2 Integrated and Ecological Nutrient Management

J.J. de Haan & F.G. Wijnands
Applied Plant Research (PPO), Lelystad, The Netherlands

2.1 Problems in nutrient management

2.1.1 Environmental and health/well-being problems

The overloading of seas, lakes, rivers and streams with nutrients (nitrogen and phosphorus) can result in a series of adverse effects known as eutrophication. Phosphorus is the important nutrient for eutrophication in fresh waters and nitrate is the important substance for salt waters. In addition, nitrate contaminates groundwater sources that are used for drinking water. Ammonia is an important source of acidification. High nitrate levels in drinking water causes high costs to purify the water. Finally, high fertilisation levels cause an increase in hardness of groundwater.

In the European Union, one can see these adverse effects in many regions. Agriculture is one of the main sources of these pollution problems. Although in the past ten years, nitrogen and phosphate emissions have been reduced and surpluses of nitrogen and phosphate have dropped by 25%, less than half of the fertiliser inputs are utilised by the products. The remainder, the mineral residue, remains behind somewhere in the environment. Agriculture is not the main source of phosphorus pollution in Europe. Households and industry are the largest contributors of phosphorus to the environment. However, in those parts of Europe with intensive agriculture, the contribution from agriculture approaches 50% of the total (http://www.eea.eu.int/).

Nutrients in ground and surface waters

The nitrogen surplus in the European Union between 1990 and 1995 remained stable at 60 kg ha^{-1}. Differences between countries were large. The nitrogen surplus in Portugal is below 25 kg ha^{-1} while the surplus in the Netherlands is over 200 kg ha^{-1}. In the Netherlands, vegetable production has high surpluses as well, although lower than average for agriculture. This large surplus is caused by very intensive production with high yields per hectare.

Large nutrient surpluses cause high concentrations of nitrogen in groundwater in many places. In the European Environment Agency's databases, it appeared that in half the groundwater sampling sites, the Drinking Water Directive guideline of 25 mg nitrate per litre was exceeded. Improvement is measured in coastal waters of the North Sea and Baltic Sea; nitrate concentrations fell by nearly half between 1985 and 1998. However, in some places, there were increases as well.

Since 1980, nitrate concentrations in major rivers in the European Union have remained constant (about three mg nitrogen per litre). There is no evidence that reduced application of nitrogen fertilisers to agricultural land has resulted in lower nitrate concentrations in rivers. Agriculture continues to be the main source of nitrate pollution in Europe (http://www.eea.eu.int/).

The reduction of phosphorus concentrations in major rivers in the European Union from above three mg l^{-1} to below two mg l^{-1} is mainly due to improved wastewater treatment and less phosphorus in household detergents, but not due to agricultural improvements. However, phosphate use in agriculture has declined between 1980 and 1995 by 38%. This reflects a growing trend within the European Union towards soil analysis, which assesses the soil's need for additional phosphates. Despite considerable reduction in phosphorus inputs, many lakes and coastal areas have not yet shown the expected environmental and ecological improvement. This is due to accumulation and release of phosphorus from lake and sea bottoms and continued contamination from agricultural sources (http://www.eea.eu.int/).

Acidification

Agriculture, particularly manure from livestock is the main source of acidification due to ammonia (NH_3). Volatilisation losses of ammonia from stables and during storage and spreading are estimated at 15-20%. Ammonia emissions have decreased slightly between 1990 and 1996, due to reduced agricultural activity and measures taken by a few member states of the European Union. In Denmark, Germany and the Netherlands, a reduction of over 10% has been attained. Emissions in some member states increased.

Nitrate content in vegetables

A special topic is the nitrate content in vegetables especially leafy vegetables. Nitrogen in crops can be converted to nitrite, which is harmful at high concentrations. This is supposed to be especially dangerous for young children. However, scientific evidence on this topic is not complete. High levels of fertilisation cause high nitrate contents in crops.

Unfortunately, figures on emission and damage of nutrients and fertilisation are not available for vegetable farming specifically. However, because of the intensive character of vegetable farming, nutrient inputs tend to be high. Some crops have lower nutrient usage efficiencies and leave high nutrient contents in the soil after harvest. Other crops leave large amounts of crop residues in the field. In some cases, nutrient advice used by the farmers is outdated. Therefore, environmental problems in vegetable farming are rather larger than other sectors of agriculture on the average.

2.1.2 Policy and legislation

Ground and surface water

EU level
At the EU level, policy and legislation has tried to reduce the adverse effects of eutrophication and drinking water contamination for more than 25 years. Most important were the directive on surface water quality for drinking water (EC 75/440) and the Nitrate directive (EC 91/676).

In 1975, the European Union passed the Council Directive EC 75/440 concerning the quality required of surface water intended for the abstraction of drinking water in the member states. In this document, maximum concentrations of several elements were set for three categories of surface water. Imperative values were set that may not be exceeded in member states' national laws. The imperative concentration for nitrate is 50 mg l^{-1}. The guideline concentrations are 25 mg l^{-1} for nitrate and 0.4 – 0.7 mg l^{-1} for phosphate (depending on category of surface water).

The Nitrates Directive (EC 91/676), which was adopted in December 1991, seeks to prevent the pollution of water by nitrate from agricultural sources. Therefore, member states are required to place mandatory restrictions on agricultural practices where these contribute to the nitrate pollution of water. The objective of the directive is to reduce water pollution caused or induced by nitrates from agricultural sources and prevent this type of pollution in the future.

In order to do so member states had to identify waters affected by nitrate pollution or which may be affected in the near future, if action is not taken. The criteria for identification are either a concentration of nitrate above 50 mg/l in freshwater, eutrophication, or water, which may become one of these in the near future. The agricultural areas, which drain into these waters and contribute to pollution, have to be designated as vulnerable zones. In addition, mandatory measures concerning applications on the land and storage of fertilisers had to taken such as:

- The requirement for each farm to have sufficient livestock manure storage capacity for the periods when they are not permitted to apply the manure to land.
- The requirement for fertiliser application to be based on a balance between the requirements of the crops and the supply to the crops from the soil and from fertilisation.
- The requirement for the application of livestock manure to be limited to 170 kg N ha^{-1} per year for each farm from the end of 2002.

In addition, each Member State had to draw up at least one code of Good Agricultural Practice (GAP).

Implementation of this directive is severely behind schedule. Many countries have not met the obligations set by the directive. No vulnerable zones were designated and no action programmes for these zones were set (http://europa.eu.int/water/water-nitrates/report.html). Regulation (EC 92/2078, 'agri-environmental measures') provides incentives for reduction of the use of fertilisers and plant protection products. This includes organic farming, for the extensification of crop and livestock production, and for voluntarily setting aside of areas of farmland for the long-term and benefiting the protection of fresh water. Compensatory payments are given for the provision of services and goods by rural societies. In the future, these payments will be extended. In addition, basic environmental regulations will be set up which all farmers have to comply with.

