6 Multifunctional Crop Rotation (MCR)

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6.1 Problems in crop rotation

6.1.1 Definition

Crop rotation can be defined as the ordered succession of crops that are repeated every certain number of years (Urbano & Moro, 1992). The Multifunctional Crop Rotation (MCR) plays a central role as major method both to preserve soil fertility and crop vitality. The preservation of soil fertility means to take into account its physical, chemical and biological properties. Crop vitality is the basis for sustaining quality production with a minimum of inputs (pesticides, machinery, fertilisers and support energy).

6.1.2 Current situation

European agriculture currently has a complex of problems, mainly caused by the one-sided development of farming with the emphasis on intensification and focusing almost exclusively on economic results. In this way, certain vegetable farming areas have become real "industries of farming production", with monoculture practices or rotations of two years in the best cases. Many areas with intensive vegetable growing throughout Europe have become "dependent" on the use of soil disinfectants such as methyl bromide. This causes serious effects on the environment and makes the growing of crops increasingly expensive. Moreover, these soils become commonly exhausted and useless in the meanwhile.

The levels of yield decline if the same crop is grown in the same field for a long time (monoculture systems). The main reasons are that roots always explore the same soil layers and demand the same proportion of different nutrients ("exhaustion" of soil). In this way, the continuous monoculture is the main cause of the high pressure and fast propagation of harmful species of weeds, pests and diseases.

On the other hand, as many of the pesticides used will soon be forbidden, the possibilities to protect the crops decrease in conventional farming systems, and therefore, the innovation in these systems is increasingly required. Crop rotation plays a central and crucial role in the basic design of sustainable farming systems. It is not only the major weapon to prevent and control pests, diseases and weeds, but it is also the basis for maintenance and improvement of soil fertility. In organic systems, correction with pesticides is limited as only few pesticides are allowed.

For farmers, the main objective of crop diversification is to obtain a higher profitability both in the mid-long term and in the short term. A well-designed crop rotation may guarantee more stable economic results because low prices for one crop can be compensated by higher prices for another. However, the market is increasingly oriented to buying produce in specialised production areas from specialised farmers. Therefore, the crop diversification, the implementation of the MCR requirements, contracting and taking part in a crop program, are compromised by the commercial sector.

6.1.3 Policy, legislation and label guidelines

Although there is no legislation in the EU for crop rotation, legislation for nutrients and pesticides does influence the set up of crop rotation. Limits on the use of nitrogen and phosphorus make it unattractive to have rotate crops with too high of a demand for nitrogen and phosphorus. The prohibition of certain pesticides can limit the choice of crops in certain regions due to a higher risk of certain pests and diseases, and insufficient possibilities to control them.

Integrated production

In label guidelines, there are only general and vague crop rotation guidelines. The new EUREP-GAP protocol, concerning Good Agricultural Practices for the year 2001, is a first attempt to standardise IP-labels throughout Europe. This protocol handles the topic of MCR in a general way and is, therefore, sensitive to different interpretations. Effectively, in this protocol, it is required that "growers must recognise the value of crop rotations and seek to employ these whenever applicable"; furthermore, "where rotations are not employed, growers must be able to provide adequate justification". Likewise, crop rotations, use of resistant varieties and the choice of appropriate crop for the location are some of the preventive measures included in a list of "basic elements of crop protection".

In the Netherlands, there are legal guidelines on cultivation intensity and choice of variety for some crops (potato, flower bulbs) if the soil is infected with specific soil-born pathogens. In addition, the regulations on soil disinfection, which is only possible once every five years and only with a permit, make longer crop rotations inevitable. In integrated guidelines, a four-year rotation is seen as the minimum.

In Italy, the integrated protocols for field-grown vegetables in Emilia-Romagna region are divided into two types: Integrated protocols for the application of 2078/92 EU rule (now 1257/99 UE rule) and integrated protocols for Emilia-Romagna Guidelines. The first one requires a minimum rotation length of four years; no stubble seeds are allowed and a minimum of three different annual crops has to be grown every four years. The Emilia-Romagna Guidelines fix a minimum interval between two cycles of the same species (variable from 2 to 3 years), but not required with to respect to rotation.

In Spain, IP Regulations in the region of Murcia sets a maximum frequency on certain regulated crops (melon, broccoli, cauliflower, celery and lettuce), and chemical soil disinfections are not allowed. Other label protocols only recommend the "long crop rotations" and forbid the monoculture of annual crops (NATURANE and AENOR guidelines for controlled production (UNE-155001-1)).

In Switzerland, according to the guidelines for integrated vegetable production, the intervals between the main crops have to be at least 24 months (crops grown more than 12 weeks are defined as main crops).

