cultivation situation on biogas farms was necessary to optimise existing cultivation concepts. A survey (a questionnaire and interviews) was designed to obtain information from the farmers on how they cultivate energy crops (fertilisation, pesticide treatments, crop rotation) and how they integrate crops into their crop rotation.

6.4.1 Results of Survey of Farmers

The results are based on the questionnaire and interviews with 76 farmers from six different districts in Lower Saxony. All the interviewees cultivate energy crops for a biogas plant. Approximately 50 % operate husbandry farms (n = 39) and 50 % cultivate field crops (n = 37). The share of farmers with an own biogas plant and farmers without one is also balanced. Figure 6.3 shows that, in most cases, small farms produce energy crops for foreign biogas plants. Biogas plant owners have more agricultural land. According to the study, most biogas plant operators have

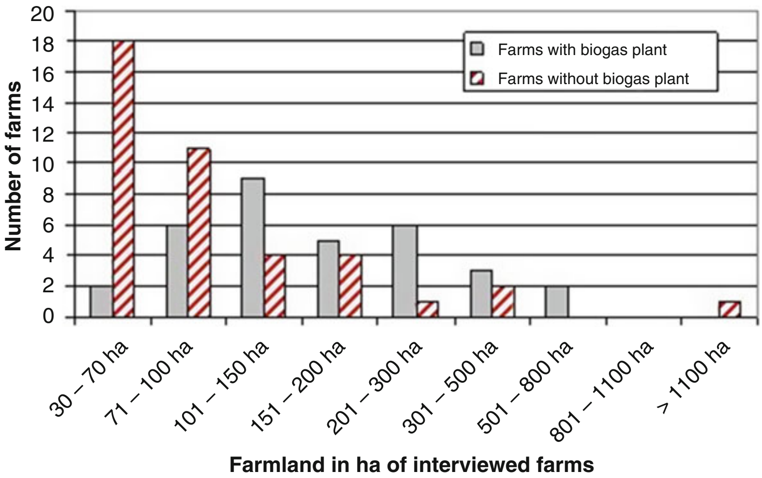

Fig. 6.3 Relationship between farmland size of interviewed farms and number of farms with biogas plants and without biogas plants

100–150 ha of farmland. For small farms, energy crop production for foreign plants offers an opportunity to stabilise their farm income if the biomass prices are acceptable and fixed over the long term. In most cases, the biomass prices are adapted, within a price corridor, to the wheat prices.

The farmers also cultivate other crops besides energy crops. Most farms (65 %) set aside 20 % of their farmland for energy crops. Only 10 % of farms cultivate energy crops on more than 50 % of their arable land. The farms high in energy crops have their own biogas plants, with one exception.

Nearly 50 % of energy crops are cultivated on fertile soils, with fertility numbers above 60. Soils with middle fertility numbers (40–60) have a 28 % share and soils with low fertility numbers (<40) 26 %.

The farmers were also asked which crops they cultivate and the shares of these crops. Maize was highest at 74 %, followed by winter rye (10 %), winter triticale (4 %), grassland (4 %), field grass (3 %), sugar beet (3 %) and diverse other crops (2 %).

A problem can arise for the environment, because 26 % of the energy crops, mainly maize, were cultivated on slopes. Furthermore, alluvial soils (7 %) and boggy soils (4 %) can create environmental problems if the cultivation concepts are not adapted. New sustainable energy concepts should specifically be tested for these soils in practice (see Sect. 6.8.4).

Through energy crop cultivation, other crops were replaced. Winter wheat was replaced the most at 62 %, followed by winter rape (17 %), winter barley (8 %), sugar beet (5 %), winter rye (3 %), triticale (2 %), potatoes (2 %) and diverse other crops (1 %).

The replacement of winter wheat can be viewed as an improvement for the environment. It has already reached a high concentration in many districts and needs several pesticide treatments against diseases and weeds. On fertile soils, winter wheat and sugar beet are often the only crops in the rotation (e.g., winter wheat, winter wheat, sugar beet). Owing to its self-incompatibility, winter rape should be cultivated with a 3-year break after cultivation. Since farmers do not always follow these rules, a reduction in the rape cultivation on locations with high concentrations can impact crop health positively.

In the next section, I analyse the situation before and after the restructuring of energy crop rotations. An example of a typical crop rotation before the cultivation of energy crops for a biogas plant: winter wheat, winter wheat, winter barley, winter rape. In fertile soils, sugar beets were cultivated instead of winter rape. However, very often, crop rotations were undertaken with only two crops (winter wheat, winter wheat, sugar beet). Since the restructuring, wheat-dominated crop rotations have been enhanced with maize (e.g., winter rape, winter wheat, winter barley, maize). Some farms lower in energy crops have integrated their energy crops very positively, which results in a more diverse crop rotation. Examples are winter rye, field grass, maize, triticale, potatoes; or winter rye, sorghum, maize, triticale, field grass, winter wheat.

Some farms high in energy crops run partial crop rotations on fertile soils with only two crops (e.g., maize, winter wheat; maize, sugar beet; or maize in monoculture). These one-sided crop rotations or monocultures can create many problems, for instance, humus degradation, plant diseases, soil erosion and nitrate leaching. Nonetheless, if all the farms are taken into consideration, the crop rotation changes that include energy crops have positive results. On average, across all the farms, the number of crops increased significantly from 3.5 crops to 4.0 crops in the crop rotation. About 50 % of the farms have had a more diverse crop rotation since the restructuring. Only 18 % of the farms have reduced the number of crops in their crop rotation.

With a crop rotation change, the humus reproduction demand changes, too. Maize is involved in most of the new crop rotations. Owing to its low soil covering in the spring and early summer and long vegetation time until October, maize is a humus-degrading crop. To retain the soil humus content, additional treatments are necessary, such as higher organic fertilisation and the cultivation of catch crops, cover crops or undersown crops.

Since the restructuring, 80 % of the farms have had a higher humus reproduction demand (on average, 91 kg $C/ha^1/a^1$) than before. However, 20 % of the farms have improved their crop rotations with humus-increasing crops such as field grass or mixtures of alfalfa and field grass, which they use as energy crops.

In energy crop cultivation, the crops requiring pesticide usage have been clearly reduced compared to the replaced crops. Table 6.1 provides an overview of these results. Seventy-seven percent of the farms use far fewer pesticides on energy crops (mainly maize). Fungicides and insecticides have been specifically reduced compared to the replaced crops. These findings can be attributed to maize diseases and pests currently not occurring in Lower Saxony; in addition, the two main maize pests (Ostrinia nubilalis, Dabrotica virgifera) have not reached Lower Saxony. This may change with a higher maize concentration in the crop rotations. In southern Germany (e.g., Baden-Wurttemberg), major problems arose due to the many years

Table 6.1 Pesticide applications in energy crops compared with the replaced crops

Pesticide applications		Energy crop maize n = 66		Energy crops winter cereals n = 15	
		Number	in %	Number	in %
Pesticides in general	No application	1	2	1	7
	Significant fewer applications	51	77	2	13
	Fewer applications	6	9	8	53
	No change	7	11	3	20
	Significant more applications	1	2	1	7
Fungicides	No application	58	88	3	20
	One application	1	2	7	47
	More than one application	0	0	3	20
Herbicides	No application	2	3	0	0
	Application before leaves emerge	9	14	1	7
	Application after leaves emerge	60	91	11	73
Insecticides	No application	58	88	3	20
	One application	0	0	3	20
	More than one application	0	0	1	7

of maize monoculture and the appearance of Dabrotica virgifera. Since no efficient insecticides are available against this pest, the government has forbidden maize cultivation in some districts to prevent the pest from spreading. This situation should be avoided in Lower Saxony through forward-looking sustainable crop rotation.

Main Cultivation Concept Changes in Lower Saxony Due to Energy Crops

- Energy maize mainly displaced winter wheat
- Number of crops on farms increased significantly from 3.5 to 4.0
- On 80 % of the farms, the humus reproduction demand increased
- Compared to reference crops, nitrogen fertilisation of and pesticide application to energy crops were reduced significantly

6.5 Optimisation of Farm Land Use for Energy, Food and Feed Production

Farmers – especially owners of bigger biogas plants – must consider how to optimise their land use, because biogas plants based on energy crops require much farmland to produce these crops. Table 6.2 provides an overview of how much land is needed to feed a plant depending on the biogas plant's size and the availability of liquid manure.

