Arab Centre for the Study of Arid Zones and Dry Lands
ACSAD
Damascus

Federal Institute for Geosciences and Natural Resources
BGR
Hannover

National Council for Scientific Research Lebanon
CNRS
Beirut

TECHNICAL COOPERATION

PROJECT NO.: 1996.2189.7

Management, Protection and Sustainable Use of Groundwater and Soil Resources in the Arab Region

Volume 8

A Guide to Sustainable Nitrogen Management in Agricultural Practice

Damascus

December 2003

Volume 8

A Guide to Sustainable Nitrogen Management in Agricultural Practice

Authors:	Andreas Möller Sven Altfelder Hans Werner Müller Talal Darwish Gilani Abdelgawad

Commissioned by:	Federal Ministry for Economic Cooperation and Development (Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung, BMZ)
Project:	Management, Protection and Sustainable Use of Groundwater and Soil Resources in the Arab Region
BMZ-No.:	1996.2189.7
BGR-Archive No.:	
Date of issuance:	December 2003
No. of pages:	87

Table of contents

1 Introduction

Nitrogen is an essential element for plant growth limiting food production and plant protein content, which are key issues in feeding the world population. Since nitrogen fertilisation is highly correlated with crop yields, growers usually apply large amounts of nitrogen fertiliser to obtain high yields of good quality. From an economic perspective, this may be a reasonable decision, but from the environmental perspective it is not, since the environmental pollution with surplus nitrate is almost inevitable.

The cost of fertiliser is small compared to the cost of lost yield. Due to this monetary imbalance the farmers motivation to avoid over-fertilisation is small, while he will be careful not to under-fertilize and risk yield loss. In over-fertilised crops large amounts of nitrogen remain in soil after harvest. This includes residual soil mineral nitrogen or nitrogen present in crop residues. Both sources of nitrogen may have a harmful effect on the environment. This unnecessary surplus of nitrogen contradicts one of the key aims of today's agriculture, namely sustainability. One of the definitions of sustainable is "capable of being maintained at a steady level without exhausting natural resources or causing severe ecological damage".

Currently many agricultural systems in the Arab region, especially intensive vegetable production, are not sustainable in this way causing severe ecological damage. Possible consequences are surface- and groundwater pollution with nitrate, leading to an increased health risk.

While the achievement of a truly sustainable production resulting in lower yield and revenue is unlikely considering the costs involved for the farmer, a minimum goal should be the avoidance of over-fertilisation to prevent severe surface- and groundwater pollution.

The avoidance of over-fertilisation may also be a benefit to farmers and consumers. Over-fertilised crops can be more susceptible to disease, or may have elevated nitrate levels in vegetable tissues thereby posing a threat to human health. Elevated nitrate levels can affect quality of vegetables in additional ways: Brussels sprouts have been found to taste bitterer when over-fertilised with nitrogen and to produce undesirable, elongated sprouts. Vitamin C levels in vegetables drop as the nitrate level increases.

The general public is concerned about high nitrate concentrations in vegetables and in drinking water because of the potential health risks for humans and animals. For example, in some semiarid areas like Botswana, cattle have died after consuming groundwater with nitrate values above 200 mg/l. Nitrates can be fatal to nursing infants, particularly those between the ages of three and six months. With efficient fertilisation health risks and environmental pollution can be reduced. Here, the term “efficient nitrogen fertilisation” refers to the ideal situation from the farmers’ point of view, in which the crop receives neither too little nor too much nitrogen.

Cost of over- or underfertilising? In Lebanon, ammonium nitrate fertiliser costs about US$ 0.3 per kg. In vegetable production the use of 750 kg/ha of nitrogen is common in this area. The cost of applying 100 kg/ha nitrogen is close to US$ 90.00 [100 kg/ha x 100 / 34 x US$ 0.30]. A reduction of nitrogen input by about 100 kg/ha would save the farmer about **90.00 US$**. Assuming that this causes a yield reduction for Carrots of 10% due to under-fertilisation, the farmer would lose 1125.00 US$. In Lebanon the yield of carrots is about 45 t/ha, while the t of carrots gains about 250 US$. A **yield reduction of 10%** would correspond to an **approximate net loss of 1035.00 US$** for the farmer**, saving** only **90.00US$ of fertilizer costs!**

Farmers frequently apply the entire nitrogen plant need in form of fertiliser because they usually neglect other sources of nitrate, such as the nitrogen present in the soil, crop residues or irrigation water. They also fail to consider processes in soil that compete with the crop for nitrogen. We generally think of crop needs as crop uptake. In reality, more nitrogen than the actual crop uptake is required for optimal growth. This additional nitrogen should be included when estimating crop needs. This guideline has been designed for farmers and agricultural professionals as a handbook of information on nitrogen fertilisation in agriculture in the Arab region. It presents tools and methods that can be used to evaluate the nitrogen status of soil and plants and that allow the calculation of fertilizer requirement for different crops within the Arab region.