Organic production

Most labels for organic production in EU are based on EC 91/2092 revised by regulation EC 01/436. In addition, the directions for the MCR can be defined as subjective. According to this regulation, it is required by the "appropriate multi-annual rotation programme" to maintain the soil fertility as a first measure to control pests, diseases and weeds. In the same way, certain crops such as green manures, legumes cultivation and deep-rooting plants must be included in this rotation. The general term "multi-annual" (that is length more than two years) and the lack of other specifications such as number, sequence and frequency of crops, and species composition will surely lead to different interpretations in the different EU-countries.

In the Netherlands, the guidelines for organic DEMETER-label are more detailed. These guidelines indicate a maximum of 50% of the area can be planted with crops that have roots and a minimum of 16% of the area can be planted with green manures (crops that are not harvested). In addition, crops that demand a high level of nitrogen should be alternated with crop that have lower nitrogen needs.

The guidelines for organic vegetable production in Switzerland require a balanced and diverse crop rotation.

6.2 Theoretical background

6.2.1 Objectives

Crop rotation is the term used to express that crops are grown over time in a very specific order (for definitions of terminology, see Table 6.1). After a number of years, (length of the crop rotation) the cycle will be repeated. The crops grown in one year on the available area of a farm make up the cropping plan. If the crop rotation is consistent and unchanged, the cropping plan is the same every year. Crop rotation has a temporal aspect: crops are grown over time in a specific order (succession of crops in time); and a spatial aspect: the crops grown this year and their division over the available space. The interaction between spatial and temporal aspects can be used to strengthen the crop rotation concept. Rotating the crops on the available space is done so that a given crop is never grown next to a field with the same preceding crop (spatial crop rotation). This helps to prevent semi-mobile pests and diseases from surviving from one year to the next.

Table 6.1 Crop rotation terminology

crop rotation	Carefully designed sequence of crops in which succession is highly advantageous.
cropping plan	The partitioning of crops over the available area in a given year, often represented as the percentage of the area for each crop (space).
crop sequence	The succession of crops in time on one field in particular (time).
crop frequency	The frequency of growing the same crop on the same field, usually expressed as once in a number of years. For example: 1 out of 3, 1:3, meaning once every three years.
crop rotation block	One year of the crop rotation succession and the crop(s) in that specific crop rotation year.
agro-ecological layout of the farm	The layout of the farm over the available space, the partitioning of the area in fields, their shape and size, the spatial crop rotation and the ecological infrastructure of the farm.
ecological infrastructure	The network of natural and specifically managed areas on the farm to provide habitats and (transport) corridors for flora and fauna.
field adjacency	The proximity in space of the fields composing the crop rotation.
adjacency of subsequent blocks	The proximity, in both time and space, of the same crop or between crops belonging to the same group. An attempt is made to avoid cultivating a crop on a field adjacent to one in which the same crop has been cultivated the previous year.

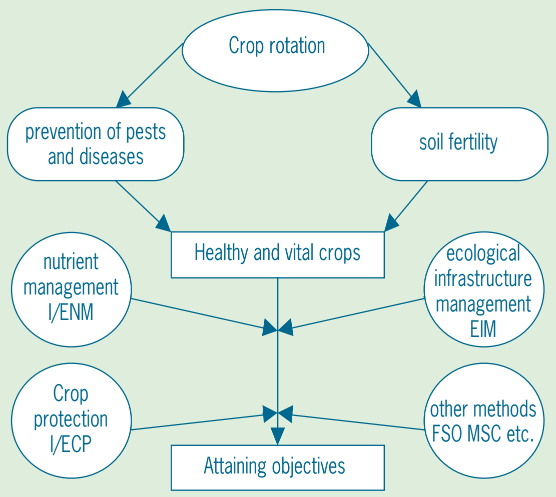

Figure 6.1 Actual results of objectives as a function of crop rotation and other methods

The main objectives of MCR are summarised as follows (Urbano & Moro, 1992):

1. To reduce the economic risk due to a greater crop diversity.
2. To avoid the exhaustion of soil as different species have different nutritional needs and colonise different soil layers.
3. To achieve a stable equilibrium of microbial life in soil by increasing the diversity or colonisation.
4. Reduction of pests and diseases, either aerial or soil-born.
5. Reduction of the competition with weeds.
6. Reduction of the seasonal employment on farms.

6.2.2 Relation with other farming methods

Crop rotation is the basis of any sustainable farming system. Its influence on different factors in the farming system such as soil fertility and soil health makes the MCR method essential to meeting most of the objectives. A poor design or the wrong choice of crops in the rotation can lead to serious increase in shortfall. Other methods support MCR in reaching the target values (Figure 6.1). The specific effect of the crop rotation on the different objectives is very much dependent on the farm, that is to say on the total set of main farming methods.