Table 6.2 Necessary farmland in ha to run a combined heat and power station as a function of increasing electric capacity of power station and livestock units (Karpenstein-Machan 2005)

	Necessary farmland area in ha			
	CHP-electricity capacity			
Livestock units (LU)	100 KW	150 KW	500 KW	1,000 KW
No LU	52	78	260	520
100 LU (=100 cows)	45	71	253	513
200 LU	37	63	245	505
500 LU	15	41	223	483
1,000 LU	0	4	186	446
2,000 LU	0	0	111	371
8,000 LU	0	0	0	24
10,000 LU	0	0	0	0

Fifty-seven percent of Lower Saxony's biogas plants have an electricity capacity of between 200 and 500 kW, while Lower Saxony's average plant size is 520 kW (ML 2010). As can be seen in Table 6.2, about 260 ha of farmland is needed to feed a 500 kW biogas plant. If liquid manure is available and used as a substrate, less farmland is necessary. However, due to liquid manure's low energy concentration, the savings are low. The manure of 8,000 live stock (manure of 8,000 cows/year) is necessary to operate a 500 kW_{el} biogas plant without energy crops. Fairly large quantities of manure are necessary to reduce the energy crop input from farmland.

Biogas production from farmland is still very land-use intensive. According to Table 6.2, 1 m^2 land can produce about 1.5 kWh electricity and 3 kWh heat energy. Approximately 50 % of the produced heat energy is needed to heat the fermentation tank, which means the usable heat energy is reduced to 1.5 $kWh_{thermal}$. Compared to photovoltaics (PV), biogas's efficiency is relatively low (Pimentel 2008). In northern Germany's climate, PV can produce approximately 100 kWh/m^2. In terms of land-use efficiency, that of PV is 33 times higher than that of biogas. However, it should be kept in mind that biogas is a renewable resource in rural areas. All types of wet biomass, crop residuals, manure and organic waste materials can be used for biogas production. Nevertheless, land use and biogas production need to be optimised to prevent negative effects – such as competition for land and unfavourable conditions for other production lines (food, husbandry, renewables for industrial uses) and to protect nature. Sustainable projects such as Jühnde's bioenergy village show that 83 % of the energy produced by the biogas plant is utilised for electricity and space heating. The energy input/output ratio of the biogas plant is high due to the village households largely using biomass heat energy for space heating (see Chap. 2).

Figure 6.4 shows possible pathways to optimise energy crop production. All the items provide optimisation without using more fertilisers and pesticides. Through those agricultural treatments (e.g., higher biodiversity through multi-cropping), crops are adapted to the location, which should increase the crop yield.

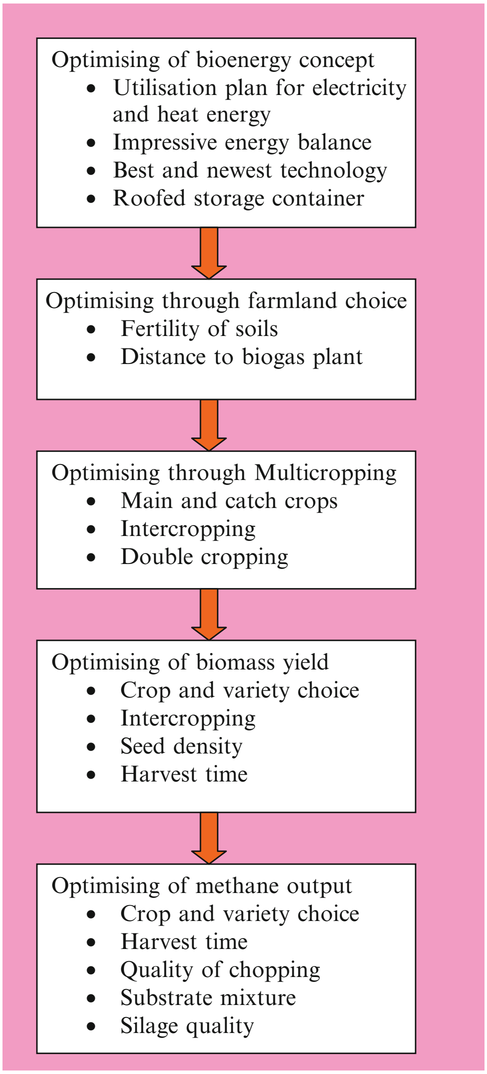

Fig. 6.4 Pathways to optimize energy crop production for biogas

6.5.1 Optimising Farm Land Usage for Biogas

To avoid long transportation routes, energy fields should be located close to the biogas or combustion plant. According to the questionnaires (Sect. 6.4), the farmers prefer fertile soils for annual crops for biogas production, as they mostly cultivate maize. However, other crops well suited to poorer soils are also suitable. Winter rye, which is highly drought resistant and is harvested as a total plant before maturity, may be a better option for poor soils than grain production, due to its shorter vegetation time and its lower risk of having to endure early summer drought.

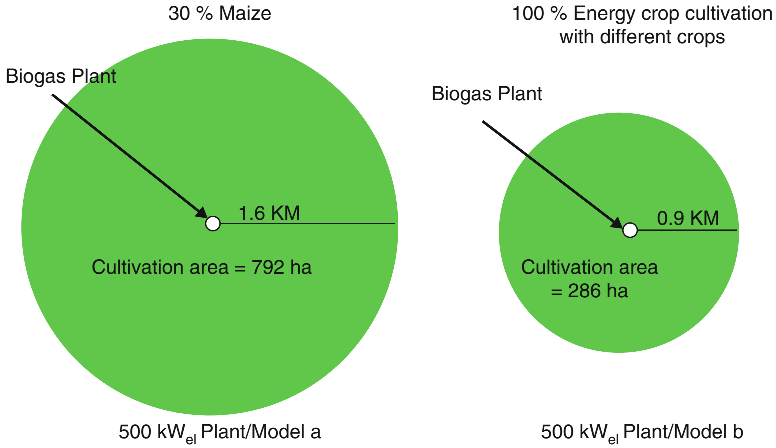

Fig. 6.5 Exemplary catchment area for biomass substrate, calculated for a 500 kW electricity power plant. Model a: only maize is used as substrate, Model b: catchment area for a pure energy crop rotation with three different energy crops

The crops cultivated around the biogas plant determine the size of the biomass catchment area. If farmers intend to feed their biogas plants only with maize, they need a catchment area that is three times larger than if they were to additionally also produce other crops. This is due to these farmers having to fulfil cross-compliance regulations concerning crop rotation diversity. The minimum is a 3-year crop rotation with maize being rotated with two other crops, mostly food market crops. With a pure energy crop rotation (e.g., winter rye/field grass, maize, winter triticale) cross-compliance can be fulfilled and the catchment area is much smaller (Fig. 6.5). The logistic concept can be optimised due to the shorter transportation routes for the harvested biomasses and the fertilisation of the fields with digestive material. In addition, perennial crops (Sect. 6.6.6) can be integratively cultivated in the biogas plant catchment area.

6.5.2 Optimising Fields Through Multi-cropping

The current climate conditions in Central Europe allows the cultivation of just one grain crop during vegetation time, while in forage production systems, two or three harvests per year are usual. Catch crops, which were established in the first half of the twentieth century, extended the fodder period in summer, which meant more farmland area could be used for market crops:

- Catch crops could supply high quantity and quality forage
- Catch crops delivered silage, which could be utilised during winter.

Biogas farmers can benefit from these experiences with fodder production concepts. Catch crops and multi-cropping concepts increase productivity and soil fertility simultaneously (Finckh and Karpenstein-Machan 2002).

Catch Crops

Catch crops are fast growing crops sown between regular crops grown in consecutive seasons. A great number of different catch crops are suitable for feed and energy production, for example, different species and varieties of cabbage, field grass, beans, feed pea, winter rape and Phacelia (see Sect. 6.6.4.)

6.5.3 Optimising Biomass Yield Through Intercropping

Beside optimisation through multi-cropping, location-adapted crops as well as crop and variety mixtures also increase the biomass yield. Several field trials show that mixtures yield better and have a better yield stability than pure stands; they are also healthier and need fewer pesticides than pure stands due to their higher genetic diversity (Aufhammer 1999; Finckh and Karpenstein-Machan 2002; Karpenstein-Machan and Finckh 2002). At this point, economic and ecological goals converge. Furthermore, to gain a high biomass yield and utilise biomass crops' potential, it is important to determine the optimal harvest time (see Sect. 6.5.4).