The Netherlands
To address the nutrient problems mentioned above, policy has reacted to the environmental damage caused by

Table 2.1 Targets for nitrate and phosphate levels in ground and surface water in The Netherlands

	Groundwater		Surface water
	Sandy soils	Clay and peat soils	
Emission reduction			50% P and N in 1995 70-75% P and N end target[1]
Limit value	11.3[2] mg N l^{-1}	11.3[2] mg N l^{-1}	0.15[3] mg total-P l^{-1} 2.2[4] mg total-N l^{-1}
Target value	0.4 mg total P l^{-1} 5.6[5] mg N l^{-1}, 3.0 mg total P l^{-1}	5.6[5] mg N l^{-1}, 0.05 mg total P l^{-1}	1 mg total N l^{-1}l

1. final target compared to 1985 from "third note water household" and "national plan for environmental policy 2"
2. all groundwater (national plan for environmental policy 2)
3. summer average for specific waters and year average for all surface water (BOWA 2)
4. summer average
5. for protection of special oligotrophe areas lower values can be demanded

Table 2.2 Targets for surplus (included fertiliser inputs and fixation, excluded deposition) of nitrogen and phosphate (kg ha^{-1}) in the MINAS legislation for arable land in The Netherlands

Year	N		P_2O_5[1]
	clay/peat	sand	
2001	150	125	35
2002	100	100	25
2003	100	60	20

[1] excluded mineral phosphate for the time being

agronomic activities by implementing legislation to reduce nutrient emissions. Targets of the Dutch policy to protect ground and surface water are summarised in Table 2.1. For ammonia volatilisation, a maximum deposition target is determined on 1600 acid equivalents in 2000 and 1000 in 2010.

In the MINAS legislation, farmers are required to register nutrient use on a farm level. From 1998 until 2000, only organic manure had to be registered. Starting in 2001, chemical nitrogen fertilisers have to be recorded as well. Maximum surpluses for nitrogen and phosphate at a farm level are set (Table 2.2). Starting in 2003, the maximum input of animal manure will be set at 170 kg N ha^{-1} for arable land. The control mechanism will be based on registration. There is a penalty when the allowed surplus is exceeded. The main purpose of the MINAS legislation is to reduce the pollution of surface and shallow groundwater with nutrients.

In addition to MINAS, there are restrictions for the application method and application time of organic manure to reduce leaching and acidification. On sandy soils, no application of animal manure is allowed between 1 September and 1 February. It is required to work animal manure under within 24 hours after its application. New legislation is being put forward to forbid nitrogen fertilisation and ploughing of grassland between September and February.

Switzerland

In reforming the agricultural policy in Switzerland (Agrarpolitik 2002), the reduction of the adverse impact of agricultural activities was an important goal. Therefore, in a first step, the payment of ecological services was introduced, in addition to the separation of price policy and income policy.

Until 2005, the following targets (compared to the average of the years 1990-1992) concerning the nutrient management should be attained (BLW, 1998):

- Reduction of the nitrogen surplus of agriculture by 33.3%.
- Decrease of the average nitrate content in groundwater about five mg nitrate l^{-1}.
- Reduction of the phosphorus surplus of agriculture by 50%.
- Reduction of phosphate content in surface water by 50%.

The maximum value for ground and surface water in Switzerland is 40 mg Nitrate per litre; the target value is 25 mg nitrate per litre. In the long term, the target is to reduce to 15 mg nitrate per litre. For P in water, no exact maximum value exists.
In the first six years after the introduction of direct payments for ecological services, the reduction of the P-surplus by 50% has already been achieved. Concerning the reduction of the nitrogen surplus, only 40% of the target has been achieved so far. It seems that the target for nitrogen in 2005 will not be attained.

The farmers are required to fulfil specific conditions in order to receive direct payments. Concerning nutrient management and soil, the law demands a nutrient balance for the entire farm and measurements for soil protection. To avoid soil erosion, an optimal soil cover in winter is required (Landwirtschaftsgesetz Art. 70).

In Switzerland, the nutrient balance has to be in equilibrium for nitrogen and P. This means that the total amount of nutrients brought onto the farm is compared to the nutrient requirements (demand) of all cultivated crops. This is different than the Annual Balance calculation used by the other VEGINECO partners, in which the nutrient input is compared to the nutrient off-take.

Nitrate in crop produce

The regulation of nitrate content in spinach and lettuce was established in 97/194/EEC. Maximum levels are 2 500 mg kg^{-1} for spinach and 2 500 – 4 500 mg kg^{-1} for lettuce, depending on time of the harvest. These values are based on 'acceptable daily intake' levels for nitrate and nitrite.
In the Netherlands, the maximum residue values for nitrate in vegetables are set for endive, spinach, beetroot and lettuce. An overview of these values is found in Table 2.3. Values are overall higher than EU values for lettuce and spinach.

Nitrate in crop produce is measured in beetroot, lettuce and endive. There are large differences between levels in summer and winter. Average levels are below the norms. However, 95 percentile values were higher for endive (summer) and lettuce (summer) (http://www.agralin.nl/kap/).

In Switzerland, maximum values for nitrate in vegetables are set for some leafy vegetables (Table 2.4). Nitrate in crop produce in Switzerland is only measured in the winter because in the summer the nitrate content is much lower. In contrast to the European Union, the maximum

Table 2.3 Maximum residues of nitrate in vegetables in the Netherlands (1993-1997) (http://www.agralin.nl/kap/)

Vegetable	Harvested in the period:	Maximum level (mg kg^{-1})	Average level (mg kg^{-1})	95 percentile level (mg kg^{-1})
Endive	Summer (May 1 - November 1)	2 500	2 000	3 300
	Winter (November 1 - May 1)	3 500	2 100	3 300
Beetroot	Summer (April 1 - July 1)	4 000	1 300	2 700
	Winter (July 1- April 1)	3 500	3 500	-
Spinach	Summer (April 1 - November 1)	3 500	-	-
	Winter (November 1 - April 1)	4 500	-	-
Lettuce	Summer (May 1 - November 1)	3 500	2 600	3 700
	Winter (November 1 - May 1)	4 500	3 500	4 400

level for nitrate residues in vegetables is the same during the entire year in Switzerland.
As a result of latest findings, the health risks of high nitrate content in vegetables are considered much lower than previously. Therefore, the maximum levels of nitrate in Switzerland will possibly be adapted to the European Union levels in the near future (BAG, 2000).

Effectiveness of the policies

In general, nutrient pollution in the European Union has been reduced when compared to 1980-1985. However, reduction is not enough to sufficiently improve the environmental quality. Different laws and regulations have been implemented to reduce nutrient pollution and to improve the environmental quality, but they have not yet been successful enough. Current nutrient management seems to be inadequate in reducing environmental pollution from agriculture to the desired levels. Especially in vegetable farming systems, nutrient surpluses are large and thus the possibilities of nutrient losses are also large. Therefore, nutrient management in vegetable farming needs to be improved to reduce these losses and to satisfy the environmental criteria.

2.1.3 Label guidelines

Integrated production

In the Netherlands in integrated production under the 'Milieukeur' label, guidelines are set for fertilisation at a crop and/or farm level. Farmers have to set up a fertilisation plan for the whole farm. The amount of nitrogen and phosphate is based on the need of the crop or rotation and on soil fertility levels.
In Emilia Romagna, the QC label ("Qualità Controllata", Quality Control) is applied to vegetable production obtained through the application of Regional Integrated Production Guidelines. These Guidelines are inspired to the IOBC directives. The current guidelines do not fix or suggest a desired balance level for nitrogen, phosphate and potash nutrient management, but simply set a maximum quantity of fertiliser permitted.
In Switzerland, the 'Schweizerische Gemüse Union' publishes the guidelines for the integrated production of vegetables. The requirements for nutrient management include a nutrient balance for an entire farm with a margin of error for nitrogen and phosphate of 10%. A fertiliser report is required with the date of application, field, crop varieties, amount and nutrient content of fertilisers. Furthermore, the soil has to be analysed every four years. The application of nitrogen fertilisers should be done according to developmental stage of the crop and N-min or plant sap analysis. The maximum single doses of nitrogen are up to 60 kg ha^{-1} and in exceptional cases up to 100 kg ha^{-1}. It is also required to provide minimum crop cover during the winter for soil conservation defined as the soil cover index.