Farming methods discussed in the other method manuals are given in Table 6.2. Other methods that have not been used in the VEGINECO project are Minimal Soil Cultivation (MSC) and Farm Structure Optimisation (FSO) (see Chapter 2.3.3 and Annex 3 for a short description of all farming methods). All methods influence each other, and they must be used together to make farming systems as sustainable as possible.

6.2.3 Themes related to MCR

As the central method, crop rotation has a relationship with all the themes within the prototyping farming system.

- Crop rotation plays a central role in maintenance and improvement of soil fertility (sustainable use of resources).
- The better fertility and health of the farming soil obtained with the crop rotations will allow a lower use of pesticides and mineral fertilisers (“Clean environment”).
- The same reasons will help to obtain a better quality-production and farm continuity. The latter is also influenced directly by the different growing costs depending on the chosen crops. Indirect influence through the potential reduction of expenses in crop protection and nutrient management.
- MCR also influences the theme of “farm nature” because biodiversity is increased with the crop diversification (both because of the crops and their associated flora and fauna).

Crop rotation influences all themes; but at the same time,

Table 6.2 Effect of crop rotation on the design of different farming methods

Method	Influence of crop rotation on the design of other methods
Crop protection	The choice of crops and/or cultivars will influence crop protection due to: • their genetic heterogeneity in time and space, • their capacity to reduce or control harmful species, • the tolerance or resistance of cultivars that are optimally used, • effects on the control of weeds (crops capacity to cover soil and how fast they develop).
Nutrient management	The chosen crops have different nutritional needs and this influences nutrient management (crops choice and order). Growing crops with different root systems will allow that every crop explore different soil layers, avoiding soil exhaustion. Likewise, the MCR design will influence in the supply of organic matter.
Ecological Infrastructure Management	Interactions between the ecological infrastructure and crops must be taken into account, mainly in the contact areas.

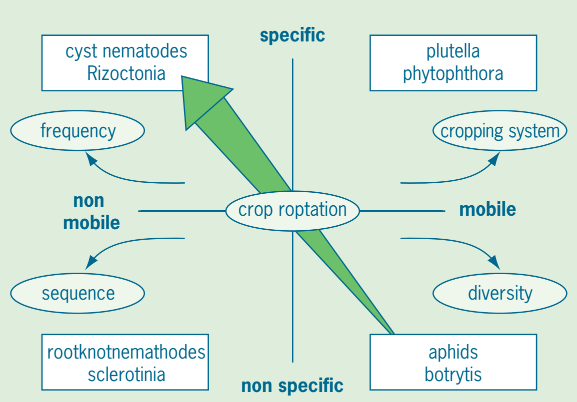

Figure 6.2 Crop rotation in relation to mobility and specificity of pests and diseases

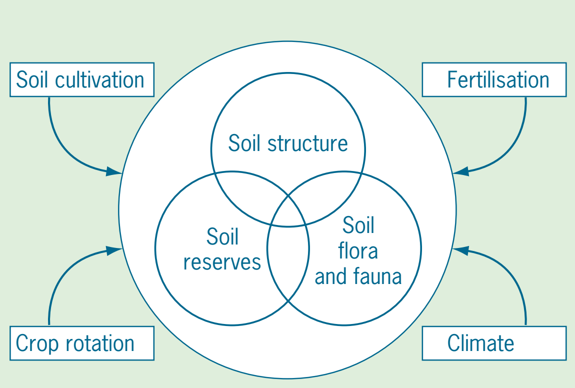

Figure 6.3 Soil fertility complex in relation to external factors

the themes are influenced by other methods. The influence of crop rotation on a theme can be variable depending on the specific agro-ecological conditions of the different farming areas. For example, crop rotation will have a greater influence on environmental effects of pesticides in areas with short rotations where soil disinfections are commonly practised.

The relationship between MCR and the other themes will be much stronger in the organic systems because the opportunities to correct any problem are usually fewer. For instance, if a crop is grown in a period with high pest or disease pressure, it is more difficult to control it in organic systems than in integrated systems.

6.2.4 Influence of crop rotation on prevention of pests and diseases, and soil fertility

Influence on prevention of pests and diseases

Figure 6.2 depicts the role of crop rotation for the prevention and control of pests, diseases and weeds (after Vereijken, 1994). Pests and diseases are placed along two axes. On the x-axis, the organisms range from non-mobile, mostly soil-born to very mobile, mostly airborne. On the y-axis, the organisms range from very specific (mostly monofageous) to non-specific (mostly polyfageous). Crop rotation is of increasing importance as the line moves from the lower right corner to the upper left corner.