6.5.4 Optimal Harvest Time

The annual biomass crop yield for biogas use is dependent on the optimal harvest time. Plant development follows a growth curve, with diminishing yield increase and increasing lignification towards maturity. To ensure the best harvest time, a high biomass yield (dry matter yield) and the best conditions for bacteria to digest the biomass, plants should reach a dry matter content of 25–35 % (Karpenstein-Machan 1997; Herrmann et al. 2009). In maize and winter cereals, this dry matter content corresponds with the milky to doughy development stage. Furthermore, the dry matter content range in plants is a precondition for high-quality silage. In southern Lower Saxony's climate conditions, winter cereals (rye, triticale, wheat) reach a milky maturity stage between mid-June and mid-July. It is important to choose locally adapted maize varieties that reach the milky maturity stage before the first autumn freeze.

6.5.5 Optimising Methane Output

Biogas farmers are interested in the methane yield per hectare. The biogas plant power station is fuelled by biogas. However, only methane is a burnable gas that can be transformed into electricity and heat energy in a combined heat and power station. Methane (CH_4) and carbon dioxide (CO_2) are the dominant gases in biogas. The CH_4 to CO_2 ratio determines the biogas quality. The methane contents in biogas vary between 50 and 75 %, depending on the input substrates. The fermentation of fatty crops and substrates leads to higher methane contents in biogas. Furthermore, compared to the mono-fermentation of maize, the co-fermentation of liquid manure and dung with crops leads to more stable fermentation and a higher specific methane content (Leonhartsberger et al. 2008). If crops and manure are fermented together, this results in higher digestion rates and higher methane contents in biogas. Anaerobic digestion trials with different crops show the same effect: The fermentation supplies the bacteria with diverse foods that have all the necessary micro-nutrients. This causes higher specific biogas and methane outputs (Leonhartsberger et al. 2008). The diverse energy crop cultivation concept therefore has a strong economic basis. We can thus conclude that:

- crop and variety mixtures lead to a higher biomass yield
- the anaerobic digestion of crop mixtures and manure lead to a higher methane yield.

Furthermore, the methane yield per hectare is influenced by the optimal harvest time, as well as the chopping and silage quality.

6.5.6 Chopping and Silage Quality

Good chopping quality is associated with the harvested material's short and constant chopping length. The shorter the harvested material, the better the biomass can be compacted in the silo and the quicker the lactic acid fermentation can start. Furthermore, short chopping length improves the anaerobic digestion rate in the fermenter. However, more diesel fuel must be spent when harvesting to obtain a short chopping length. Therefore, farmers seek to balance the optimal chopping length and the energy input. In practice, a chopping length between 4 and 40 mm is common.

The right harvest time at the milky to doughy stage of crop development and a short chopping length are the best preconditions for good silage quality. Heiermann et al. (2009) show that ensiled biomass has positive effects on biomethanation, producing higher biogas yields and methane contents than fresh material. They also show that ensiling can be considered a pre-treatment with the potential to also improve methane production from plant matter. To achieve high-quality silage, crops should be harvested, rapidly and well compressed and, as soon as possible after the silo has been filled, sealed tightly with a plastic cover. The plastic cover prevents oxygen from entering the stored material and minimises further biomass decomposition.

6.6 Adapting Cultivation Concepts to a Location

The area requirement for a biogas plant is considerable. Locally adapted cultivation concepts, which enable farmers to exploit income possibilities from biogas under different climatic conditions, are of great importance. For the best methane output, annual crops should be harvested when the kernels are milky to doughy. The biomass is harvested with a fodder harvester. Compared to grain crops, which are harvested about 4–6 weeks later, biomass crop production shortens the vegetation time. The early harvest of bioenergy crops allows additional cropping on the same land, which, in turn, means that, depending on the climate conditions, new cultivation concepts can be introduced:

- The winter main crop in cool and dry locations, for instance on the foothills of low mountains ranges.
- The winter main crop and summer catch crop in cool and moderate wet locations, for instance on the foothills of low mountains ranges.
- The winter catch crops and summer main crops in moderately dry and more temperate locations.
- Two main crops when the climate is very favourable, has sufficient summer precipitation or irrigation and a long summer vegetation period.
- The summer main crop when climatic conditions are dry but the temperatures favourable.
- The perennial crops in moderately dry and moderately wet locations.
- Permanent grassland or perennial forage mixtures in moist and cool regions with a short summer vegetation period.

Figure 6.6 shows energy cultivation concepts adapted to climate conditions with different combinations of winter and summer main crops as well as winter and summer catch crops. All the crops in Fig. 6.6 are energy crops but for different utilisation purposes. Grain crops can also utilised for human nutrition and bioenergy crops as fodder for cattle.

Climate conditions are defined by means of the soil moisture level (SML) and summer vegetation period length. The SML characterises a location's moisture situation. Pedological, hydrological, morphological and climatic parameters influence the SML (LBEG 2011). The summer vegetation period length is defined as the number of months with a daily average temperature of more than 10 °C. In dry locations with short summer vegetation periods, winter annuals (e.g., rye, barley, triticale, rape) generally reach grain maturity. In moderate dry regions with a short summer vegetation period, winter triticale and winter rye yield well. A perennial crop, such as the undemanding Silphie, is also possible (see Sect. 6.5). A further moisture increase allows double-crop farming with winter and summer cereals for biomass or grain use and in keeping with each crop's vegetation time length. In wet and very wet soils, annual or perennial grass-legume mixtures yield well. In locations with higher summer temperatures (5 and 6 months of daily average temperatures of more than 10 °C), more thermopile crops with good dry resistance can reach high

Water supply in the vegetation time	Summer vegetation time in month > 10° C								
	3 month° C	4 month° C		5 month > 10° C		6 month > 10° C		7 month > 10° C	
		Winter crop	Summer crop	Winter crop	Summer crop	Winter crop	Summer crop	Winter crop	Summer crop
Dry (SM 3)		Rye, Barley, Triticale, Rape (all grain prod.)			Maize BM, Sunflowers BM Sugar beet		Maize BM, Sugar Millet BM Amaranth BM		Maize -CCM Maize grain, Sugar Millet BM Amaranth BM
Moderately dry (SM 4)		Triticale BM, Rye BM; Ethanol wheat; Rape seed		Barley BM	Maize BM, Sunflowers BM	Barley Grain, Triticale BM, Rye BM	Maize BM, Sugar Millet BM Amaranth BM	Rye grain	Maize BM, Sugar Millet BM Amaranth BM
				Winter catch crop (e.g., Phacelia, Mustard)	Ethanol-potatoes	Winter catch crop (e.g., Phacelia, Brassicaceae)	Ethanol potatoes		
		Perennial Silphie		Perennial Silphie		Perennial Silphie			
Moderately wet (SM 5)		Triticale BM, Rye BM; Ethanol wheat; Rape seed	Rye BM; Oat BM	Early Rye BM	Maize BM, Sugar Millet BM	Rape Seed	Maize BM, Sugar Millet BM Amaranth BM		
		Perennials Fast-growing trees: willow, poplar		Perennials e.g., Miscanthus, fast-growing trees: willow, poplar		Perennials e.g., Miscanthus, fast-growing trees: willow, poplar			
Wet (SM 6)	Permanent grass land	Wheat BM Triticale BM, Rape Seed	Rye grass, Landsberger "Gemenge"						
Very wet (SM 7)	Permanent grass land	Permanent grass land or perennial forage, grass-legume mixtures							

Fig. 6.6 Climate conditions as a function of possible crop combinations of winter and summer annuals and cultivation concepts. BM = Biomass

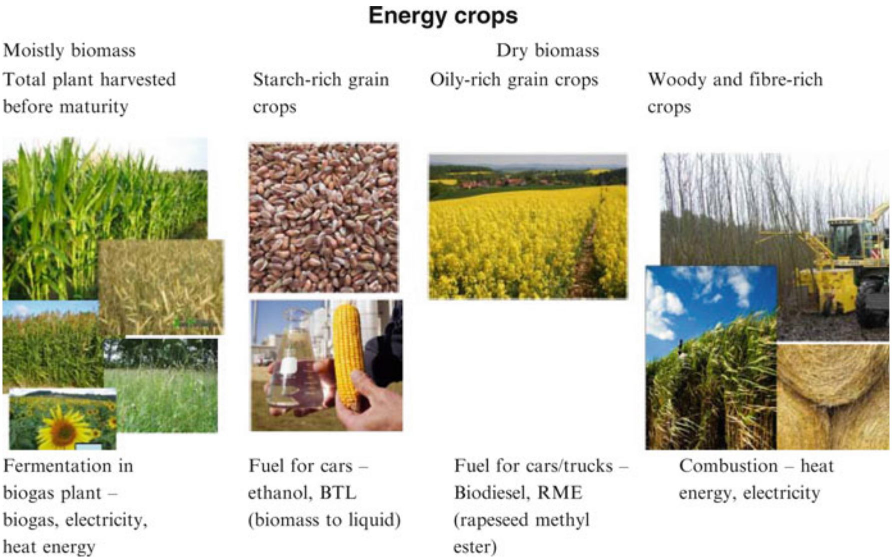

Fig. 6.7 Energy crops and their utilisation lines

yields. In moderately dry and moderately wet conditions, double-cropping systems with many different crops as well as perennials are feasible. Under very favourable summer temperatures (7 months of daily average temperatures above 10 °C), but in dry locations, thermopile subtropical crops such as maize – for corn cobs or grain production –, sugar millet and amaranth yield well.