Table 2.4 Maximum levels of nitrate in vegetables in Switserland (Fremd- und Inhaltsstoffverordnung)

Vegetable	Maximum level (mg kg^{-1})
lettuce	3 500
spinach	3 500
corn salad	3 500
fennel	2 000
Chinese leaves	1 500
cabbage varieties	875

Organic production

The EC 91/2092 is followed for organic production. This guideline does not fix any limit regarding the total amount of fertilisers, but only restricts the number of organic and natural fertilisers used.
In integrated and organic farming, farmers are required to record in special forms the amount and the type of fertilisers distributed. No extra conditions are set up for nutrient management for the DEMETER label when compared to the EU guideline.
In Switzerland, the most important label for *organic farming* is the 'Knospe' (bud) of the 'BIO SUISSE'. The certification of the farms is done by 'bio.inspecta'. The requirements for nutrient management include a nutrient balance for the whole farm with a tolerance for nitrogen and phosphate

of 10%. A positive list of fertilisers exists. The application of chemical nitrogen fertilisers is not allowed. Soil analysis has to be done once every five years. It is recommended to analyse the soil for the mineral nitrogen in springtime. A minimum of 25% of the total area has to be covered with leys or green manure.

2.2 Theoretical Background

2.2.1 Definition and objectives of I/ENM

Definition

> *Integrated/Ecological Nutrient Management (I/ENM):* I/ENM provides directions on the supply of nutrients to crops in such amounts, forms and at such time to achieve 1) optimal quality production, 2) minimal nutrient losses to the environment and 3) adequate levels of nutrients and organic matter in soil reserves both agronomically as well as environmentally.

The nutrient management method is used in the prototype that can either be an integrated model or an ecological model. The general principles of the method are the same for both versions of the prototypes. The difference between the prototypes is based on the requirements of fertiliser type in organic systems (in general, only organic fertilisers may be used).
The I/ENM methodology in this manual is focussed on the macronutrients: nitrogen (N), phosphate (P_2O_5) and potassium (K_2O) and organic matter. These nutrients are essential for all crops in achieving quality production.
In Chapter 2.3, I/ENM strategies will be described. Attention will be paid to both versions (agronomical and environmental) of the method. First, general nutrient management theory is reviewed.

Relationship of I/ENM with other methods

Nutrient management does not function independently of other farming methods. The farming methods Multifunctional Crop Rotation (MCR) and Minimum Soil Cultivation (MSC) are closely related to I/ENM. There are many interactions between these farming methods, especially MCR. The rotation is defined in the MCR, and each rotation has its own nutrient requirements.
Especially in organic systems, the link between MCR and nutrient management is very important because balanced nutrient inputs from organic fertilisers, crop residues and biological fixation is one of the pillars of the MCR for an organic system. In integrated systems, this is of less importance because nutrient inputs can be balanced with simple, inorganic fertilisers. However, it is possible that an integrated rotation has to be adjusted as well to better meet the objectives.
Timing and intensity of soil cultivation influence mineralisation rates. There are links between I/ENM and other methods as well, but these are more indirect or of less importance. For example, pests and diseases or weed competition can influence nutrient uptake or levels of nitrogen that are too high can induce diseases.

I/ENM related themes

There is a strong connection between I/ENM and the themes 'Clean environment (nutrients)', Sustainable management of resources' and 'Quality production', which were explained in paragraph 1.3. Nutrient management influences the environment through leaching, acidification, erosion and depletion. It influences sustainable use of resources by keeping soil reserves at acceptable levels and by preventing erosion and leaching. Nutrient management influences quality production through nutrient content in the produce and the quantity and quality of produce. I/ENM has indirect connections with the objective 'Farm continuity' through quality production and costs of fertilisation.

2.2.2 Nutrient management theory

Soil-plant system

Nutrients in the soil can be present in the nutrient pool or in the soil solution, in which it is available for plant uptake (Figure 2.1). Plant uptake depends on crop characteristics, amount of nutrients in the soil solution and external factors such as soil characteristics and climate. Nutrients in the nutrient pool are in organic or in (solid) mineral form. Equilibrium exists between the nutrients in the nutrient pool and the soil solution. Different factors such as the amount of nutrients in the nutrient pool and the soil solution, temperature, rainfall, organic matter content and texture, influence this equilibrium. Processes that play a role in the equilibrium are, for example, mineralisation-immobilisation and adsorption-solution. The speed and direction of these processes are different for each nutrient.

I/ENM attempts to fulfil the nutrient requirements of the crop, while preventing or minimising losses. Therefore, the amount of nutrients in the soil solution has to be large enough to fulfil the crop requirements (agronomically acceptable) and small enough to prevent environmental losses. Fertilisation can be directly added to the soil solution with easily soluble mineral fertilisers or indirectly added to the nutrient pool with organic fertilisers and insoluble mineral fertilisers.

In formulating strategies, nitrogen is treated in more detail than phosphate and potash. This difference is necessary because of the difference in behaviour in the soil-plant system (Figure 2.1). The difference between nitrogen and phosphate or potash in the soil system is that nitrogen is easily soluble and phosphate and potash are not. In addition, in the nutrient pool, the most important nitrogen compounds are mainly present in the organic form while important phosphate and potash compounds

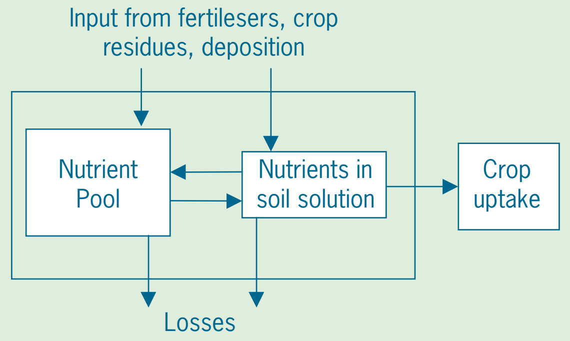

Figure 2.1 Nutrients in the soil-plant system

are mainly present in mineral form. Therefore, the amount of nitrogen in the soil solution is relatively large in comparison to the amount in the nutrient pool. The amount of phosphate and potash in the soil solution is relatively small in comparison to the amount in the nutrient pool. Frequently used terms are defined in Table 2.5.

Nitrogen

As stated above, the amount of nitrogen in the soil solution is relatively large. This is necessary for crop growth as well because the crops' demand for nitrogen is relative large. The disadvantage of this large amount in the soil solution is, in addition to the high solubility, that the risk of leaching losses is high. Availability of nitrogen from the nutrient pool is important, but variable and it is difficult to estimate. Nitrogen from the nutrient pool is stored in organic matter. It is released by mineralisation, a process that is difficult to estimate due to variation in weather, soil properties and the input of organic materials. Therefore, in contrast to phosphate and potash, there is no close relationship to the amount of nitrogen in the

Table 2.5 Definition of terms used in nutrient management

N available	mineral nitrogen available for plant growth.
$N/P_2O_5/K_2O$ content	the nutrient content in fertiliser, manure or crops expressed in kg per 100 kg or per ton and in the case of crops, usually as kg per ton of fresh material. In the case of organic manure, total nitrogen is mend; as well the organic as inorganic nitrogen in the manure.
N demand	nitrogen demand is nitrogen uptake divided by nitrogen recovery (theoretically). This often is the nitrogen demand input of some non-fertilisation sources such as soil organic matter and deposition are included as well, then nitrogen demand is lower then the theoretical demand.
P_2O_5/K_2O demand	phosphate/potash demand is equal to phosphate/potash off-take corrected for the soil reserve level. If soil reserves are high, then demand is lower than off-take. If soil reserves are low, then demand is higher than off-take.
$N/P_2O_5/K_2O$ deposition	Total nutrient input from dry and wet deposition within 12 months, only used on farm scale calculations that are obtained from regional measurements (kg ha^{-1}).
N fixation	The amount of nitrogen fixed in leguminous crops to be calculated as a standard amount per ha crop or to be based on a standard per ton of crop produce (kg ha^{-1}).
$N/P_2O_5/K_2O$ input	all nutrients from external sources that are put into a crop, field or farm.
N mineral soil	The mineral nitrogen available in soil reserves in a specific depth of the soil profile at a given moment (kg ha^{-1}) to be defined later.
$N/P_2O_5/K_2O$ off-take	nutrients exported from the fields either in crop produce or in crop residues or in both.
$N/P_2O_5/K_2O$ output	all nutrients that are exported from the fields or farms (could be livestock as well).
N recovery	fraction of a defined amount and type of nitrogen (1) found again in biomass (2). (1) and (2) have to be clearly defined.
$N/P_2O_5/K_2O$ uptake	nutrients included in the biomass, to be defined if it concerns above ground biomass, root biomass, or both or produce or crop residues.
Working coefficient	percentage of total amount of nutrients that have the same effect as mineral fertiliser.

nutrient pool and in the soil solution. In integrated systems, this can be overcome by measuring soil reserves regularly and fertilising based on the reserves in the soil solution.