1. Specific and non-mobile pests and diseases (upper, left corner): mostly soil-born, such as the cyst nematodes and Rhizoctonia spp. Low crop frequency of the organisms favourite crop, is usually sufficient to suppress these pests and diseases. The use of resistant and tolerant cultivars supports this approach.
2. Non-specific and non-mobile pests and diseases (lower left corner): this concerns also mostly soil-born pests and diseases like Sclerotinia and root knot nematodes. The composition of the crop rotation is important; which crops are grown and in which sequence. Support for this approach can be found in the cropping systems (sowing or planting date, cultivar choice) depending on the organism involved.
3. Specific and mobile pests and diseases (upper, right corner): concerns organisms such as Plutella and Phytophthora: classical crop rotation is not helpful here, although spatial crop rotation can contribute to the control of semi-mobile, specific pests and diseases. Other solutions might be found in the cropping systems (cultivar choice, sowing or planting date, crop structure). Control measures during cropping might be necessary.
4. Non-specific and mobile pests and diseases (lower, right corner): many pests and diseases. Crop rotation is of no use, although crop diversification might be helpful, especially when applied on a regional scale (diversification in space). Again, the design of cropping systems can contribute to prevention.

In these two last cases, natural predators might fulfil this function or pesticides will have to be used. Natural predators must be stimulated by a carefully designed and managed ecological infrastructure on the farm that offers year round shelter and food (functional biodiversity). Also factors such as shape and size of fields, and the total farm (parcel) layout become increasingly important: the agro-ecological layout of the farm. The control of pests and diseases is treated in the Integrated and Ecological Crop Protection manual (VEGINECO project report no. 4).

Influence of crop rotation on soil and nutrient management

Crop rotation plays a central role in maintenance and improvement of soil fertility in the broadest sense. This includes the physical (structure), biological (soil flora and fauna, positive and negative), and chemical factors (nutrient reserves and organic matter composition). The interaction between crops, soil, cultivation, fertilisation and weather determines the soil fertility, which is dynamic in time and space (Figure 6.3). The specific objective is to keep

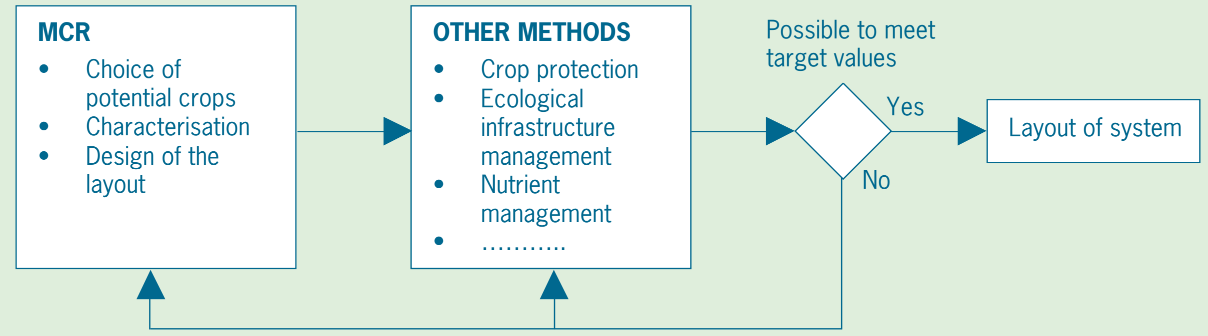

Figure 6.4 Process of designing farming methods and position of MCR in the design process

nutrients and organic matter reserves at agronomically desired levels and to minimise energy use.

Other factors such as the level of soil coverage by crops, the input of organic matter by crop residues contribute to the sustainability of soil fertility. Different characteristics and capacities of selected crops will define how long the soil is covered during rotation and protect it from erosive agents. The amount of crop residues in the rotation, which form a source of organic matter, is determined by the crops' characteristics.

6.3 The MCR design

6.3.1 The design process

The design of a crop rotation refers to the selection of crops and placing them in the correct order. The analysis, diagnosis and the objectives will provide some initial direction to the design process. For the design of a consistent MCR, three main steps have to be taken:

1. *Selection of potential crops* and their characteristics (Chapter 6.3.2).
   The procedure of this phase would be:
   - Set up a list of potential crops.
   - Characterisation of crops in their potential role in the MCR taking into account biological, physical and chemical aspects.
   - Choose main, secondary and tertiary crops.
2. *Setting up a crop rotation* with a maximum of positive and a minimum of negative interactions between the crops, which meet a multi-functional set of demands (6.3.3). First, the rotation length and number of crops in the rotation should be determined; secondly the order of crops is fixed.
3. The *design of an optimal agro-ecological layout* of the system in time and space (Chapter 6.3.4). There are factors concerning the layout such as field adjacency, field size and shape, field length and width, adjacency of subsequent crop rotation blocks (see Chapter 6.2.1, Definitions and Objectives), or the ecological infrastructure that ensure a maximum contribution of the MCR to the prevention of pests and diseases (Vereijken, 1994).