2 Nitrogen cycle

The interaction between the various forms of nitrogen in soil, plants, and animals and nitrogen in the atmosphere constitute the nitrogen cycle (Figure 1; Wolkowski et al., Internet pub.). The nitrogen input into arable soils usually consists of nitrogen from commercial fertilisers, crop residues, green and farm manures, ammonium and nitrate salts dissolved in rainwater and certain mircoorganisms that incorporate atmospheric nitrogen into compounds usable by plants. Nitrogen depletion of soils results from crop removal, drainage, erosion, and loss in gaseous forms. Most of the nitrogen added to the soil is subject to many transformations such as immobilisation and mobilisation processes before it is removed. The nitrogen dynamic in soil is also coupled with other systems like the phosphorus cycle or the carbon cycle. By modifying inputs and outputs, we can change the balance of nitrogen in soil. The efficient management of nitrogen involves the calculation of optimum inputs that are balanced to achieve an ideal output and maximum yield with no health and environmental risks hazards.

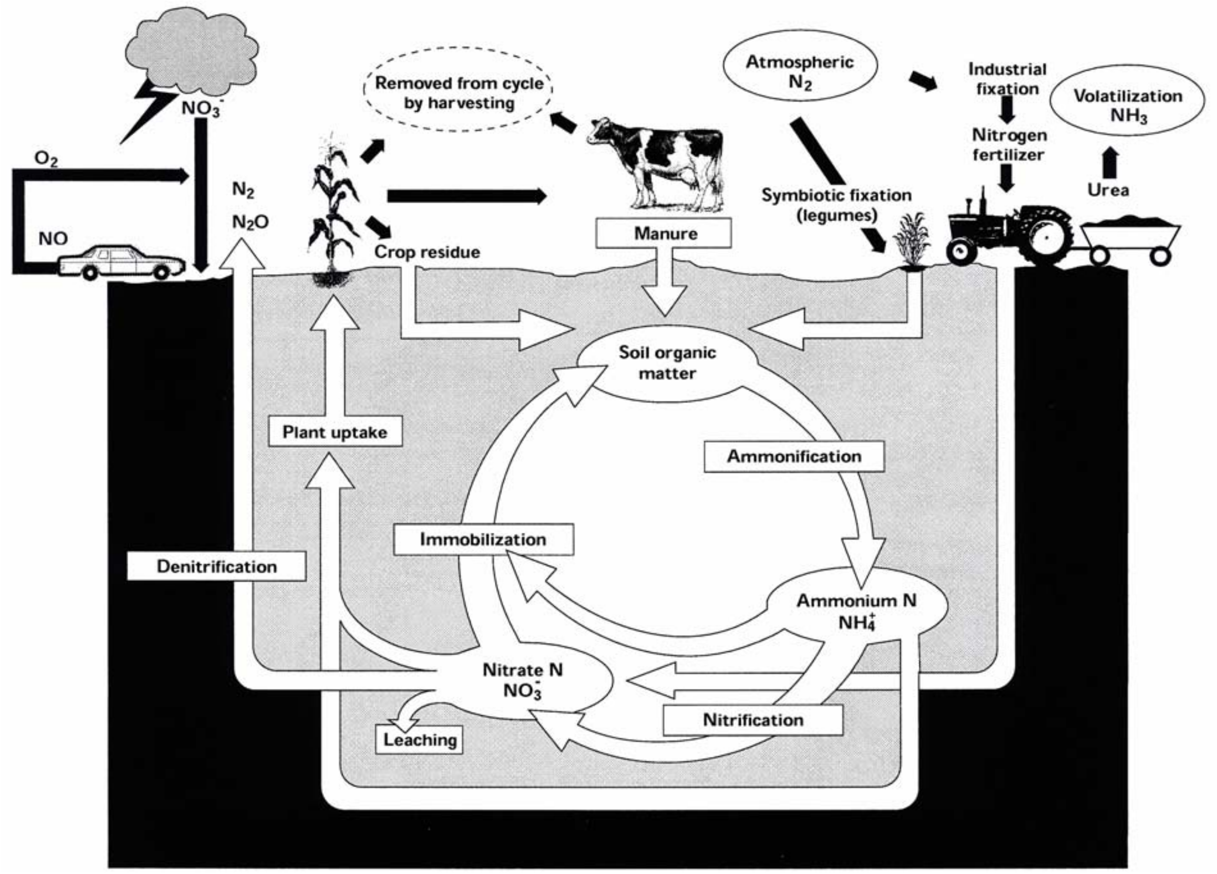

Figure 1: Nitrogen in an agricultural system (Wolkowski et al., Internet pub.)