Phosphate and Potash
Phosphate and potash are added to the crop indirectly via the nutrient pool. By keeping the amount of nutrients in the nutrient pool within certain limits, the amount of nutrients in the soil solution is influenced in such a way that a sufficient amount of nutrition can be supplied to the crop. Because of low solubility and bonding to organic agents, the amount of nutrients in the soil solution is limited and the risks of losses are minimised. The amounts of phosphate and potash in the soil solution and in the nutrient pool are closely related to each other. Therefore, the processes of exchange between the two nutrient pools are not as important as for nitrogen.
When measuring the size of the nutrient pool, the entire nutrient pool is not measured because extraction methods cannot extract all forms in which nutrients are available in the nutrient pool. In fact, the same is true for the soil composition. Some forms of the nutrients cannot be taken up by plants or can be insoluble. Therefore, the part that is measured is called the available reserves.
It appeared that the partners in the project measure phosphate and potash available soil reserves in different ways. To get an impression what the partners in the project call agronomically acceptable and to compare the different analysis methods of the partners, we have conducted a ring test for soil analysis of phosphate, potash, magnesium, calcium, texture, pH and organic matter. In addition, each partner had to set up fertiliser recommendations for four crops. In Annex 6, the results of the measurements are described.

Organic matter
Soil organic matter is an important factor in crop production, although its role is still poorly understood. Soil organic matter influences physical, chemical and biological properties of the soil. Organic matter dynamics are very important in nutrient management because of the large amounts of nutrients that can come available from the mineralisation of organic materials.
Effects of organic matter in the soil are:
- Soil physical effects.
  - Increase in resistance to wind erosion.
  - Increase of water holding capacity.
  - Increase in soil pore volume.
- Effects on chemical soil fertility.
  - Bonding of elements because of increased cat ion exchange capacity.
  - Availability of micronutrients.
- Effects on plant protection.
- Effects on soil-born diseases.
- Effects on chemical weed control.

Probably for every soil, there is an optimum organic matter content based on the different functions of organic matter, and the soil and climate type. This optimum content has to be reached or stabilised. The optimum level is difficult to establish because it is dependent on many factors. Influencing the organic mater content of the soil will take a long time because the organic matter that is added is very small compared to the amount of organic matter in the soil.

2.3 Design of nutrient management strategies

2.3.1 Procedure to construct I/ENM strategies
This chapter describes how strategic plans for nutrient management are set up that meet the objectives of the prototype. These objectives have to be defined before a strategy is set up (see Manual on Prototyping Methodology and Multifunctional Crop Rotation). In the previous paragraph, attention was paid to the relationship between the nutrient management method, the objectives (categories) and other methods.
The base for a fertilisation plan is crop rotation. This rotation is drawn up with aid of the method of the Multifunctional Crop Rotation (see Manual on Prototyping Methodology and Multifunctional Crop Rotation). In formulating an I/ENM strategy based on a defined rotation, the following procedure has to be followed (see Figure 2.2):
1. Calculate the nutrient demand for the crop rotation taking into account the specific needs of the crops and the soil reserves.
2. Calculate nutrient availability from non-fertilisation sources. External sources (deposition, irrigation water and fixation) and internal sources (crop residues, green manure and soil mineralisation) are discussed.
3. Establish the need for fertilisation taking into account timing, application method and choice of fertiliser.
4. Evaluate the strategy according to the objectives (parameters and target values). In first case, this is done on paper based on calculations and expert judgement. In second case, this is done in practice by testing and improving. When the plan does not meet sufficiently the set targets, the strategy has to be changed. When it is not possible to change the strategy sufficiently, the rotation should be altered (see Figure 2.2).

Each step is treated in the following paragraphs. In Annex 4, biomass amounts, yields and nutrient concentrations are given for the different systems. Examples from the Netherlands for the integrated (NL INT1) and the organic farming systems (NL ORG) are used to illustrate the procedure. In Chapters 3 to 6, region specific examples of these plans and their results during the project are presented.

2.3.2 Nutrient demand
The first step is to quantify the nutrient demand of the rotation. This means that for all crops in the rotation, the nutrient demands have to be established and a mean for

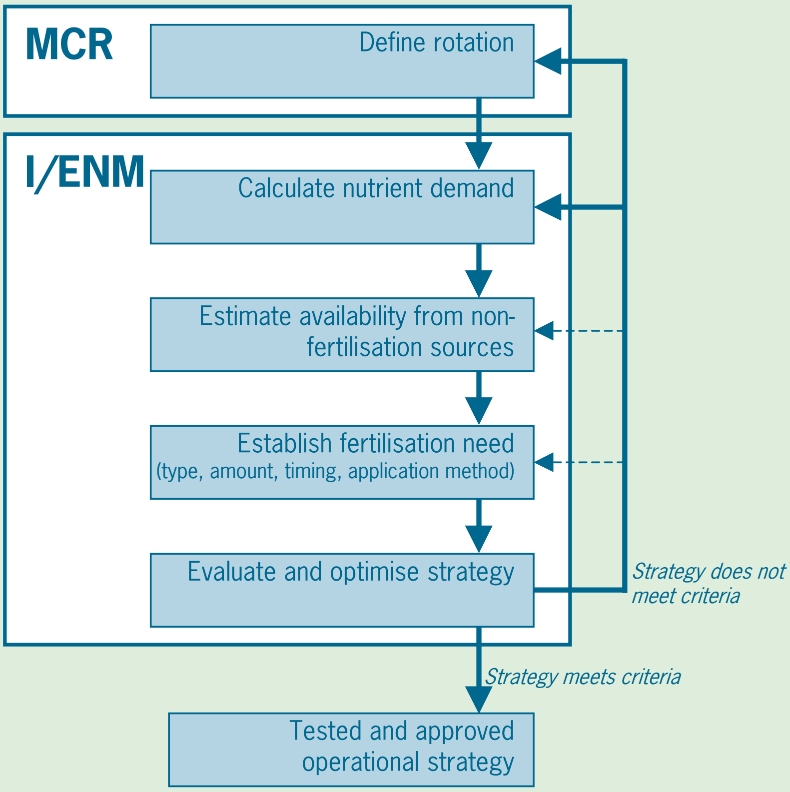

Figure 2.2 Procedure to construct a fertilisation strategy

the rotation has to be calculated. Nutrient demand is based on the objective to achieve an optimal quality production and to keep soil reserves within acceptable limits. Nitrogen demand and phosphate and potash demand is treated separately. Establishing nitrogen demand is more complicated and soil reserves do not play an important role.