Once the MCR has been designed, all other methods (crop protection and nutrient management, mainly) must be reviewed. The review checks whether they fit properly into the designed MCR and whether the objectives have been properly set. In the case of a negative answer, the strategies of the 'other methods' have to be reconsidered or new MCR has to be designed. If all the methods fit together properly, the farming system can be laid out (Figure 6.4).

Completing the cycle of the prototyping methodology, the layout of the system leads to test and, if necessary, improve the prototype, by improving the methods (see Chapter 6.3.5).

6.3.2 Choice of potential crops

Selection of crops based on environmental and farm conditions

The selection of potential crops that will be in the MCR will be based on many different factors that can be divided into two groups:

1. Environment conditions.
2. The farm context (social, economical and commercial conditions).

The first selection is made of crops, which are adapted to the agronomic and climatic conditions of the area. Regarding climate, the most important aspects could be (Urbano & Moro, 1992):

- frequency, direction and intensity of winds,
- average temperatures throughout the year,
- dates of first and last frosts, if they occur,
- rainfall and its seasonal distribution,
- hours of sunshine and evapo-transpiration,
- possibility of hailstorms and
- occurrence of dew and snow.

The climatic conditions will be especially important to determine the best periods to grow a crop.

In relation to soil, the crops have to fit the biological, chemical and physical properties of the soil. Each soil

has a *different growing vocation*. Selected crops will have to be adapted to soil characteristics such as surface depth, acidity and structure, as well as fertility.
Once this first selection is made, there are certain preconditions to be considered so that a second crop selection will be made from the first list. These preconditions include: the characteristics of the farm, knowledge and capabilities of the farmer and advisors, and the trade and agricultural trends in the area. Crops that have no market potential at all are removed.

Characterisation of crops
After this second selection, the selected crops are characterised. As many crop characteristics as possible are included (see examples in Tables 7.2, 8.2 and 9.2). The table with crop characteristics will be adjusted to regional settings and to the objectives of the project: extra characteristics can be added while others can be removed.
The importance of certain characteristics can be different per region, depend on the objectives or the farming system type.

The organic and integrated farming systems differ in the weight that particular factors play in choosing the main crops in the rotation (different criteria). In the integrated systems, profitability and market possibilities are more important than in the organic systems. In the organic system, weed control, the availability of nitrogen, and the prevention of pests and diseases are more important factors.

The sustainability of any farming system will depend mainly on the economic results. Although a well-organised crop rotation is very convenient agronomically and can improve economic results in the long term, it will not be feasible if it is not profitable in the short term as well.
Gross margin, input costs and the input of manual labour can be used to indicate the economic potential. The level of profitability and marketability of the different crops can be used to define the hierarchy in the rotation.

Agronomic, physical, morphologic and organic characteristics of crops are taken into account. Before organising the definitive rotation, it is necessary to know the length of the growing period of each crop. It is also essential to distinguish different botanic families because of their different sensitivity to pests and diseases, and their different influence on soil fertility. Influence on soil structure and sensitivity to poor structure is important. Root crops often leave a poor structure behind after harvest, while intensively rooting crops can improve the soil structure.

Concerning weed control, all crops have different capacities to cover the soil and how much mechanical control can be utilised during the growing season. The supplemental use of pesticides for each crop is useful as well.
The need for continuous treatments against certain pests or diseases can have large negative environmental effects. In some cases, it may be necessary to check whether the required pesticides are authorised or not for specific crops. From an environmental point of view, it will be also critical that the MCR will not only be composed of crops that require a high number of pesticide applications.

Main and secondary crops
The role of a crop in the MCR can be derived from the characterisation. The team (crops in the rotation) should be more than the sum of the players. Some of the players can only score well, if others (preceding crops) carefully prepare the performance and in addition to defence against attacks (pests an diseases). The target of the crop rotation is offering appropriate, optimal and homogenous conditions to all the players in the team, but especially to those considered as "stars" (main crops).
It is advisable to identify more crops than necessary and to consider substitutions in order to prevent certain unexpected problems (commercial, environmental or organisational).