6.6.1 *Characterisation of Energy Crops*

Energy crops can be defined as crops utilised for the production of electricity, space heating energy, cooling energy and fuel energy for mobility. Figure 6.7 shows the different utilisations of energy crops according to the maturity stage at which the biomass is harvested and the part of the biomass used for energy production (the total plant or just the grain). Many different crops are suitable for fermentation in a biogas plant. Anaerobic digestion depends on a high moisture content (about 70 %) in the biomass. Therefore, the biomass for anaerobic digestion must be harvested before maturity. The product of the fermentation process is biogas, which can be transformed into electricity, heat and cooling energy. Biogas can be used as fuel for cars with gas engines. Starch-rich grain crops, such as maize, cereals and potatoes, are the raw materials for ethanol production. In Germany, ethanol is mixed with other fossil fuels (gasoline) and utilised as a car fuel. Oil-rich grain crops, such as rape seed or sunflower seed, are used for biodiesel production

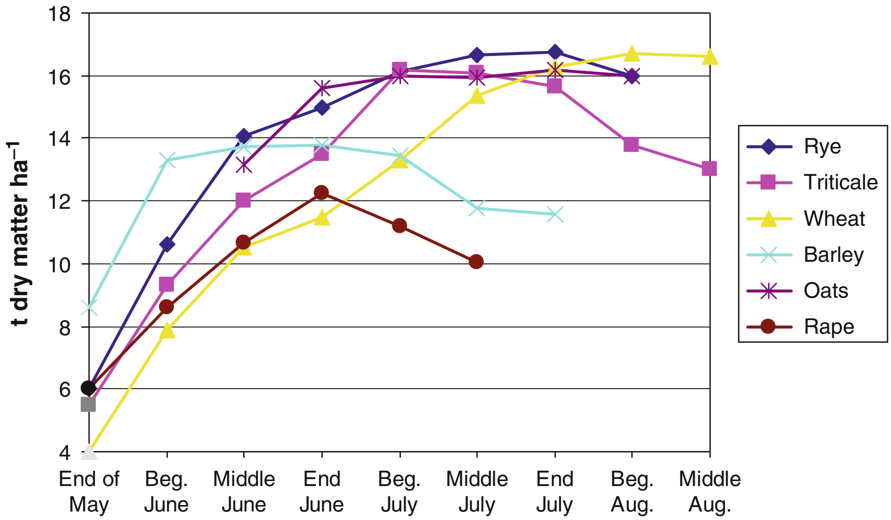

Fig. 6.8 Development of biomass dry matter yield in winter annuals (Karpenstein-Machan 2005)

to fuel diesel cars and trucks. In Germany, nearly one million ha of rape seed are cultivated for this purpose (FNR 2010). Woody and fibre-rich crops, such as fast-growing trees, hemp, miscanthus and straw, which is a by-product of grain production, are suitable for direct use as an energy carrier in a special biomass combustion plant, or, together with fossil energy carriers (e.g., coal), as an energy carrier in a co-firing plant (biomass and fossil fuels are burned together).

6.6.2 Winter Annuals

As energy crops, winter annuals are suitable for locations with cool and moderate climates and locations that lack a high summer precipitation. Winter annuals utilise winter soil moisture to produce biomass in the spring. They already reach the maximum biomass yield in the first half of the year. They are therefore hardly affected by summer dryness. Figure 6.8 shows biomass dry matter yield development and Fig. 6.9 the dry matter content of winter annuals harvested at different times between early May and mid-August. Triticale, rye, wheat, oats, barley and rape have different biomass yield curves that depend on the length of their vegetation time, their development rate and productivity. Cereals and rape reach their maximum biomass yields between end-June and mid-July. Dry matter yields range between 12 and 16 t/ha. Triticale and rye grow in valued locations in southern Lower Saxony; they are the most productive winter energy crops for biogas production. Even on poorer soils, rye and triticale are very productive biomass

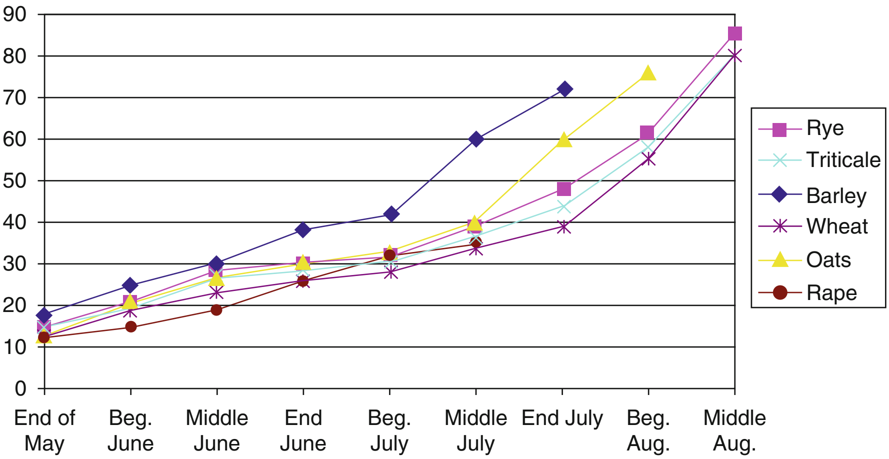

Fig. 6.9 Development of dry matter content in winter cereals (Karpenstein-Machan 2005)

producers (Karpenstein-Machan 2005). As is shown in Sect. 6.5.4 dry matter content is essential for anaerobic digestion, with a content of between 25 and 35 % optimal for anaerobic digestion. Depending on the crop development and climate conditions, the optimal harvest time is between mid-June and early July. A high dry matter yield and optimal dry matter content occur between mid-June and early July in most crops besides winter wheat, which reaches its highest dry matter yield too late for optimal digestion. For digestion, winter wheat has to be harvested before the maximum dry matter yield is reached.

The grain of winter annuals such as winter wheat and winter triticale is very suitable for ethanol production, due to its high starch content. If they are to be used for this purpose, cereals should be harvested at full maturity.

Winter rye and winter triticale are the most suitable of the winter cereals for mixing with winter legumes such as winter vetch (Vicia villosa L.), winter pea (Pisum sativum L.) and winter crimson clover (Trifolium incarnatum L.) (Karpenstein-Machan and Stülpnagel 2000; Aufhammer 1999).

6.6.3 Summer Annuals

Maize (Zea mays L.) is the most important summer annual for biogas production. Currently, alternative crops like sunflower (Helianthus annuus L.), sorghum (Sorghum ssp.) (see Fig. 6.10) and amaranth (Amaranthus spp.) receive attention and have been tested in field trials and in practice. While maize breeding is advanced, breeding work must still be done on sorghum spp. and amaranth to adapt these crops to mid-European climates. However, they have the potential for very high biomass yields in favourable climate conditions.

Fig. 6.10 Different varieties of Sorghum subspecies

Sunflowers are better adapted to mid-European climates because they originated in Middle and North America. They have shown a high biomass yield potential in many field trials (see Fig. 6.11). Sunflowers' high genetic diversity (Khoshbakht and Hammer 2008) offer many possibilities for breeding optimal varieties for biomass use. Furthermore, as a substrate for digestion, sugar and fodder beets are an option to increase the diversity in biogas crop rotations. Farmers have cultivated beets for many years as crops for sugar and fodder production. For biogas production, soil must be removed from the beets after harvesting and they must be chaffed before fermentation. Summer cereals are also suitable as a biomass source, but due to their limited vegetation time, the biomass yield is lower than that of winter cereals. Summer cereals can be used in double-cropping systems as catch crops after a winter annual main crop (see Sect. 6.6.4).