Nitrogen demand
Theoretically, nitrogen demand is equal to the nitrogen uptake of the above ground crop parts divided by the recovery factor. However, in practice, sources such as fixation, soil organic matter mineralisation and deposition are not excluded in determining the nitrogen demand. Nitrogen demand data as defined above is not readily available. Therefore, nitrogen demand is redefined as the site-specific, empirically determined amount of nutrients that is necessary for crop growth. This practical demand is generally lower than the theoretical demand and defined by using conventional techniques. When fertilisation techniques are changed, a correction on the nitrogen demand has to be made. More efficient fertilisation techniques require lower nitrogen demand than inefficient techniques. When fertilisation is split in smaller doses, it is important to know the nitrogen uptake pattern of the crop, or the nitrogen demand in specific periods.

Phosphate and potash demand
Nutrient demands of phosphate and potash are dependent on the off-take for crop produce and soil reserve levels. When soil reserve levels are within the desired levels, phosphate and potash demand should be equal to the nutrient off-take from crop produce (Figure 2.3). At the crop level, the demand can be calculated by multiplying the off-take with the nutrient content in the crop produce:

P_2O_5/K_2O demand crop (kg ha^{-1})
= P_2O_5/K_2O off-take crop (kg ha^{-1})
*= off-take crop (ton ha^{-1}) * P_2O_5/K_2O content off-take crop (kg ton^{-1})*

The average demand of phosphate and potash per year per hectare can be calculated by adding up all of the crops' demand and dividing by the length of rotation. Levels of phosphate and potash in the soil that are too high are ecologically unacceptable (Figure 2.3). Phosphate and potash demand at the rotation level are, therefore, lowered or reduced to zero when soil reserves

Appraisal available soil reserves of phosphate and potash	Low levels Agronomically undesirable	Optimum range	High levels Ecologically unacceptable
Nutrient management to be followed	↓ Input > output (+ repair gifts)	↓ Input = output	↓ Input < output (reduced gifts)

Figure 2.3 Integrated approach for phosphate and potash fertilisation

are higher than the desired range. Levels that are too low are agronomically undesirable, and endanger quality of production.

The demand is therefore increased when soil reserves are lower than the desired range. In addition, phosphate and potash demand can be increased, when unavoidable losses are taken into account. Total availability of phosphate and potash can be calculated as follows:

$$P_2O_5/K_2O \text{ demand rotation (kg ha}^{-1}) = \sum (P_2O_5/K_2O \text{ demand crop (kg ha}^{-1})) + \text{correction soil reserves (kg ha}^{-1}) + \text{unavoidable losses (kg ha}^{-1})$$

Example

Examples of nutrient demand for NL ORG and NL INT1 are presented in Table 2.6. Nutrient demands in NL ORG are lower for all crops compared to NL INT1 because of lower estimated yields in this system and because more crops with low nitrogen demand are included in the rotation. In the Netherlands, soil mineralisation and deposition are included in determining the nutrient demand. For phosphate, an annual unavoidable loss of 20 kg ha^{-1} is estimated. Therefore, in conclusion, the phosphate balance should have a remainder of 20 kg ha^{-1} phosphate. Nutrient contents of crop produce, crop residues and target yields are summarised for all systems in Annex 4.

2.3.3 Nutrient availability from non-fertilisation sources

In optimal crop production, the nutrient demand is equal to the nutrient availability. Nutrients can become available from fertilisation, but other sources can be very important as well. Although the amount of nutrients available from these sources is not usually sufficient for crop growth, it is often a considerable amount, especially for nitrogen. Other sources can be divided into external and internal sources. External sources are deposition, irrigation water and fixation. Internal sources are crop residues, catch crops or green manures preceding the present crop and mineralisation of soil organic matter.

In internal sources, only nitrogen availability is important as phosphate and potash availability is assessed at the rotation level. In external sources, phosphate and potash are generally of little importance. Internal sources, green manures and catch crops can be an important input of organic matter. External sources can be important as well as large amounts of organic matter can be imported with paper or peat pots. The input of nutrients of these sources is often limited.

Some of the sources are implicitly taken into account in determining the nutrient demand. In these cases, these sources should not be assessed again. For example, if soil mineralisation was not taken into account in deter-

Table 2.6 Nutrient demand, NL ORG and NL INT1 in kg ha^{-1}, the demand includes deposition and mineralisation from soil organic matter

Year	Crop / green manure	N	P_2O_5	K_2O
NL ORG				
1	Iceberg lettuce summer	105	13	63
	Iceberg lettuce autumn	60	13	63
2	Spring barley	50	48	36
	White clover	0	0	0
3	Brussels sprouts	170	29	84
4	Fennel early	105	9	108
	Fennel autumn	60	9	108
5	Spring barley	50	48	36
	White clover	0	0	0
6	Potatoes	130	39	179
	Vetch/grass	0	0	0
Average		**122**	**35**	**113**
NL INT1				
1	Fennel early	120	10	120
	Fennel autumn	100	10	120
2	Potatoes	190	50	230
3	Brussels sprouts	220	38	108
4	Spring barley	70	56	42
Average		**175**	**41**	**155**

mining the nitrogen demand, it would not be taken into account in determining the amount of nutrients available from within the rotation.

External sources

The most important external sources are deposition and irrigation water. Deposition of nutrients from the air can be a considerable source of nutrients. The amounts are site-specific. Nitrogen deposition can be as high as 50 kg ha^{-1}. The deposition of other nutrients is negligible, measuring only a few kilograms. Often, deposits are already included in the empirical estimation of the nutrient demand.

Irrigation water can contain considerable amounts of nutrients. The amount of nutrients in irrigation water varies dramatically between locations. In addition, the need for irrigation is dependent on rainfall, evapo-transpiration and the crops grown. Therefore, the importance of this source is strongly dependent on the system and its location.

Fixation can be an important source of nitrogen within cropping systems, especially in biological cropping systems where often one or more legumes (peas, beans and clovers) are included to input nitrogen into the system. In fact, the crop does not actually fixate the nitrogen, but it is done by the symbiotic bacteria Rhizobia. This bacterium "invades" the plant and causes the formation of a nodule by inducing localised proliferation of the plant host's cells. The amount of nitrogen that can be fixated is dependent on presence of the Rhizobium bacteria, length of growing period, weather conditions and level of nitrogen in the soil. High nitrogen content in the soil or nitrogen fertilisation slows nitrogen fixation. In the Netherlands, the rule of thumb used to estimate the nitrogen fixation of green manure is:

N fixation (kg ha^{-1})
*= 4/3 * N-content above ground biomass (kg ton^{-1})*
** above ground biomass production (ton ha^{-1})*

Part of the nitrogen fixated is available for plant growth for following years. This availability is seen as an internal source as at the moment of availability, the nitrogen is already in the system.

Internal sources

From green manures, catch crops or crop residues from the preceding crop, a considerable amount of nutrients can become available for the next crop, as the organic material is very young and decomposition and mineralisation is fast. The different processes, which play a role in nitrogen availability, have lead to general rules of thumb for the nitrogen availability from green manure, catch crops and crop residues. These rules of thumb are expressed as working coefficients (percentage) for a certain crop, time of incorporation and soil type (see Annex 5, Table 1). The nitrogen that becomes available as mineral nitrogen for the present crop can be expressed as follows:

N gm av (kg ha^{-1})
= (working coefficient (%) /100) x N-content (kg ton^{-1})
x biomass (tons ha^{-1})

The working coefficient is dependent on different factors such as type of material (however not often considered), the time of incorporation (before or after a period of surplus precipitation), depth of incorporation and biological activity in the soil. Although soil organic matter is often relatively old (compared to organic matter in crop residues), the amount of nitrogen that becomes available for crop growth can be as large as the size of the nutrient pool, which is enormous. Often it is a net mineralisation term that expresses the result of many processes resulting in a net contribution to the nutrient pool of available mineral nitrogen.
There are many difficulties in estimating decomposition of soil organic matter and mineralisation of nitrogen. Therefore, nitrogen from organic matter in the soil is in many fertilisation strategies not taken into account directly, but included in the nitrogen demand or estimated through assessments of mineral nitrogen amounts. In this way, amounts of fertilisation are based on the crop's need minus the amount of mineral nitrogen in the soil.