Crops can be classified in three different groups (main, secondary and tertiary group). Main crops can be defined as the most relevant crops in the MCR with especial attention to profitability, labour and mechanisation needed. Tertiary crops are included in the MCR to improve conditions for the main crops in the system and to improve overall system performance. Tertiary crops can improve soil structure, prevent leaching and reduce pressure of pests and diseases. Profitability is not their main priority. Examples of tertiary crops are green manures and cereals. Secondary crops are used to fill the crop rotation. They need to contribute to the profitability and to be compatible with the main crops.
After the classification, the definitive crop selection is not yet made, as interactions between crops still need to taken into account. The definitive selection takes place in the next step, the planning of the rotation.

6.3.3 Planning the crop rotation
During the MCR planning stage, the proper sequence of the different crops in the rotation must be set. It may take several attempts to set up the whole crop rotation. This is the most difficult and complex step in planning the rotation.

Defining the length of the crop rotation and number of crops
The main crops and the type of farming system (organic or integrated) are the two most important factors that determine both the length of the MCR as well as the number of crops in the rotation. In fact, the minimum frequency of the main crop(s) must be determined to prevent decreases in yield due to nutrient or phyto-pathological problems. If several main crops are selected for a specific MCR, the rotation length is based on the crop with the lowest frequency of occurrence in the rotation. Although

frequencies are difficult to determine for most crops, the minimum rotation length is at least four years. In organic farming, this may be longer (≥6 years) because the methods in crop protection and nutrient management are much more limited.

For example, under the Dutch conditions, potatoes should be grown maximally every four years to prevent nematode infestation in the potato crop. As in organic systems, the tools for control are much more limited, a margin of two years is set as a preventive measure. Then, the length of the MCR would be four years in integrated farming and six years in organic farming. Crops can occur twice in a rotation when the maximum frequency is equal to or higher than half the longest frequency in the rotation. For example, if the maximum frequency of wheat is once every two years. In combination with potatoes, wheat can be grown twice in an integrated four-year rotation.

In vegetable crops, especially in the Mediterranean region, more than one crop can often be grown in a year. This means that the number of crops selected can be as twice as high as the number of years in the rotation. Sometimes it is possible to have two or three plantings of the same crops, in a sequence. Then the frequency rule is applied to the all of the crops.

Planning the crop rotation: placing the crops

The crop grown in a specific year of the rotation (crop rotation block) will grow in the conditions created by the preceding crop and in its turn will contribute to the conditions for the next crop, as illustrated in Figure 6.5. In this way, every crop rotation block has its own identity and its own function: for example, restoring soil fertility, utilising the high nitrogen reserves from a preceding grass/clover year or offering excellent opportunities to control weeds before a crop that is not as competitive. The sequence in a model facilitates the choice of crops when changes have to be made in the crop rotation.

It can be necessary to include more than one crop in one crop rotation block. Then, crops should be chosen with the same characteristics to make as little difference as possible between the starting times of the following crop.

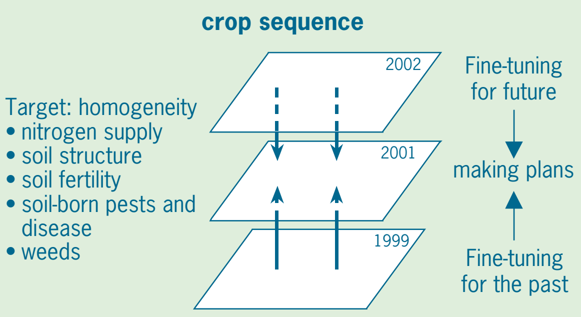

Figure 6.5 Planning of the crop rotation includes looking backwards and forwards in time

It may be important to set up several rotation variations or substitute crops with equal or similar characteristics to those to be substituted, in case it is necessary because of labour capacity, market demands or any other reason. For example in the case of the Netherlands, two main crops, iceberg lettuce and Brussels sprouts, were selected as a basis for various alternatives with different secondary crops.

Main crops are placed first, followed by secondary and tertiary crops. Several criteria must be taken into account when planning the MCR concerning:

1. soil fertility,
2. botanic families, phyto-pathological groups and harvested part of plant (leaves, grains, roots),
3. competitiveness of crops with weeds and volunteer plants,
4. cultivar choice,
5. crop succession,
6. labour demands.

Soil fertility

Crop rotation interacts clearly with nutrient management because of the characteristics and specific role of crops and crop sequences in this process. This interaction is more important in organic systems because (mineral) fertilisers cannot be used. Therefore in organic farming systems, it is important to give more priority to crop properties as nutrient demand, efficiency of use in time and space, nitrogen fixation, amount and composition of organic residues, and nutrient transfer to the following crops.