2.1 Inputs

Nitrogen inputs are usually assumed as only those inputs that are actively applied to soil, such as manure and fertiliser. In fact, there are different nitrogen sources which are most often not considered in fertiliser management, but should be included when trying to achieve a system with minimized inputs and maximum yields. Examples are the release of nitrogen from soil organic matter, or the influx of nitrogen with irrigation. For example, in Lebanon, for one spring potato season the nitrogen derived from irrigation water reached 55 kg/ha (Darwish et al., 2003). It is also quite common that a high quantity of nitrogen is still present in the soil in spring. Managing nitrogen in intensive agricultural production calls for an understanding of these processes which contribute to the soil-plant environment.

2.1.1 Soil mineral nitrogen in spring (SMNS)

In intensive agricultural systems, soil may still contain a significant amount of nitrogen before the cultivation of a new crop. This nitrogen should be treated as an additional input. Figure 2 shows results of a field study in Lebanon with different cropping systems. SMNS levels are highest with the continuous vegetable cropping system, where 169 kg N/ha are found within the first 90 cm of soil. Figure 2 also shows the total nitrogen found in fall in the top 90 cm of soil. In the continuous vegetable cropping system this amount is 659 kg N/ha. This value is very high, but reflects the high fertiliser input into the system, which is typical for vegetables production in the region. Even after a heavy rainy season in the non-growing season in 2002/2003 in the Bekaa in Lebanon with 1400 mm of rain about 40 kg N/ha remained within the first 90 cm of soil.

Nitrogen amounts left in the soil in fall have the potential to leach out of the rooting zone by deep percolation during the rainy season (fall to spring). Leaching may continue even beyond planting of the first crop, because the root systems of seedlings or transplants are still small and unable to take up much of the remaining nitrogen. A winter trap crop helps to conserve soil nitrogen and thus minimizing the N-leaching by rain.

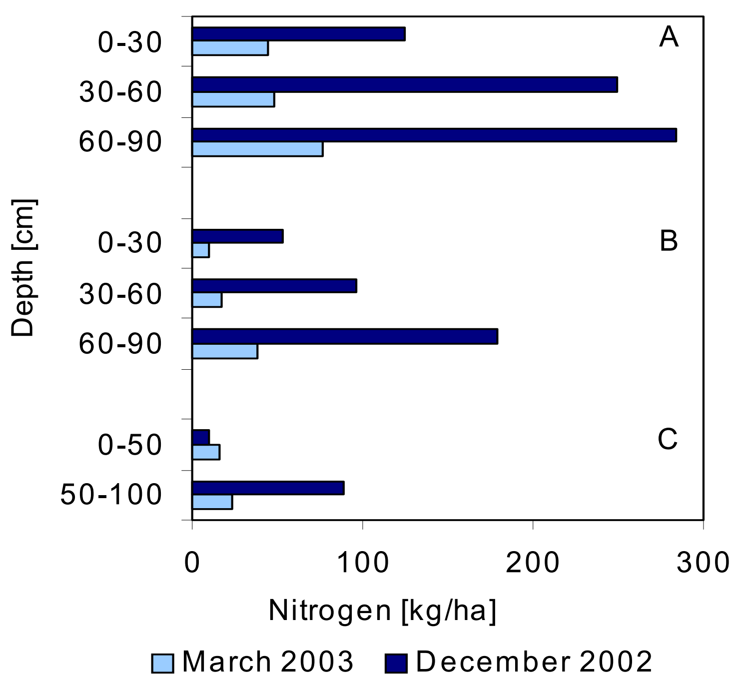

Figure 2: Nitrogen values in fall and spring within the root zone of different cropping systems. (A: continuous vegetable, B: peach tree plantation, C: grain potato rotation)

Table 1: Balance of nitrogen in different crops grown in the West Asia Region fertilised and irrigated with conventional means[1]

Country	Crop	N input	N removal	Excess N	% Fertilizer utilization using 15N methodology
		Kg/ha			
Lebanon	Potato	450	250	200	24
	Potato*	240	235	5	40-61
	Protected cucumber*	258	190	68	50-69
Syria	Cotton	180	260	-80	43
Jordan	Tomato	168	125	43	7.2
	Garlic	200	62	138	7.5
Emirates	Cucumber*	400	50.6	341.4	29.7
Iran	Tomato	500	76	434	5.75
Turkey	Pepper	300	230.7	70	22.6
	Melon	400	71.8	328.2	11.0
	Eggplant	400	51.8	347.2	18.8

1. Source: IAEA_TECDOC-1266 (2002);
2. * Fertigation using drip system.

Research run in the Middle East area points to the relatively low nitrogen recovery by vegetables and field crops cultivated through conventional ways (Table 1). So even when leaching over winter occurs, SMNS is likely to be high in the region.