6.6.4 Catch Crops

Catch crops like Brassica napus L., Phacelia tanacetifolia L., Sinapsis alba L., Trifolium incarnatum L., Raphanus sativus var. oleiformis L., Fagopyrum esculentum L., Lolium multiflorum L. as well as summer cereals and sunflowers can be used in double-cropping systems as a complement crop after the main crop. Photoperiod-insensitive varieties can utilise residual vegetation time after the main crop for biomass production. For biogas production, photoperiod-insensitive varieties are sown in June to early July and harvested in the autumn before the first frost. They have a vegetation time of approximately 12 weeks. As green manure, they are not

Fig. 6.11 Herb free buffer strip with sunflowers on maize field

harvested but last through winter and are killed by frost. In field trials, the biomass yields of different catch crops, which are harvested in October, range between 4 and 8 t of dry matter per hectare when cultivated after a winter annual (see Fig. 6.12) (Karpenstein-Machan 2009b).

6.6.5 Undersown Crops

Winter main crops and summer main crops can be undersown with other crops. If main crops and undersown crops are sown together in one operation to save time, energy and costs, the undersown varieties in the winter main crops must be winter hardy. The following crops are suitable for this purpose in winter main crops: winter crimson clover (Trifolium incarnatum L.), winter vetch (Vicia villosa L.), winter pea (Pisum sativum L.), ryegrass (Lolium sp. L.) and red fescue (Festuca rubra L.) Different varieties of ryegrasses, red fescue (see Fig. 6.13), or white clover, can be utilised as undersown crops with summer main crops (e.g., maize). Especially with maize, crop competition must be considered. Since young maize plants compete poorly against weeds and other crops, different undersowing concepts have been developed for maize:

1. A very slow-growing grass (e.g., red fescue) is sown before maize seeding.
2. A faster-growing grass (e.g., Italian ryegrass) is sown after maize seeding when the maize has developed four to six leaves.

Fig. 6.12 Fagopyrum esculentum (Buckwheat) and Sinapsis alba (white mustard) mixtures as catch crops in a double cropping system

Fig. 6.13 Maize with undersown red fescue

Concept 1 is very suitable as protection against erosion and nitrate leaching with maize, while, with concept 2, an additional biomass yield can be realised the following spring with ryegrass. Both of these grasses survive winter and protect the soil against erosion and ensure a balanced humus content in soil.

6.6.6 Perennials

Perennial forage crops (e.g., red and white clover, alfalfa, ryegrass) are suitable energy crops. They are mostly cultivated with legumes and grasses and can be utilised for 2–3 years. Depending on the climate conditions and soil fertility, they can deliver several harvests per year.

A very long useful life is anticipated for Silphie (Silphium perfoliatum L.), also known as the cup plant. With its cupped leaves, Silphie can collect air moisture and is therefore relatively resistant to dry conditions. It is adapted to the moderate climate conditions of eastern North America and can be cultivated 400 m above sea level (Conrad and Biertümpfel 2010). Silphie has been cultivated as fodder for cattle in North America and in the former GDR. It was tested as an alternative biogas crop in field trials in Germany from 2005 onward (FNR 2010). In 2010, farmers cultivated Silphie on about 20 ha of farmland. The best results have been obtained when the seeds are sown and nursed in greenhouses and transplanted as young plants with three or four leaves into the fields in May or June (Biertümpfel and Conrad 2013). In the first year, the crop should establish itself in the soil and the plants should only build a leaf rosette before winter (see Fig. 6.14). In the following spring, the plants grow very quickly and can deliver their first harvest in the autumn. The first results show that Silphie has a very high yield, similar to that of maize (FNR 2010). Its advantage is that, after the first year, the crop needs no further weed control and no additional pesticides. However, the seed quality and cultivation concepts must be improved to help broaden Silphie's use as a crop.

6.6.7 Wild Herbs as Biogas Substrate

Some breeders, together with nature protection organisations and seed producers, try to select productive wild herbs as mixtures for biogas (Vollrath et al. 2011). The idea is to combine ecological (a low input of fertiliser and agricultural treatments) and economic aims (a high yield, high methane output, good silage quality). In conventional agriculture, there is a lack of flowerings plants, especially in summer. Bees need flowering herbs' pollen and nectar (bee bread) to survive and reproduce. The newly bred mixtures are perennials, which flower for long owing to herbs' different development rhythms. They change their composition from year to year. In the first year, annuals are dominant in the mixture, but in the following years, high-yielding perennials (shrubs) form the canopy (Vollrath et al. 2011). Further research is necessary to stabilise the yield and other economically important parameters of wild herb mixtures, as well as to multiply the seed mixtures before these concepts can be optimally utilised in practice.

Fig. 6.14 Silphie (Silphium perfoliatum L.) in the first year of development

6.7 Energy Crop Rotation Design

Energy cultivation concepts can be designed as pure energy crop rotations, or as mixed rotations with food, feed and energy crops. Many crops can be used as energy, food or forage crops. However, the cultivation concepts must fulfil the cross-compliance regulations regarding crop diversity and humus balance. At least three crops should be combined in a rotation. The advantage of pure energy rotations is that the plant catchment area for biomass production for the biogas plant is much smaller (see Fig. 6.5) than for mixed rotations with food, feed and energy crop rotations.

Figure 6.15 shows an example of pure energy crop rotations designed as a 3-year rotation with five different crops. In the first year, winter rye is cultivated, followed by Italian ryegrass. The field grass can be harvested twice – in autumn and in spring – before maize is planted in May. Maize is sown in early May with a conventional corn seed drill machine; approximately 2 weeks later, fescue is sown with a pneumatic seed drill between the rows of maize. The later fescue seed gives maize a head start and the grass develops very slowly under the maize canopy and does not compete with the maize (see Fig. 6.13). After the maize harvest in October, the fescue continues to grow and builds a stable green cover against soil erosion over the winter. The vegetative growth of fescue ends with the ploughing at the end of April. While red fescue is generally not harvested owing to its low yield, the grass adds much subsoil and root biomass and is inserted to protect the soil over winter, increases the soil's carrying capacity and supports humus reproduction (see Fig. 6.16). The last crop in the rotation is sunflowers. Sunflowers interrupt cereals' cultivation sequence before the rotations restarts with winter rye as a biomass crop. With the recycling of digestate, the soil's humus content can be kept in balance for biogas production with this pure energy crop rotation.

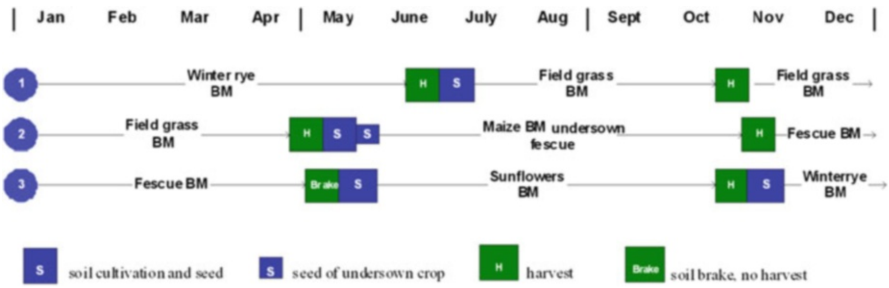

Fig. 6.15 Example for pure energy crop rotation

Fig. 6.16 Subsoil root biomass of red fescue delivers humus reproduction material

Figure 6.17 shows a mixed rotation with food, feed and energy crops. Eight different crops are involved in this exemplary crop rotation, with a 33 % share of energy crops and a 66 % share of market crops (winter wheat, sugar beet, winter rape). These market crops for food or fodder can also be used as energy crops: Winter rape for biodiesel and winter wheat and sugar beet for ethanol production. Furthermore, sugar beets are currently also utilised for biogas production.