Nitrogen fixation is especially important in the design of a rotation because nitrogen availability can often be limiting although inputs of phosphate and potash are already sufficient. Including nitrogen fixating crops or green manures can contribute dramatically to nitrogen availability.

In current organic farming practices, nutrient management is often not adapted to the specific limiting conditions and targets of sustainability. Maintaining an appropriate level of soil fertility does not mean increasing it to a level that is ecologically damaging, and using organic manure does not mean that nutrient losses are limited. Proper planning of crop rotation in accordance with nutrient management will help in adapting to these demands. Raising the organic matter input by choosing crops with large amounts of crop residues can improve soil structure. Deep and intensive rooting crops can improve physical soil properties as well.

Crop mix

The influence of MCR on pests and disease was already discussed in Chapter 6.2.4. However, crop rotation layout is as important as the choice of crops for the success of crop protection. Not only the frequency limit for crops is important, but also the alternation of crops with different functions (leaf, root, flower, fruit) because they differ in susceptibility to pests and diseases.

Soil cover and weed control
Due to its importance in weed control, the capacities of crops to cover the soil and their rate of development must be considered when planning the rotation. Some crops are considered as "dirty" (non-competitive to weeds) and others as cleaner (competitive). For instance, onion is appropriate to follow cauliflower because the latter normally leaves a very low seed bank due to its high speed of development and high capacity to cover the soil.

Cultivar choice
Appropriate cultivars should be selected during the planning of the MCR. Cultivars are commonly selected on expected quality and yield. In addition, susceptibility to pests and diseases, and nutrient demands should be added as criteria. The choice of tolerant or resistant cultivars is preferred, especially in organic systems. This can mean a somewhat lower productivity. Between cultivars, there can be significant difference in nutrient demands. In organic systems, nutrient availability is often limiting and an appropriate cultivar choice can lower nutrient demands.

Crop succession
It is also very important in the design of the rotation to be aware of harvesting, planting and time between crops. For instance, tilling depends on soil humidity conditions and sufficient time has to be taken to do false plantings if necessary. Another important point is optimising the time between crops to maximise the nitrogen availability from mineralising crop residues.

Labour demands
The labour demands of the crops in the rotation should be tuned to one another. Labour peaks for one crop should coincide with low labour demands for other crops.

The resulting MCR (and their alternatives) should be as superior as any other crop rotation due to good short-term economic results and optimum fertility conditions of the soil in the long-term with minimum need of external inputs.

6.3.4 The design of the agro-ecological layout

When the rotation is planned, the layout of the MCR has to be designed in the agro-ecological context of the farm. The first step of the layout is to divide the farm into as many fields as the previous years. Next, the crops have to be divided over these blocks in such way that field adjacency is maximal and adjacency of subsequent blocks minimal (see Table 6.1 for definitions). Maximum field adjacency is desired to obtain an agro-ecological unity as a prerequisite for an agro-ecological identity. Soil and climatic conditions should be as homogeneous as possible. However in practice, only a small number of farms have adjacent fields. In addition, different conditions between fields are common. When this occurs, it may be advisable to set different crop rotations for different fields according to their conditions to maximise the performance of the system.

Planting or seeding crops adjacent to subsequent blocks should be prevented to prevent harmful semi-soil-born species from following their host crop during the crop rotation (Figure 6.6) (Vereijken, 1994). This can be more important when crops in the MCR are planted for two years or more because the same crop will be grown at the same time during a certain period in adjacent fields.