An important factor affecting SMNS is Soil texture. Contrary to sandy soils, heavy soils with small pore spaces and a high soil particle surface are usually considered to have a high capacity to bind nitrogen and to hold back water (e.g. Cameron et al. 1997). However, there is a danger of preferential flow along soil cracks and macro pores in these soils which may lead to a rapid translocation of nitrate to deeper soil horizons (White 1985). At sites with a high over-fertilisation the risk of groundwater pollution with nitrogen is often high. However, heavy soils can keep more nitrogen during the non growing season than sandy soils. N-losses during winter time can be tremendous. Figure 3 shows the estimated N-losses for different cropping systems in the Bekaa valley, Lebanon for the non growing season in 2001/2002. Especially high losses can be seen for the continuous vegetable cropping system with 264 kg N/ha, while N losses for the grain-potato cropping system are little.

2.1.1 Mineralisation of organic matter

The process of mineralisation is the transformation of organic nitrogen into ammonium (NH_4^+) and nitrate (NO_3^-) by microbial activity. Inorganic nitrogen forms are the only forms which are absorbed by plants from the soil solution in significant quantities. Mineralisation occurs naturally near the soil surface, where microbial activity is highest. Soil organic matter, cover crops, crop residues, manure, compost and other types of organic fertilisers also supply growing crops with nitrogen through mineralisation.

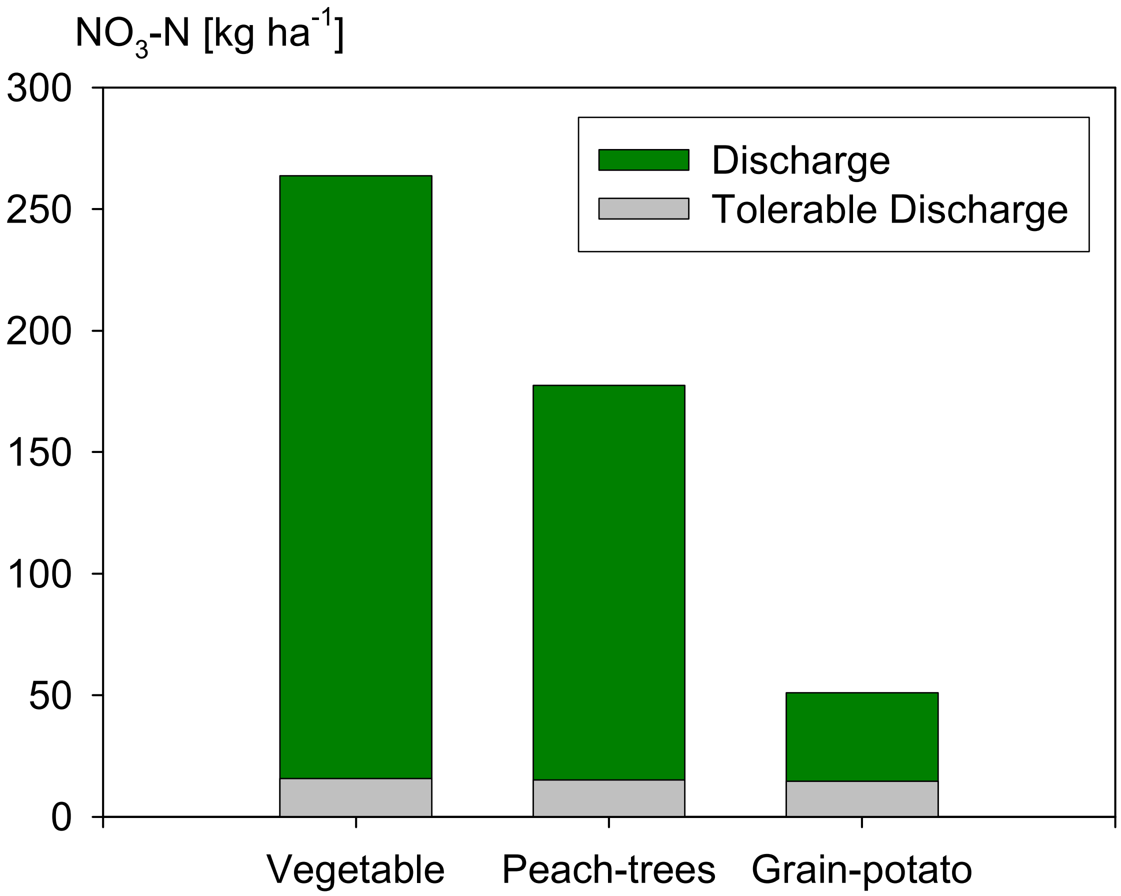

Figure 3: Estimated nitrate-N losses (Discharge) below the root zone through leaching for the period December 2001 to March 2002

Soil organic matter

The top 15 cm of a 3% organic matter (OM) soil will contain about 1800 kg of nitrogen per acre in the organic form (Brandy 1990). Frequently there is twice as much N in the entire soil profile. Crops are unable to use organic N directly. Soil tests in South Dakota have shown that within a year an average of 45-70 kg of N/ha are released through OM decay and become available to plants (Gerwing and Gelderman 1993). These values can vary greatly and may be less than 30 more than 120 kg/ha.