Establishing the fertilisation need

The nutrients needed from fertilisation can be calculated by subtracting the nutrients available from non-fertilisation sources from the nitrogen demand. Only those sources have to be subtracted, which are not included in the estimation of nutrient demand. If the nitrogen contribution from some sources is not estimated, fertilisation can be corrected with the aid of N-min measurements during the growing season. This is only possible in integrated systems because in organic systems fertilisation during the growing season is almost impossible.

In Table 2.7, the nitrogen availability from non-fertilisation is shown for the two systems in the Netherlands. Other nutrients are not shown because deposition is taken up in the determination of nitrogen demand and the amount of nutrients in irrigation water is negligible. Nitrogen availability of soil organic matter was included in determining the nitrogen demand as well. Therefore, these sources were not taken into account in calculating nitrogen availability. Total availability from non-fertilisation sources is the sum of the values in the columns green manure and crop residues. Nitrogen fixation is added to the total input, but is not added directly to the nitrogen availability. The nitrogen fixation is recalculated to the amount of available nitrogen from green manure for the next crop in the following year. Therefore, the resultant is given in the column 'green manure'. For example, white clover fixates 100 kg ha^{-1} of nitrogen for the next crop, which indicates nitrogen

Table 2.7 Nitrogen demand, nitrogen availability from non-fertilisation sources and nitrogen availability needed from fertilisers for NL ORG and NL INT1 system in kg ha^{-1}. Only the internal sources green manure and crop residues are considered, other sources are not important or included in the determination of the nutrient demand.

Year	Crop / green manure	N-demand	N-availability Total	N-availability Green manure	N-availability Crop residues	N-available needed from fertilisers
NL ORG						
1	Iceberg lettuce summer	105	10	10	0	95
	Iceberg lettuce autumn	60	60	10	50	0
2	Spring barley	50	0	0	0	50
	White clover	0	0	0	0	0
3	Brussels sprouts	170	50	50	0	120
4	Fennel early	105	17	0	17	88
	Fennel autumn	60	58	0	58	2
5	Spring barley	50	0	0	0	50
	White clover	0	0	0	0	0
6	Potatoes	130	50	50	0	80
	Vetch/grass	0	48	0	48	-48
Average		**122**	**49**	**20**	**29**	**73**
NL INT1						
1	Fennel early	120	0	0	0	120
	Fennel autumn	100	58	0	58	42
2	Potatoes	190	0	0	0	190
3	Brussels sprouts	220	0	0	0	220
4	Spring barley	70	17	0	17	53
Average		**175**	**19**	**0**	**19**	**156**

available from green manure is 50 kg ha^{-1} (working coefficient 50%). In the last column, the available nitrogen needed from organic and chemical fertilisers is given per crop. This nitrogen need is calculated by subtracting the total nitrogen availability from the nitrogen demand. In NL ORG, 60% of the nitrogen is required from fertilisers, and in NL INT1, the figure is 90%.

2.3.4 Fertilisation

Nutrients from non-fertilisation sources are, in many cases, not able to counterbalance nutrient demand at the desired yield levels. Therefore, nutrients have to be applied with fertilisers to achieve the quality of production targets. As stated previously, the amount of nutrients available from fertilisers has to be equal to the demand minus the available nutrients from non-fertilisation sources (see Table 2.7).

Fertiliser choice

There are many types of fertilisers. Important characteristics of fertilisers are the rate of availability of the nutrients in the fertiliser and the number of nutrients in a fertiliser (single or compound fertilisers). In addition, there is also additional organic matter in the organic fertilisers.

The main groups of fertilisers are organic and mineral fertilisers. Each group can be subdivided into many different types. The type of fertiliser used is dependent on the objectives. For example, if nutrient losses are large, it is better to choose mineral fertilisers because fewer nutrients have to be supplied to fulfil crop needs. On the other hand, if organic matter needs to be applied as well, organic fertilisers can be a better choice. In addition, availability and price can play a role. In organic systems, the choice is generally limited because mineral fertilisers may not be used at all.

Organic fertilisers

Organic fertilisers, such as animal manure and composts, deliver several nutrients at once to soil and crop. In addition, organic fertilisers add organic matter to the soil as well. The choice of organic fertiliser to use can depend on the desired nutrient ratios, the need or desire for organic matter, and the price and availability of organic fertilisers.

The nutrient ratios (NP, NK) in the manure should roughly be equal to the nutrient ratios of the fertilisation demand that are already available within the system. This is especially important for organic systems because there are only few, single mineral fertilisers allowed to adjust the needed ratios. In integrated systems, this is a small problem because deficits can be corrected with mineral fertilisers. Except for liquid cow manure, most organic fertilisers have a nitrogen-phosphate ratio that is below two, while most ratios between nitrogen demand and phosphate demand from fertilisers for crop rotations are well above two. If the nutrient ratio differs greatly compared to the crop need, accumulation or losses of nutrients in the soil or nutrient deficits in the crop can occur.

Concerning nitrogen, only the mineral fraction of nitrogen in the organic material is directly available for plant uptake. The organic fraction has to mineralise first, before uptake is possible. Part of this organic fraction mineralises within the first year after application; the rest mineralises in the following years. The pattern of mineralisation is dependent on weather conditions and is difficult to influence. Therefore, nitrogen leaching can occur, as nitrogen can be available at times that it is not needed for crop growth.

To calculate the nitrogen available from organic manure, the working-coefficient has to be available. The working-coefficient represents the percentage of nitrogen, which will become available as mineral nitrogen in the first year after application. Working-coefficients (percentage) are dependent on the type of manure, application time, and soil type (see Annex 5, Table 2). The formula to calculate the availability of nitrogen (kg ha^{-1}) from organic manure is as follows:

N organic manure (kg ha^{-1})
*= working-coefficient (%) * N-content manure (kg ton^{-1})*
** weight applied manure (tons ha^{-1})*

The nutrient content of one type of organic fertiliser can vary greatly in time and between different supply sources. For example, nutrient concentrations in animal manure depend on the feed given to the animals, moisture content and additions (such as straw). Ammonium in manure can volatise, the amount depends on the type of storage. Therefore, by choosing the best fertiliser on paper will not always work out well in practice because concentrations differ from what is expected. In that case, corrections need to be made in the fertilisation levels during the following months (nitrogen) and years (phosphate and potash). The same corrections have to be made when off-take is not equal to what was planned.

If organic matter needs to be applied in addition to nutrients, organic fertilisers can be used. Dependent on the need for organic matter and nutrients, a different type of organic fertiliser should be chosen. Solid manures and composts have a relatively high content of organic matter and low nutrient content. Liquid manures have a relatively low content of organic matter and high nutrient content. In addition, liquid manure has normally higher nitrogen-phosphate ratios and liquid manure has higher working-coefficients as it contains more mineral nitrogen that is directly available. Solid manures and compost have low working-coefficients because nitrogen is mainly present in organic form and in mineral form with low solubility.