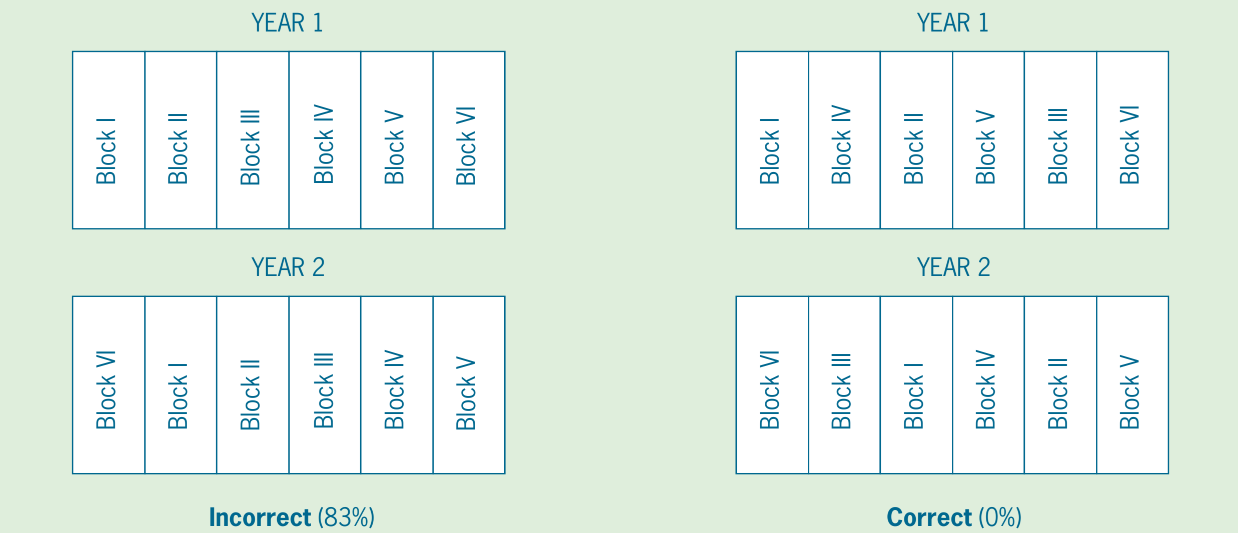

Figure 6.6 Examples of adjacency of consecutive blocks

The crop row distance is also an important element in the design of the layout, mainly for mechanical weed control. The distance must be adapted to the available machinery and tools.
The farm size and shape will also determine the length and width of blocks and, therefore, the influence the MCR layout. For instance, the narrower the fields are, the easier the pests and diseases can move between fields. Vereijken proposes for arable farming a field size of at least one hectare and field length/width ratio should be smaller than four.
In addition, the implementation of the ecological infrastructure (in quantity and in quality) will be largely influenced by these conditions. For instance, the small field size in Spain is a large obstacle for the creation of adequate natural areas because they can be obstacles for normal farming tasks.

Temporal aspects make the design of the layout even more complicated. Leasing land can also be an obstacle because it disrupts the necessary continuity over time that MCR requires to attain the proposed objectives. The crop rotation sequence should be continued on the same fields over the years. Commonly experienced difficulties are changes in crops or area per crop. This might be appropriate given the market conditions and opportunities. However, changes in crops should be done accordingly to the conceptual MCR model. Crops should only be substituted with comparable crops. Shifts in areas per crop from year to year threaten the homogeneity.

6.3.5 The review of the resulting prototype

The layout of the MCR along with the other methods implies testing and improving the prototype until the objectives have been attained. Because 'testing and improving' is the most laborious and expensive step, requiring at least a full rotation of the prototype on each field (at least 4-6 years), it will be crucial that all preceding steps have been followed with the greatest accuracy. Therefore, it is useful to take a critical retrospective view before laying out the resulting prototype (Vereijken, 1999). For example, checking incompatibilities of the MCR with the other methods used. If the resulting crop rotation contains a crop, which is grown in a period with high sensitivity to a certain disease or a virus, the rotation should be reviewed. The crop can be given another place or it can be removed from the rotation. Another example, often occurring in organic systems, is the replacement of a crop with a high nitrogen demand by a crop with a lower demand when nitrogen availability is limited.

The review of the prototype allows checking whether the desired results can be achieved for the parameters related to the method, or whether shortfall in any of them can be expected. The value of each parameter must be estimated. Estimations are based on literature and/or expert judgement. Estimations or calculations can be done on:

- Crop 'x' following crop 'y' can give a yield reduction/surplus of 5%.
- The effective organic matter input of the rotation.
- The average pesticide use in the rotation.
- The average economic value of the yield in the rotation.

Attention has to be paid to the benefits and strong points as well as the disadvantages in crop rotation. Crop rotation influences almost all parameters used to evaluate the farming systems (except those related to the 'Ecological Infrastructure Management'). However, in most cases, these parameters are more influenced by other methods. Therefore, MCR evaluation requires the determination of the relationship between possible shortfalls in parameters and the MCR design. This is often very difficult to point out. If shortfalls are due to the rotation design, obviously, re-design is necessary.

Chapter 4 explains which parameters are used and why these are chosen. In Table 4.7, the parameters used in the VEGINECO project are briefly defined. In Annex 2, a brief definition of these parameters together with the calculation procedure is given.

This chapter is the theoretical process in the design of a 'Multifunctional Crop Rotation'; it has been written with the experience gained from the farming systems of the VEGINECO project. Several of the steps and directions included in it are a consequence of this experience. Therefore, several of these directions were not followed in the first design of the MCR in all tested systems. This can be read in the following chapters, which present some practical examples of MCR design and results in testing and improvement.