Crop residues and green manures

Sufficiently high soil temperature favour a fast decomposition of fresh crop residues and green manures. Results from Germany have shown that within 10 weeks after incorporation 70% of the organic nitrogen contained in crop residues can be taken up by the following crop under normal summer weather conditions (Tremblay et al. Internet pub.). However, the amount of nitrogen that mineralises and the timeframe over which mineralisation occurs can vary depending on region, climate and soil. For example under the prevailing pedoclimatic conditions of the Lebanon, the soil mineralization power was measured between 1.5 and 2.4% per season (Kechli, 1999). The mineralisation rates of different organic fertilisers are given in Pansu and Thuries (2003).

Temperature, moisture, and aeration are important factors determining the mineralisation rate of plant residues in soil. Incorporation and size reduction also enhance mineralisation by increased microbial amenability. Differences in mineralisation rates of different crop residues are caused by the composition of the individual plant tissue. On the one hand, the ratio of carbon to nitrogen is important - tissues containing a higher carbon to nitrogen ratio (more carbon) are more resistant to mineralisation. On the other hand, plants with higher lignin and hemicellulose content are more persistent to microbial degradation than others.

Crop residues and green manures are able to release significant amounts of nitrogen. This amount depends on the composition of the residues as well as the mineralisation rate. Crop residues can supply 100 kg or more mineral nitrogen per ha (Table 2; Tremblay et al. Internet pub.). Most plant species release an average of 3 kg of mineral nitrogen per tonne of fresh biomass (plant tissue). Legumes, based on their ability to fix nitrogen are able to release up to 5 kg of mineral nitrogen per tonne of fresh biomass. The reported amounts of incorporated fresh plant residues in the Lebanon indicate that the potato residues reach 17.5 ton/ha, with a potential release of 128 kg N/ha. The dry cotton residues are around 10000 kg/ha carrying 220 kg N/ha.

Table 2: Potential nitrogen mineralisation from crop residues

Crop	Fresh biomass normally incorporated after harvest (t/ha)	Potential nitrogen from mineralisation (kg/ha)
Brussels Sprouts	50-60	150-200
white Cabbage, red Cabbage (processing)	40-50	120-150
Broccoli, Chinese Cabbage, Savoy Cabbage, white Cabbage (fresh), Cauliflower, Fennel, Peas	30-40	90-120
Beans, Carrots, Celery, Iceberg Lettuce	20-30	60-90
Kohlrabi, Leeks, Spinach	10-20	30-90
Corn salad, Lettuce, red Radish, white Radish	<10	< 30

(Tremblay et al. Internet pub.)

The incorporation of crop residues and green manures in fall leads to an increased nitrogen availability for the next crop but also to a higher leaching potential compared to incorporation in spring. In general the management of crop residues and green manure involves the detailed planning of time and source of application and incorporation, so a highly efficient use of nitrogen is guaranteed.

Compost

Less mineral nitrogen is generally supplied by compost, proportionately, than crop residues and green manures. During the composting process, the easily degradable N rich materials are mineralised first, while the more resistant organic matter remains. Compost contains only small amounts of mineral nitrogen, which is immediately available to plants (Tremblay et al. Internet pub.). In some cases even more N is assimilated by microorganisms to degrade compost, than is released by mineralisation. A compost with low C:N releases the greatest quantities of nitrogen. However, applying compost year after year indirectly enhances the supply of organic nitrogen by increasing the soil humus content, improving soil structure and creating conditions favourable to microbial activity.

As an example in the Lebanon the C:N ratio in the compost of Beirut Municipal Treatment Plant was slightly below 70 with a total N content of 0.58%. The use of this compost in agriculture revealed that compost added to a loamy soil at a ratio of 1:6.6 yielded significantly higher tomato yield. Plants receiving extremely high compost application suffered from N starvation and or salinity. (Darwish and Serhal, 1987).

Manure

In crop production manure is an excellent organic amendment. It contains nitrogen in both, mineral and organic form, and contains many other nutrients as well. Manure management is highly complex. Detailed recommendations are not within the scope of this guide, but some principles should be mentioned (Tremblay et al. Internet pub.).

Inadequate management of manure leads to the pollution of groundwater with nitrate and phosphorus. Manures of different kinds compost differently, hence storage, its duration as well as the manner of application influence their decomposition. To estimate the nitrogen content of manure, data can be found in literature, though it is preferable to analyse the composition of the manure.

The average amount of available nitrogen per ton of manure in the first year is listed in Table 3. Up to 50% of the total nitrogen in liquid manures and poultry manure is readily available to plants but also susceptible to leaching (Tremblay et al. Internet pub.). The mineralisation rate of organic nitrogen, which is held in the solid particles of manures, is comparable to that of organic nitrogen from easily degradable compost. Twenty tons of cattle and hog manure or 4 tons of poultry manure may provide 50 kg of available N in the year of application.