The 6-year rotation starts with winter triticale, winter vetch and a field grass mixture. The development of field grass is reduced by the fast-growing mixture of winter rye and winter vetch. After the harvest of the biomass mixture winter rye/ winter vetch at the end of June, field grass grows swiftly and provides biomass for the biogas plant in autumn. The following crop – winter wheat – can be used as a market crop for food or animal fodder. The wheat crop's straw remains on the field to keep the soil's humus content balanced. The following catch crop helps turn the straw into

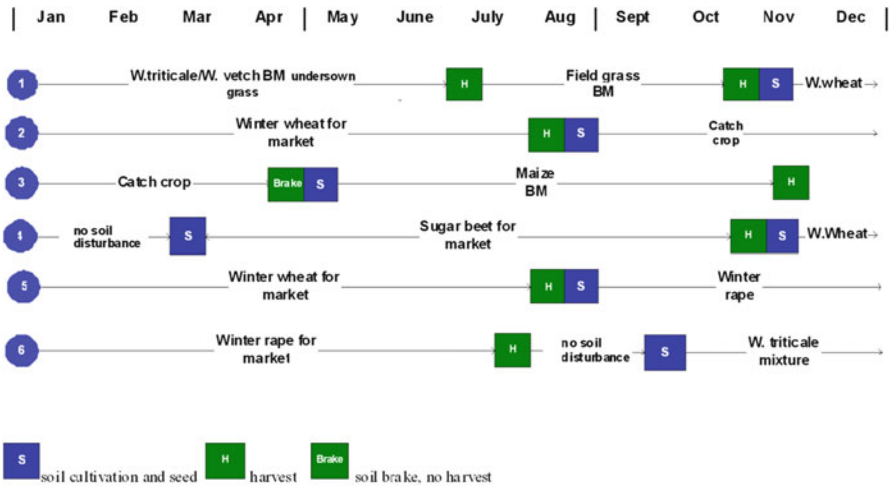

Fig. 6.17 Example for mixed crop rotation with energy and food/fodder crops for market Karpenstein-Machan in Schmuck et al. (2012)

humus and prepares the soil for conservation tillage systems. Maize is then sown by mulch till or strip till. After the maize harvest, the soil is not disturbed until March or April for sugar beet drilling. Sugar beets are used for sugar production and are a market crop. Two further market crops follow with winter wheat and winter rape. These two grain crops, with their straw residuals, are necessary for humus reproduction because maize and sugar beets are very humus-draining crops. After the rape has been harvested, the soil remains undisturbed until September, when the rotation restarts with a mixture of winter triticale, winter vetch and field grass for biogas production.

6.8 Model Farms as Lighthouse Projects

6.8.1 Why Model Farms?

During the district partner selection process (see Chap. 11), we also looked for suitable partners to research agricultural questions. The farmers were given an opportunity to express their willingness to cooperate with the university team and answer a questionnaire. Representatives of agricultural organisations distributed the questionnaire to farmers with energy crop production. The questionnaires also gave the farmers the opportunity to have their farms recognised as model farms. In three selected districts, we began to cooperate with three interested farmers, who were keen to try out new approaches to improve their cultivation concepts. The model farm initiative sought to develop new ecologically and economically optimal cultivation concepts for bioenergy, food and forage crops with the help of the farmers. They would act as new project leaders to motivate other farmers to change their cultivation systems to obtain increased sustainability and productivity.

6.8.2 Characterisation of Model Farms

6.8.2.1 Farm Types and Biogas Plant Operation

Table 6.3 provides an overview of the model farm types and biogas plant specifics. Farm A uses most of its farmland for energy production (80 %). Maize, rye kernels and a part of the sugar beet cultivation are supplied to the biogas plant. Farm B uses only 10 % of its farmland for energy production, mainly for maize production; the market crops winter wheat and sugar beets are produced on 80 % of its farmland. Farm C produces fodder for dairy cattle on farmland (50 %) and grassland (25 %). On the remaining 50 % farmland, energy crops for biogas (mainly maize) are produced. Liquid manure is only used as an energy carrier in farm C's plant, while the other biogas plants are based on renewable resources from farmland only.

Farm A has a contract with the other farmers to produce energy crops for the biogas plant with an 800 kW electrical capacity. Together, Farms B and C, which operate biogas plants in cooperation with other farms, own enough farmland to operate the biogas plant with their biomass. A combined heat and power station (CHP) is attached to every biogas plant and this, in turn, produces electricity and heat. Electricity is fed into the public grid. However, only farm C's plant has a sufficient heat utilisation concept. Communal industry buildings and private homes are heated with the heat from the combined heat and power plant. At Farm B, the CHP's heat output is used to run an organic rankine cycle (ORC) plant. The ORC process converts heat output from CHP into electricity. Owing to the low temperatures generated, ORC heat output can no longer be used for heating. Much of the heat energy is therefore still unused. In farm B's biogas plant, the biogas process takes place in two fermentation tanks. The hydrolysis process takes place in fermenter 1 and is separated from the biogas production, which takes place in fermenter 2. With these facilities, the different demands of bacteria on temperature, pH-value and nutrient ratio should be fulfilled better. Another technical upgrading is a press that separates the digestive material in a liquid phase and a solid phase. The liquid, water-rich digestate is used as fertiliser on soils near the plant, while the solid phase can be transported over longer distances and is especially used on low humus content soils.

6.8.2.2 Climate, Soil Specifics and Crop Rotations

Table 6.4 show the three model farms' climatic conditions and soil characteristics. The mean annual air temperature increases from farm A, farm B to farm C. Farm A is located close to the Harz Mountains, while the other two farms have a more

Table 6.3 Specifics of the model farms

	Farm type and % area for crops	Capacity of biogas plant	Type of energy plant	Owner/ Operator of the plant	Substrates for biogas plant	Specific feature of the plant
Farm A						
213 ha farm land	Field (20%) and energy crops (80%)	800 kW_{el}	Renewable resources plant with separated hydrolysis	1 farmer, supply contracts with other farmers	Maize; sugar beet; rye cornels	Part of the residuals is separated in the liquid and solid phase, no heat concept
Farm B						
253 ha farm land	Field (90%) and energy crops (10%)	500 kW_{el}	Renewable resources plant	6 farmers in a cooperation	Maize, field grass, winter rye, sunflowers catch crops	Heat output from the combined heat and power plant (CHP) is used in the ORC plant
Farm C						
90 ha farm land, 90 ha grassland	Dairy cattle (75%) and energy crops (25%)	500 kW_{el}	Co-fermentation plant	4 farmers in a cooperation	Maize, cattle manure	Heat output from the combined heat and power plant (CHP) is used for space heating (industry and communal buildings)

favourable lowland climate. Mean annual precipitation is between 600 and 720 mm/year, which is typical for moderate dry to moderate wet climates. The soil types range from sand, loam and less loam to organic soils. The soil heterogeneity is reflected in the soil fertility code, which ranges from 30 to 100.

On farm A, 35 % of the soil has developed from karst, is rich in limestone and has a low rooting depth. Much of the soil has been irrigated with sewage for more than 50 years; one can therefore assume that it is contaminated with toxic substances. For the past 10 years, the farm's sandy soil has been part of a water protection area. In water protection areas, land utilisation is regulated by water protection guidelines such as the amount and the time period of mineral and organic fertilisers that can be applied. Farm C also produces energy and feed crops in a water protection area. Farm B produces food and energy on very fertile mineral and organic soils (fen soils). About 60 years ago, fen soils (floating grassland) were ploughed and drained and then used as farmland. This land use change has led to soil degradation, carbon loss (humus) and high mineralisation rates (see the Chap. 7). The cultivated crops are oversupplied with nitrogen and other nutrients. Without pesticides, they suffer from plant diseases,

Table 6.4 Climate, soil specifics and crop rotations

	Mean annual air temperature; Mean annual precipitation	Soil Type	Soil fertility code	Soil specific	Current crop rotations	Crop parts in % of farmland
Farm A	8° C, 720 mm	sandy loam and loam	32–82	Karst formation, water protection area, 50–60 years' sewage irrigation	1) w.rye/maize/sugar beet 2) w.wheat/maize/maize/maize	Maize 65%; sugar beet 15%; winter rye 13%; winter wheat 7%
Farm B	9° C, 600 mm	lossial loam and organic soils	50–100	fen, used as farm land for 50 years, previously grassland	1) maize/maize/s.wheat 2) w.wheat/w.wheat/w.wheat/sugar beet	winter wheat 53%; sugar beet 28%; maize 10%; summer wheat 6%, winter rye 3%
Farm C	9,2° C, 670 mm	sandy loam and sand	30–50	water protection area	1) maize/w.wheat/ w. triticale 2) maize/maize/maize	maize 63%; triticale 20%; winter wheat 17%

lodging and weeds; pesticide input into these soils is therefore high. Only a few crops are rotated in the crop rotation.

The most frequently cultivated crops are maize, winter wheat and sugar beet. Farms A and C respectively cultivate 65 and 63 % maize on their farmland. On farm A, maize is rotated with winter wheat; on farm B, maize is rotated with winter rye; while maize is rotated with winter triticale on farm C. On farm B, winter wheat production covers 53 % of the farmland. Winter wheat is rotated with sugar beet. On organic soil, maize is rotated with summer wheat. Owing to the high maize demand for dairy cattle and the biogas plant, farm C produces maize in rotation with triticale and winter wheat and in monoculture.