Mineral fertilisers
Mineral fertilisers make it possible to apply the precise amount needed by the crop because mineral fertilisers can be applied in the desired ratio, which is often not possible with organic fertilisers. Generally, mineral fertilisers are directly available for plant growth, although increasingly slow release fertilisers are being developed. The advantage of slow release fertilisers is that nitrogen becomes available over a long period in small amounts for plant growth. It is expected that leaching of nutrients is lower when slow release fertilisers are used.
In organic systems, some fertilisers are allowed that are considered to be mineral fertilisers. Although they have often an organic origin, they are considered mineral because mineralisation is fast. It is recommended to avoid these fertilisers because the sources are questionable or are finite. However, they are sometimes used to cover (partially) nitrogen shortages for the short term.
In the long term, soil mineralisation needs to be at such levels that these fertilisers are not necessary any longer. For example, in the organic system in the Netherlands, hydrolysed blood is used as is illustrated in Table 2.9.

Timing of fertilisation
Timing of fertilisation is important in lowering nutrient losses. This is especially important when fertilisation is done to stimulate crop growth (nitrogen fertilisation).
In this case, the best situation is, if possible, to apply fertilisers short before planting. When fertilisation is done to “refill” the nutrient pool, timing is less important.
Although when mineral nitrogen content in the fertiliser is high, growing a (catch) crop after application can prevent nitrogen leaching.

Timing in rotation
Phosphate and potash fertilisation is done before crops with high demands or before crops with low recoveries.
In addition, fertilisation is often carried out before crops that are growing in periods with low availability. This can be the case in early spring. In this case, often a relative easily soluble form of the nutrient is supplied and fertiliser is placed in the cropping row or plant hole. Phosphate and potash fertilisation is field-specific, depending on the fertility levels of the fields (see paragraph 2.3.2).

To be able to spread fertilisers throughout the rotation in organic systems, crops with high demand are alternated with crops that have lower demands. Fertilisers are applied before crops with high demands. By following these strategies, the amount of nutrients in the soil solution is relative large for these crops and smaller for crops with lower demands.

On heavy soils in wet climates, it is often not possible to apply organic fertilisers just before planting. If manure has to be applied long before the start of crop growth, it is better to choose organic manure with low mineral nitrogen content. Up until now, there are only limited possibilities to apply organic fertilisers during crop growth, although experiments are being done on the application of liquid manure in row fertilisation.

Timing during crop growth
To be able to anticipate variations in mineralisation of organic material (because of variations in temperature and humidity) and to keep the amount of nitrogen in the soil solution within certain limits, it is better not to apply all of the nitrogen at once, but to divide the application into smaller doses. The quantity per dose can be based on the crop's uptake-requirements patterns, or be made dependent on the nitrogen content of the plant tissue or the soil. One of these should be measured several times during the growing season to judge if nitrogen soil reserves are sufficient. An extreme variant of this is fert-irrigation. In this system, a small amount of nutrients is added every few days with the irrigation water through plastic tubes on or in the ground. Splitting doses can be eliminated by the use of slow release fertilisers as mentioned in the previous section. A disadvantage of slow release fertilisers is that it is impossible to correct for higher availability from other sources.

Application technique
Application techniques are specific for each fertiliser type. For instance, organic fertilisers are often very bulky and needs to be applied in a different way than mineral fertilisers. Within each group, there are different types as fertilisers that need to be applied differently as well (solid and liquid fertilisers).
Most fertilisers are applied on or in the soil and taken up by the plants' roots. One exception is leaf fertilisation, when fertilisers are sprayed directly on the leaves. However, part of the fertiliser is still absorbed through the soil by the roots. Fertilisers can be applied to the soil full field, in row applications or by irrigation tubes (fert-irrigation). Row application is preferred over full field application if the row distance is large (≥ 75 cm) or for first applications of planting or seeding. In these cases, roots are not capable (yet) of absorbing nutrients from the entire surface. Nutrients between the rows cannot be absorbed by the plants and will be lost.

It is often difficult to apply fertilisers equally over the field, especially for organic fertilisers. However, this problem is largely solved with improved mechanisation. When organic fertilisers are applied in the soil or worked under shortly after application, volatilisation losses will be limited.

Example
In Table 2.8, the organic fertilisation plan for the systems in the Netherlands is presented. In the organic system, liquid and solid cow manure was used. In the integrated systems, Champost was used. In Table 2.9, the planned amount of nutrients from mineral fertilisers, the total availability of nutrients from fertilisers, the total nitrogen availability and the balance between demand and availability are listed. Total planned availability of phosphate and

Table 2.8 Organic fertilisation for NL ORG and NL INT1

Year	Crop / green manure	Type[1)]	Amount ton ha^{-1}	N kg ha^{-1}	P_2O_5 kg ha^{-1}	K_2O kg ha^{-1}	N-available kg ha^{-1}
NL ORG							
1	Iceberg lettuce summer	LCM	30	144	51	195	58
	Iceberg lettuce autumn			0	0	0	29
3	Brussels sprouts	SCM/LCM	35/30	193/144	133/51	123/195	39/86
6	Potatoes	SCM	30	165	114	105	25
	Vetch/grass			0	0	0	8
Average		**SCM/LCM**	**11/10**	**108**	**58**	**103**	**41**
NL INT1							
1	Fennel early	CHP	20	116	72	174	41
	Fennel autumn				0	0	0
2	Potatoes	CHP	20	116	72	174	41
Average		**CHP**	**10**	**58**	**36**	**87**	**20**

1) LCM = Liquid Cow Manure, SCM = Solid Cow Manure, CHP = Champost

Table 2.9 Planned input of organic and mineral fertilisers for NL ORG and NL INT1 in kg ha^{-1}

Year	Crop / green manure	Mineral fertiliser input			Total fertiliser available			Total N-availability	Demand–Total availability		
		N	P_2O_5	K_2O	N	P_2O_5	K_2O		N	P_2O_5	K_2O
NL ORG											
1	Iceberg lettuce summer	35	0	0	93	51	195	103	-2	38	132
	Iceberg lettuce autumn	15	0	0	44	0	0	104	44	-13	-63
2	Spring barley	0	0	0	0	0	0	0	-50	-48	-36
	White clover	0	0	0	0	0	0	0	0	0	0
3	Brussels sprouts	0	0	0	125	184	317	175	5	155	234
4	Fennel early	95	0	0	95	0	0	113	7	-9	-108
	Fennel autumn	35	0	0	35	0	0	93	33	-9	-108
5	Spring barley	0	0	0	0	0	0	0	-50	-48	-36
	White clover	0	0	0	0	0	0	0	0	0	0
6	Potatoes	60	0	0	85	114	105	135	5	75	-74
	Vetch/grass	0	0	0	8	0	0	48	56	0	0
Average		**40**	**0**	**0**	**0**	**81**	**58**	**129**	**8**	**24**	**-10**
NL INT1											
1	Fennel early	80	50	54	121	122	228	122	1	112	108
	Fennel autumn	60	0	54	60	0	54	118	18	-10	-120
2	Potatoes	150	0	0	191	72	174	181	1	22	170
3	Brussels sprouts	220	50	226	220	50	226	220	0	12	-108
4	Spring barley	50	0	0	50	0	0	67	-3	-56	-42
Average		**140**	**25**	**70**	**161**	**61**	**171**	**178**	**4**	**20**	**2**

potash was equal to the planned availability of nutrients from fertilisers.

2.3.5 Evaluation and optimisation of the nutrient management strategy plan

Evaluation and optimisation

The strategy is evaluated and optimised on basis of the defined agronomical and environmental parameters at two points: before implementation in practice and during the testing and improving phase. Expert evaluation is necessary before the strategy can be implemented in practice.

In the evaluation, the expected or attained parameter values are compared with the targeted values or ranges. Often, shortages can occur between the targets and the results, and these shortages can be assessed for acceptably. In Annex 2, an overview is given of the parameters chosen to evaluate the prototypes. The parameters used to evaluate I/ENM can be divided in three groups (Table 2.10). The first group of parameters is influenced by I/ENM directly. The second group of parameters is influenced by I/ENM directly as well, but other methods are at least as important to determine the parameter values. The third group is only indirectly influenced by I/ENM.