Table 3: Nitrogen Credits from Manure in the first year after application

Kind of Manure	**Nitrogen credit**
Solid	*kg/tonnes*
Cattle or hog	2,5
Sheep	7,5
Poultry	12,5
Liquid	kg/1000 l
Dairy	210
Beef	225
Swine	275
Poultry	600

Gerwing and Gelderman 1993

Legumes

The amount of nitrogen supplied by legumes depends on the type of legume and the amount of residues incorporated. The amount of nitrogen available from legumes is listed in Table 4. Alfalfa can contribute up to 170 kg of available nitrogen per ha in the first year after incorporation.

Table 4: Legume Nitrogen Credits

Previous Crop	**Crop to be grown Short season (small grains)** *kg N/ha*	**Crop to be grown Full season (corn, sunflower, sorghum)** *kg N/ha*
Soybeans	0.6	1.2
Alfalfa (harvested) Sweet clover (unharvested) *plants/m²*		
>50	85	170
30-40	55	110
10-20	28	56
<10	0	0
Sweet clover (harvested)	11	22
Red clover (harvested)	40	80
Edible beans, Field peas	11	22

Gerwing and Gelderman 1993

Other organic fertilisers

Other types of organic fertilisers, such as feathers, meat, crab, fish, cottonseed meal and dried whey, are used primarily by organic farmers. These materials decompose very differently, but may release a high amount of Nitrogen in a short time. The mineralization rate of these materials is generally slower than that of synthetic fertilisers, but the rate can vary significantly depending on the characteristics of the product (Pansu and Thuries 2003; Thuries et al. 2001).

2.1.2 Precipitation

Nitrogen oxides (NO_x) are released to the air through fossil fuels combustion in motor vehicles, households, industry and various other sources. In the atmosphere nitrogen oxide is converted to nitric acid before reaching the soil in the form of precipitation and dry deposition. The input of nitrogen, in the form of ammonia, ammonium and nitrate, varies between less than 1 and 7 kg N/ha*a in the USA and 5-30 kg N/ha*a in Germany (Tremblay et al. Internet pub.). For the Arab countries it may also vary within these values.

2.1.3 Irrigation

A significant amount of nitrogen can be found in irrigation water, particularly in areas with a high density of animal production or intensive agricultural and horticultural production. Irrigation water should be analysed regularly to obtain an estimate of the nitrogen input from this source.

Example calculation for the N input from irrigation in the Bekaa, Lebanon: Irrigation at a rate of 600 mm/a (potato field) with shallow groundwater containing 100 mg/L nitrate, supplies the soil with an amount of 600 kg /ha* season of nitrate (600 mm x 100 mg/L x 10 000 m^2/ha x 1 kg / 1 000 000 mg). This is equivalent to 135.6 kg /ha of N, which is usually not considered in the nitrogen balance.

For example while studying the sources of N in potato yield using nuclear techniques in Lebanon Darwish et al. (2003) found out that up to 55 kg N/ha per season came from irrigation water of local quality. This was equivalent to 25% of the N removed by crops.

2.1.4 Mineral fertilisation

The amount of N available from natural sources (mineralisation, irrigation, precipitation, etc.) is often not sufficient to meet crop needs. The remainder must be applied as fertiliser. The nitrogen balance can be used to calculate the amount of fertiliser to be applied.

Many kinds of nitrogen fertilisers are available on the market. They differ in composition (ammonium, nitrate, urea), concentration, rate of release, price, presence of impurities and availability of other nutrients. Different forms are available (solid, liquid, gas) and hence require different methods of application for a safe and efficient use. All of these factors should be considered when choosing a fertiliser (Tremblay et al. Internet pub.).

2.2 Outputs

2.1.5 Plant needs

Crop requirement for quantitative nitrogen consist of: 1) the amount of nitrogen that will actually be taken up by the plant, and 2) the quantity of nitrogen that must be present in soil in order to achieve the crops full potential yield, in this paper called surplus target value (STV). The two values represent the total plant nitrogen requirement.

Uptake

Plants take up nitrate in greater amounts than ammonium. Nitrate, unlike ammonium, accumulates in plant tissues when available in greater amount than required for optimal growth. The quantity of nitrogen uptake by plants depends on many variables, including the stage of plant growth, the concentration of other nutrients in the soil, the availability of soil water, and the weather conditions.

Nitrogen uptake is enhanced by a warm, sunny weather and sufficient water supply because photosynthesis rates are high under these conditions. The maximum Nitrogen demand of crops is at the stage of maximum growth. For many crops growth delays caused by nitrogen deficiency lead to irreversible yield reductions. Other crops may recover, but maturity may also be delayed. Different crops demand different amounts of nitrogen. Table 5 contains the total nitrogen uptake of various vegetables. If yield differs significantly from these averages, the total nitrogen uptake per ha based on average yield, can be adjusted accordingly using a ratio calculation (Tremblay et al. Internet pub.).