6.8.2.3 State of Ecological Challenges Regarding Current Cultivation Concepts

Table 6.5 provides an analysis of the ecological challenges on the model farms. All farmers operate their farms conventionally, which means the use of mineral fertiliser and pesticides rather than practising biological or organic farming. Owing to the very one-sided crop rotation with only a few crops (mainly maize, sugar beet and wheat), many problems can arise. If maize and sugar beet are cultivated, this means two humus-wasting crops are in a single rotation. Both of these crops start their vegetation time in April to May and are sown in wide rows, taking 4–6 weeks to build a canopy to cover the soil. During this time, maize development is specifically very affected by weeds. Weed management with herbicides or mechanical weed removal is necessary owing to young maize plants' poor competitive power against

Table 6.5 Analysis of current ecological challenges of the model farms

	Farm A	Farm B	Farm C
Crop rotation	Crop rotation with low diversity	Crop rotation with low diversity	Crop rotation with low diversity
Humus	High risk of humus-wasting crop rotation	Humus degradation on organic soils, high risk of humus-wasting crop rotation on mineral soils	High risk of humus wasting crop rotation
Diseases, pests	European corn borer (Ostrinia nubilalis) in maize	Heterodera schachtii	European corn borer (Ostrinia nubilalis) in maize
Soil compaction	Middle to high risk	High to very high risk	Low risk
Soil cultivation	Minimum tillage	Plough, conventional tillage	Plough, conventional tillage
Nitrate	High danger of nitrate leaching on karst soils	Low danger	High danger of nitrate leaching on sandy soils
Digestate recycling	Separation into solid and liquid phases, digestate back to biomass suppliers	Back to cooperation farms	Back to cooperation farms
Pesticide input	Conventional	Very high pesticide input	Conventional
Wind erosion (EFA)	Medium	Medium	Low
Water erosion (EFW)	Low susceptibility	Low to middle susceptibility	Low susceptibility
Water deficiency in summer	−63 to −5 mm	−120 to −180 mm	−130 to −84 mm
Soil water capacity	Low to medium	High	Low to medium
Ground water level	Soils with low, medium and high ground water levels	Soils with low, medium high ground water levels	Soils with low and medium ground water levels
Water protection area	All soils in area under water protection	water protection area borders soils of the farm	All soils in area under water protection and landscape protection,
Nature protection area	Few soils under fauna-flora protection		Few soils under fauna-flora protection

weeds. The uncovered soil at the outset and maize's long vegetation period (until autumn) leads to humus degradation. Furthermore, the amounts of harvest residuals that remain on the field after harvesting are very low. Humus-accumulating crops such as field grass or legumes should be followed by humus-wasting crops. On organic soils, maize and sugar beet cultivation specifically leads to strong humus degradation and enormous greenhouse gas emissions. Other problems are linked to tight rotations, including those of maize and sugar beet. Rotations with poor diversity or monoculture support crop-specific pests and diseases.

Farms A and C have problems with the European corn borer (Ostrinia nubilalis) in maize. In the larval stage, this pest hibernates in the base of maize straw, pupates in May, after which female moths deposit their eggs in clusters onto the underside of maize leaves. The borer larvae bore into the upper part of the maize plant and feed downwards inside the stalk. The older the larvae are, the further they move downwards, and the greater the damage caused. Farm B cultivates sugar beets in high concentration. The soil is infected with the beet nematode (Heterodera Schachtii), which infects nearly all Brassicaceae species. These pests and diseases are typical effects of low-diversity crop rotations and monoculture.

Sugar beet and maize are harvested with heavy machines in late autumn (October, November) and often in unfavourable weather conditions, which promote soil compaction. The loam and organic soils of farm A and B are more at risk of soil compaction than the sandy soils of farm C.

In combination with cash crop cultivation, minimum tillage and conservation cultivation improve the soil structure and the biological life in the soil. Only farm B cultivates the soil with a plough – the other two farmers use a field cultivator and minimum tillage techniques.

The danger of nitrate leaching is very high in the karst soil of farm A and the sandy soil of farm C. Water protection areas are often allocated where these soils occur.

All three farms' biogas plant digestate is recycled and used on the fields. Since farm A's biogas plant obtains biomass from other farmers and the digestate has to be subsequently transported over a long distance to the suppliers again, a part of farm A's digestate is separated into a liquid and a solid phase. The liquid fertiliser is recycled in the nearby fields, while the solid phase is used to fertilise distant fields.

All farms use pesticides for weed, diseases and insect pest control. Farm B has an above-average input of pesticides on its organic soils. A high mineralisation rate of organic soils leads to plants that are oversupplied with nutrients. The crops are very susceptible to diseases, stem weakness leads to lodging and the high weed pressure reduces the crop yield.

The water and wind erosion susceptibility of all three farms is low. Only on a few of farm B's fields is the soil susceptible to water erosion. Water deficiency in summer is highest on farm B, but its fertile loam and organic soils have a high water storage capacity, which is counter to farm C's sandy soils with their low water storage capacity. Farm A has less water deficiency in summer due to the middle-mountain climate; however, on karst soils with low water storage capacity, early summer dryness can cause problems. The soil condition heterogeneity is reflected in the groundwater level, especially on farms A and B, where soils with low, middle and high ground water levels occur. Farms A and C cultivate their crops in water protection areas, while farm B borders on a water protection area. Furthermore, few of farm A and farm C's soils are under fauna and flora protection.

6.8.3 Implications for Sustainable Crop Cultivation Design on Model Farms

Most of the problems and challenges are due to the low crop rotation diversification. Two crops in a 2-year rotation is an undesirable situation. The minimum should be a 3-year crop rotation with three different crops to prevent crop-specific diseases and pests, humus degradation and soil compaction. The model farms' crop rotations often have a 4-year "rotation", but with only two crops (e.g., winter wheat, winter wheat, winter wheat, sugar beet; maize, maize, maize, rye). These rotations resemble a monoculture more than a crop rotation. The first aim should be to diversify the crop rotations.

Examples are given on how all the farms can optimise their crop rotations regarding their diversity, humus balance, yield stability and economical basis.

6.8.4 Examples of More Diverse Cultivation Concepts

Tables 6.6, 6.7 and 6.8 show the farms' crop rotations, humus accumulation/ degradation and the contribution margins before and after the reorganisation. Farm A needs most of its agricultural land for the biogas plant. Therefore, maize, some sugar beets and rye corn were previously used as fodder for the biogas plant. During the crop rotation reorganisation, high biomass production, well-designed crop rotations to improve the crops' yield and yield stability, and achieving a balanced humus-soil content to maintain or increase the soil fertility were very important (Table 6.7). The old crop rotations wasted humus and a humus-soil balance was only possible through external purchase of manure in keeping with cross-compliance regulations. The new crop rotations are well balanced due to the field grass production (field grass after triticale biomass cultivation and ryegrass undersown in maize). The humus content is balanced by means of cereal straw incubation from the grain production and the digestate fertilisation. With the new crop rotations, the crop diversity has been increased from 4 to 7. The new crop numbers per rotation are now much higher.

Owing to the well-designed crop rotations with more favourable pre- and post-crop combinations, positive effects are anticipated on the yield and yield stability. Positive effects on the yield were quantified by using schematic classification tables to calculate a farm's contribution margin (financial revenues) before and after the reorganisation. Classification tables are normally used in organic farming systems to plan crop rotations and to estimate the pre-crop effect on subsequent crops (Kolbe 2006). Karpenstein-Machan (2010) has exceeded Kolbe's (2006) classification table with many bioenergy crops. According to Kolbe, four rankings were established: very favourable, favourable, unfavourable and very unfavourable crop combinations. Crop yields of very favourable combinations show a 10 % surplus on the yield, favourable combination a surplus of 5 %, unfavourable combinations a minus of 5 %, and very unfavourable combinations a minus of 10 % on the yield.