The parameter values have to estimated in order to evaluate the prototype. If the total parameters cannot be estimated, supporting parameters can be used. For instance, it is difficult to estimate the complete net surplus. However, costs and revenues of new fertilisation strategies can be compared to conventional strategies. Optimal quality of production should be guaranteed when the available nutrients meet the demand. Potential losses can be estimated for expected surplus, expected nitrogen availability at the start of the leaching season and estimated development of nutrient pools (build up, reduction or stabilisation in nutrient pool). The latter can be used as well to evaluate sustainability of resource use.
To evaluate developments in the soil's organic matter content in general, the organic matter balance for the fertilisation plan can be calculated. Within a stable system, the decomposition (or respiration) of organic matter should be compensated for by the input of external (organic manure, compost, straw, paper pots) and internal (crop residues, green manures) organic matter sources. In this way, the beneficial effects of organic matter can be preserved.

If the conclusion is that the strategy does not meet sufficiently the objectives, the strategy should be adjusted. The strategy can be changed at different points (Figure 2.2):

Table 2.10 I/ENM related major objectives, parameters and other methods

Parameter	Theme	Other methods involved
Parameters directly influenced by I/ENM		
Phosphate Annual Balance (PAB)	Clean Environment	MCR
Potash Annual Balance (KAB)		
Nitrogen Available Reserves (NAR)	Clean Environment	MCR
Phosphate Annual Reserves (PAR)	Sustainable management of resources	MCR
Potash Annual Reserves (KAR)		
Organic Matter Annual Balance (OMAB)	Sustainable management of resources	MCR
Nitrate Content of crop produce (NCONT)	Quality production	MCR
Parameters partially influenced by I/ENM		
Energy Input (ENIN)	Sustainable management of resources	all methods
Quantity Production (QNP)	Quality production	all methods
Quality Production (QLP	Quality production	all methods
Net Surplus (NS)	Farm continuity	all methods

1. Within the I/ENM method:
   a. *Change nutrient demand.*
      The amount of phosphate and potash can only be adjusted by changing objectives because the off-take has to be changed. There are many options for changing the nitrogen demand by improving the recovery fraction. Recovery can be improved by implementing fertilisation techniques, which limit nutrient losses as dividing doses over different portions or using liquid instead of solid mineral fertilisers.
   b. *Change nutrient availability from non-fertiliser sources.*
      External inputs cannot be changed, but internal inputs can be changed. It is possible to improve nutrient availability from these sources by managing the green manures, crop residues and catch crops. For instance, time of ploughing has an influence on the mineralisation behaviour of these sources. However, changes are small if the rotation is not altered at the same time.
   c. *Change input of total nutrients.*
      Choosing another type of fertiliser can change input of total nutrients. For example, replacing an organic fertiliser with a mineral fertiliser reduces nutrient emission. Mineral fertilisers can be supplied with a higher efficiency to the crop and total nutrient input will be lower as well.
2. In the MCR method:
   The rotation can be changed in the MCR method. If it is not possible to change nutrient input and availability sufficiently to reach the objectives, a change in the rotation is necessary. Therefore, it is necessary to return to the MCR method. Sometimes it may be necessary to review other methods (MSC or I/ECP as well).

Example

Nutrient balances and expected nitrogen availability at the start of the leaching season for the two systems in the Netherlands are presented in Tables 2.9 and 2.11. In Table 2.9, the availability and surplus (except nitrogen) of nutrients is presented. In Table 2.11, the simplified nitrogen balance and the expected mineral nitrogen, based on expert evaluation, are presented.

In NL ORG at a rotation level, nitrogen availability was almost equal to the demand because of the doses of hydrolysed blood. In general, quality production targets would be attained. However, at a crop level, this was not the case: spring barley was not fertilised and the second crops of iceberg lettuce and fennel had too large reserves of nitrogen. The surpluses for the second crops were caused by the goal to fertilise the first crops sufficiently. Spring barley had a low financial return, thus optimal fertilisation was not targeted for this crop. Probably, actual yield levels would be lower than target values in this crop. The difference at a rotation level between demand and availability for phosphate was 24 kg ha^{-1}, which is almost equal to the expected unavoidable loss of 20 kg ha^{-1}. There was a small shortage of potash. This was in the range of the soil fertility levels at the farm, which are within the target limits.

In the Integrated system, chemical fertilisers were used to supply nitrogen, phosphate and potash. All nutrients were in ample supply in the mineral fertilisers. This was valid for nitrogen at a crop level as well. Thus, all quality production targets should have be achieved. The difference between demand and availability for phosphate was exactly equal to the unavoidable loss of 20 kg ha^{-1}. This was in the range of the soil fertility levels at the farm, which are within the target limits.

The expected nitrogen surplus in NL ORG was about 20 kg higher than in NL INT1, mainly because of lower expected off-take of nitrogen. The mineral nitrogen values

Table 2.11 Simplified nitrogen balance and expected N-min after harvest and at the start of the leaching season (based on expert evaluation) for NL ORG and NL INT1 in kg ha⁻¹

Year	Crop / green manure	Input	Off-take	Surplus	N-min after harvest	N-min start leaching season
NL ORG						
1	Iceberg lettuce summer	179	38	141	70	
	Iceberg lettuce autumn	15	38	-23	70	90
2	Spring barley	0	90	-90	10	
	White clover	100	0	100		30
3	Brussels sprouts	337	77	260	10	20
4	Fennel early	95	36	59	10	
	Fennel autumn	35	36	-1	30	50
5	Spring barley	0	90	-90	10	
	White clover	100	0	100		30
6	Potatoes	225	116	109	70	
	Vetch/grass	80	0	80		70
Average		**194**	**87**	**108**	**47**	**48**
NL INT1						
1	Fennel early	196	40	156	30	
	Fennel autumn	60	40	20	30	60
2	Potatoes	266	149	117	70	90
3	Brussels sprouts	220	99	121	10	10
4	Spring barley	50	105	-55	20	30
Average		**198**	**108**	**90**	**40**	**48**

were on average for the rotation sufficiently within the target value of 70 kg ha⁻¹, although after some crops, the value was expected to be higher than the target.

Table 2.12 OMAB for NL ORG and NL INT1 in kg ha⁻¹

		NL ORG	NL INT1
Organic matter supply			
External	Organic fertiliser	1 033	1 000
	Paper pots	825	838
Internal	Crop residues	1 156	1 579
	Green manure	554	0
Total		3 568	3.416
Organic matter respiration			
Organic matter content		3.1%	2.3%
Respiration per ha/year		2 558	1 898
OMAB		*1.40*	*1.80*

For phosphate and potash, the surplus is presented in Table 2.11 because demand is equal to input for these nutrients. The phosphate surplus is about equal to the unavoidable loss of 20 kg ha⁻¹. The potash surplus is within the range of balance fertilisation. The organic matter balance is discussed separately in the next paragraph.

Both systems met the legal requirements. Under the Dutch legislation, input of nitrogen should be smaller than 265 kg ha⁻¹ of which a maximum of 170 kg ha⁻¹ from animal manure. Input of phosphate should be a maximum of 85 kg ha⁻¹. These requirements will be in force starting in 2003. In the years before, input maximums are being gradually reduced.
In Table 2.12, an example of organic matter calculations for the Netherlands is given. All organic matter sources were counted. It is remarkable that paper pots contributed a quarter of the total organic matter. In both systems, crop residues contributed most to the supply. Respiration is estimated at 2.5% of the total active organic matter content. The OMAB is for both systems above the target of one. It is expected that organic matter content in both systems will rise.