Surplus target value

For optimum growth plants require a surplus of nitrogen available in soil compared to their total uptake. This additional amount is called surplus target value. The surplus target value for a crop is determined experimentally as the quantity of mineral nitrogen that is present in soil at harvest when optimal yield is obtained.

Studies showed that the surplus target value was more or less constant, and that reducing it caused yields reduction. One role of the surplus target value is to prevent nitrogen shortage that might occur if the amount of nitrogen available in soil is limited to that which is usually taken up by the plant. The reason for this shortage is the low fertilizer recovery of the plant which is only able to remove a fraction of the total amount of mineral nitrogen available in soil.

The efficiency of plants to extract soil nitrogen is diminished below a critical soil solution concentration. The surplus target value given in Table 6 for crops with small, shallow roots and few hair roots like leeks or onions are rather high and so an inefficient nitrogen use from soil is the result (Tremblay et al. Internet pub.).

Table 5: Approximate nitrogen uptake per tonne of yield of common vegetables, as well as the nitrogen uptake based on the average yield.

Crop	Approximate nitrogen uptake per tonne of yield (kg N/ha)	Average yield (t/ha)	Nitrogen uptake for average yield (kg N/ha)
Beans, bush	8	12	100
Beets	5	50	250
Broccoli	13	20	260
Brussels sprouts	16	25	400
Cabbage, Chinese	3.5	70	250
Cabbage, white (early)	4	40	160
Cabbage, white (late)	3.5	80	280
Carrots	2.5	60	160
Cauliflower	7.5	35	260
Celery	4	50	200
Corn salad	4	15	60
Endive	3	40	120
Kale	5	30	150
Kohlrabi	4.5	40	180
Leeks	3.5	40	140
Lettuce, Boston	2.5	40	100
Onions	2.5	60	150
Peas	4	30	120
Radishes	3.2	25	80
Spinach	5	25	120

(Tremblay et al. Internet pub.)

Plants with long, deep, extensive root systems, and long cropping periods require smaller surplus target values. The surplus target value should be as small as possible but should still allow maximum growth. Any additional fertilisation will lead to nitrogen accumulation in soil and increase the risk of leaching. To prevent or lower the leaching of nitrogen after harvest, the remaining soluble soil nitrogen can be removed from the soil by growing a cover crop, such as radishes or mustard, which are excellent nitrogen scavengers.

One possibility to lower the surplus target value is the application of nutrients in the root zone at concentrations and frequency required by the crop. Fertigation with drip system presents a flexible system allowing the control of timing, concentration and amount of added water and fertilisers. The automation of irrigation scheduling using crop models would contribute to an optimisation of water and fertiliser use (El Moujabber et al., 2002).

2.1.6 Mineral nitrogen not absorbed by the plant

Plants are able to absorb only up to 60 to 80% of the nitrogen applied in form of mineral fertilisers. In many Middle East countries, nitrogen recovery is less than 40% under conventional agricultural practices. Most of the remainder becomes unavailable to plants through various processes: leaching, denitrification, immobilisation, ammonium fixation, and volatilization. In many cropping systems, nitrogen losses are primarily due to leaching and denitrification. In fact, the U.S. Environmental Protection Agency estimates that fertiliser use contributes to over 60% of the total ammonia emissions to the atmosphere in the United States, or more than 500 million tonnes annually (Tremblay et al. Internet pub.).

Table 6: Surplus target value of Nitrogen required for some vegetable crops

Mineral nitrogen required in rooted soil layer until harvest (Surplus target value)		
30 kg N/ha	30 to 60 kg N/ha	60-90 kg N/ha
Brussels sprouts Cabbage, late Carrots, late	Beans Beets Broccoli, late Cabbage, Chinese Cabbage, early Carrots, early Celery Endive Kale, curly Kohlrabi Lettuce, head Lettuce, iceberg Radicchio Radish	Broccoli, early Cauliflower Leek Onion Spinach

(Tremblay et al. Internet pub.)

Leaching

Leaching occurs primarily in fall and spring when precipitation is high. Infiltrating water carries nitrate beyond the rooting zone. Leaching only occurs in summer by access irrigation and heavy rains. For example, the resident time of soluble pollutants in the soils of the Bekaa, Lebanon, depending on soil depth, texture and water table depth is several months to three years (Darwish et al., 2000). Thus, the groundwater in this area is highly vulnerable to nitrate contamination.

The quantity of nitrate leached depends mainly on four factors: the amount of precipitation/irrigation, the concentration of nitrate in the soil, the soil characteristics and the distribution of plant roots. The probability of leaching increases with the amount of precipitation and with the concentration of nitrate in soil (Steevoorden 1989). Table 7 shows that light soils (sandy) are more susceptible to nitrate leaching than heavy soils (clay). Root distribution also influences leaching. Leaching of nitrogen is greater in furrow soil zones where roots are scarce (Tremblay et al. Internet pub.).