Table 6.6 Crop rotations, humus accumulation/degradation and the contribution margins of farm A before and after reorganization

Farm A			
Old crop rotations		**New crop rotations**	
1. w.-rye/maize/sugar beet		1. w.rape/w.triticale-fieldgras/maize/maize-untersown/w.rye corn	
2. w.wheat/maize/maize/maize		2. w.triticale-fieldgras/maize/sugar beet/summer wheat(corn)	
Cultivation area	**208** ha	**Cultivation area**	**208** ha
Maize	134 ha	W.rape	30 ha
Sugar beet	31 ha	W.triticale/fieldgras	44 ha
W.rye	27 ha	Maize	74 ha
W.wheat	14 ha	Sugar beet	14 ha
		W.rye	30 ha
		S.wheat	14 ha
Crops/farm	4	**Crops/farm**	7
Crops/rotation	2 and 3	**Crops/rotation**	5
Humus/accumulation/degradation in kg C/ha/a			
Old crop rotations		**New crop rotations**	
Crop rotation 1	-712		90
Crop rotation 2	-496		-14
Contribution margin in Euro/farm			
	Before	**After**	
Winter rape		15,495	
Triticale and fieldgrass		26,400	
Maize	54,806	33,300	
Sugar beet	36,898	18,354	
Winter rye	10868	12,000	
Summer wheat		5,364	
Winter wheat	7,953		
Total	**110,525**	**110,913**	

To quantify the crop combinations' effects on the crop yield, numerous crop rotations trails have been undertaken over the last decades (for the results, see Gliemeroth 1964; Klapp 1967; Könnecke 1967; Brouwer 1972; Bachthaler 1979; Baeumer 1990; Christen 1997, 2001). The contribution margins of the old and new crop rotations were calculated, using a farm's averaged crop yields and the exceeded classification table to adjust the crop yield to the crop rotations. The market prices of the last 5 years (2007–2011) were averaged to avoid market volatility affecting the results too much. Farm A's cultivation shows that the new, more sustainable and more diverse crop rotations are economically comparable to the older crop rotations. Through the crop rotation reorganisation, further positive effects, for instance, lower pesticide input and lower fuel energy demand during soil cultivation are anticipated due to the improved soil structure.

Table 6.7 Crop rotations, humus accumulation/degradation and the contribution margins of farm B before and after reorganization

Farm B			
Old crop rotations		**New crop rotations**	
1. Maize/maize/s.wheat		1. W.triticale-fieldgrass/maize/summer wheat	
2. W.wheat/w.wheat/w.wheat/sugar beet		2. S.oats/w.wheat/w.wheat/sugar beet	
		3. Silphie (perennial crop)	
Cultivation area	**253 ha**	**Cultivation area**	**253 ha**
W.wheat	134 ha	W.triticale/fieldgras	13.3 ha
Sugar beet	71 ha	Maize	13.3 ha
Maize	25 ha	Summer wheat	13.3 ha
Summer wheat	15 ha	W.triticale corn	50 ha
W.rye	8 ha	W.wheat	50 ha
		Silphie	13 ha
Crops/farm	4	**Crops/farm**	7
Crops/rotation	2	**Crops/rotation**	3 and 4
Humus/akkumulation/degradation in kg C/ha/a			
Old crop rotations		**New crop rotations**	
Crop rotation 1	-242	Crop rotation 1	268
Crop rotation 2	-60	Crop rotation 2	224

Contribution margin in Euro/farm	**Before**	**After**
W.wheat	78.256	78.100
Sugar beet	83.354	58.700
S.oats	0	19.950
Maize	13.325	7.767
S.wheat	8.445	8.246
TC-fieldgrass	2.400	3.990
W-rye	0	0
e.g. Silphie	0	3.900
Total	**185.780**	**180.653**

Farm B cultivates bioenergy crops on only 15 % of its farmland, because this farm operates the biogas plant in cooperation with three other farms. Its bioenergy crops can thus be mixed with food crops. Approximately 40 ha of the arable farm soils are high-yielding organic soils. For climate protection reasons, it would be better to convert these soils to wet grassland again to avoid further humus loss (see Chap. 7). However, this would imply high reductions in the farmers' income. A compromise could be the cultivation of a perennial crop such as Silphie, which needs no further soil cultivation after planting. Unlike the annual crop cultivation, this would reduce the humus degradation. In own trials, Silphie reached high biomass yields similar to the maize yield (Karpenstein-Machan, unpublished). Further investigations were necessary to evaluate the opportunities and risks for Silphie in organic soils.

Table 6.8 Crop rotations, humus accumulation/degradation and the contribution margins of Farm C before and after reorganization

Farm C				
Old crop rotations			**New crop rotations**	
1. Maize/w.barley/w.triticale			1. Maize/w.triticale-fieldgras-leg/ Maize/w.wheat/maize/w.rye corn-phacelia	
2. Maize/maize/maize				
Cultivation area		**92 ha**	**Cultivation area**	**92 ha**
Maize		58 ha	Maize	46 ha
W.wheat		15 ha	W.triticale-Fieldgrass-legume	15 ha
W.triticale		19 ha	W.wheat	15 ha
			W.rye corn	15 ha
Crops/farm		3	**Crops/farm**	6
Crops/rotation		3 and 1	**Crops/rotation**	6
Humus/accumulation/degradation in kg C/ha/a				
Old crop rotations			**New crop rotation**	
Crop rotation 1		61	Crop rotation 1	54
Crop rotation 2		-816		
Contribution margin in Euro/farm	**Before**		**After**	
Maize	23,722		22,126	
W.wheat	8,415		8,602	
W.triticale	4,465		0,000	
W.triticale-Fieldgrass-leg	0,000		4,600	
W.rye corn	0,000		3,971	
Total	36,602		39,299	

In this example (see Table 6.7), some of the organic soils were allocated for the cultivation of Silphie. Two crop rotations were designed, one with mostly energy crops and one with food crops. Biomass triticale, followed by field grass is a substitute for maize cultivation and stabilises the humus balance. The following maize is thus in a better rotation position, allowing the anticipation of higher yields. Summer wheat completes the rotation, which ensures appropriate seed time for the following winter triticale.

The food crop rotation starts with summer oats. Oats is a very good pre-crop for winter wheat, because it does not multiply “take-all” cereal diseases (Gaeumannomyces graminis var. tritici). In a cereal crop rotation, oats has the same positive effect as a crop shift. This allows a 2-year cultivation of winter wheat. Sugar beets at the end of the rotation represent a second crop shift. The late harvest of sugar beets seldom allows adequate winter crop seeds; therefore, summer oats should ideally follow sugar beets. After the reorganisation, the crop diversity has increased from 4 to 7 crops per farm, while the crop rotation diversity has increased from 2 to 3 and 4. The humus balance now tends towards humus accumulation, which is especially important in organic soils.

As the contribution margin shows, the more sustainable use of organic soils with a perennial crop sometimes leads to farmers suffering income losses. The calculated margins for Silphie in Table 6.7 are based on 15 t dry matter yield and the presently very high costs of young plants and transplantation of about 4,400 euro/ha. More cultivation experiments on a farm scale, knowledge of plant yields and long-term yield stability are necessary to verify and enhance the margins. In particular, seed quality should be improved to avoid the high nursery and transplantations costs of Silphie cultivation. If these breeding problems are solved, Silphie could be a more climate-friendly alternative to annual crops in organic soils.

Farm C needs nearly all its arable land for fodder for its dairy cattle and the biogas plant, which is operated in cooperation with others. As fodder for dairy production, maize reduces the cultivation area for maize as fodder for the biogas plant. Therefore, the farmer cultivates maize on large areas in monoculture. To fulfil cross-compliance regulations, he cultivates the winter crops wheat and triticale on a small scale. With the new 6-year crop rotation, the farmer has many options for feeding his dairy cattle and the biogas plant (see Table 6.8). Winter triticale harvested at the milky stage is very suitable as fodder for the biogas plant. After triticale, a mixture of field grass and alfalfa follows in the same year. Two harvests are possible, the first in the autumn and the second in early May. The mixture of field grass and alfalfa can be utilised either as dairy fodder or for the biogas plant. Maize is now cultivated three times in the crop rotations and is still the dominant crop, but it is now integrated into the rotation with six other crops/catch crops. Owing to maize's better position in the crop rotation, higher yields and a better soil structure are anticipated. The humus content is now in balance and the contribution margin has been increased by approximately 7 %.

6.9 Conclusion: Implementation Opportunities

New crop rotation proposals were developed with the model farms' farmers. On parts of the farmland, new crops and cultivation concepts – for example, undersown seeds, crop mixtures, perennials and herbicide-free buffer strips (Silphie, wild herbs) – were tested. As their experience increases, the farmers plan to reorganise their farms step-by-step to include more sustainable concepts. To increase the implementation opportunities on the model farms and to allow other district farmers to share in this experience, information tours have been organised to these farms (Karpenstein-Machan in Schmuck et al. 2012). Members of nature protection organisations, district politicians, administration officials, journalists and village inhabitants have taken part in these tours. The meeting of people from different groups enriches discussions, since the topics are broader than just cultivation questions, and increases understanding of the different positions. Furthermore, if farmers acquire good media coverage, this increases their motivation to pioneer and establish more sustainable cultivation concepts. Furthermore, on the district scale, energy farmers and the district landscape management can be motivated to work together to support sustainable landscaping, especially regarding the planning and implementation of new energy plants (e.g., biogas plants, woodchip-firing plants and ethanol plants). Different societal groups can thus influence the process and support the development of integrative energy crop cultivation and integrative bioenergy regions (see Chap. 11).

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