Table 7: Relationship between soil texture, field capacity and probability of nitrate leaching

Soil type	Field capacity (mm of water per mm of soil depth)	Probability of leaching
Sand	135	High
Loamy sand	210	|
Sandy loam	245	|
Loam	360	|
Silty loam	330	V
Clay	400	Low

(Tremblay et al. Internet pub.)

Immobilisation

During breakdown of organic matter, microorganisms use nitrogen. If the organic matter does not contain enough nitrogen to supply their requirements, they absorb mineral nitrogen and convert it to organic compounds which are unavailable to plants. This conversion is called immobilisation. Roughly estimated, microorganisms immobilise 15 to 20% of mineral nitrogen incorporated or present in the upper soil layer during a growing season. This figure may rise up to 40 % if little mineral nitrogen is available in soil.

Denitrification

Denitrifying bacteria are able to use nitrate as energy source in oxygen-depleted soils. During this process, soil nitrate is converted to gaseous nitrous oxide (N_2O) or Nitrogen (N_2). The process occurs in soils such as marshes, peaty soils, and poorly drained ground and it is favoured by high soil temperatures (> 15°C). In general, 10 to 30% of applied mineral nitrogen is subject to denitrification (Tremblay et al. Internet pub.).

Nitrification

Nitrification is a microbial two-step process beginning with the oxidation of ammonium to nitrite, followed by the oxidation of nitrite to nitrate. It can contribute to leaching when ammonia fertiliser is converted primarily to nitrate instead of ammonium, which binds readily to clay particles.

Ammonium (NH_4^+) fixation

For short periods, crops may lack mineral nitrogen because of ammonium fixation. Clay particles may trap ammonium between their layers, making it unavailable to crops or microbes that would otherwise convert it to nitrate.

NH_3 volatilization

The process by which ammonium (NH_4^+) is converted to ammonia (NH_3) and is released into the atmosphere is called volatilization. This conversion is sped up under certain conditions such as high soil and air temperatures and dry weather. The likelihood that ammonium will be converted rises exponentially with increasing pH. Ammonium fertilisers should be avoided when the soil pH exceeds 7.0. Under ideal conditions for volatilization, up to 50% of the nitrogen applied may be lost due to this process (Tremblay et al. Internet pub.).

Economic loss through volatilization: The price of urea containing 46% of nitrogen and ammonium nitrate containing 34 % of nitrogen is similar. Considering the plus in nitrogen contained in urea its application seems to be the natural choice. However in hot, dry and windy weather as typical for most of the Arab region, urea is much more susceptible to ammonia volatilization, and a loss of up to 40 % of Nitrogen is not uncommon. A simple calculation illustrates how a farmer may save money. Suppose the farmer wants to supply 50 kg N/ha to his crop – choosing Urea would cost him:

78 US$ = 181 kg/ha urea x 0.43 US$/kg (50 kg N/ha = 181 kg/ha x 0.46 N/kg x 0.60 N/kg remaining after volatilization loss of 40%)

On the other hand the choice of ammonium nitrate would cost him:

63 US$ = 147 kg/ha ammonium nitrate x 0.43 US$/kg (50 kg N/ha = 147 kg/ha x 0.34 N/kg)

Although urea contains more nitrogen than ammonium nitrate, the loss through volatilization actually increases the costs of fertilization with urea. The choice of ammonium nitrate would save the farmer about 15 US$.

3 Methods of estimating the nitrogen fertiliser requirements of crops

The quantity of nitrogen fertiliser to be applied is primarily a function of the difference between the mineral nitrogen content in soil plus the amount expected to be released during the season from organic sources, and the nitrogen requirements of the plant. Before applying fertilisers, it is important to measure or estimate these two main sources of mineral nitrogen in the soil: the nitrogen already available at the beginning of the season (called soil mineral nitrogen, or SMN) and the nitrogen released by mineralisation throughout the season. Vegetable producers may estimate these nitrogen quantities based on their experiences and observations, by performing calculations, or by directly measuring them using methods of soil and plant analysis.

3.1 Methods based on experience and observations

3.1.1 Experience

In agriculture, fertiliser application is often based on experience and not on control measurements. Thus often more fertiliser is applied than necessary, to guarantee good yields. When trying to fertilise efficiently, it is also wise to consider the conditions and characteristics of each field, and year-to-year variations as well.

Single recommendation

Regardless of the condition of the soil or the history of the field, several guides give single recommendations for a given crop. These guides are general, but can be used by farmers to improve their own experience by using correction factors. These correction factors summarized by Tremblay et al. (Internet pub.) are as followed.

Correction factors

Fertiliser N may be reduced where:

- A large quantity of crop residue was left in fall of the previous year;
- The previous winter was mild and dry;
- The date of planting is late in the season;
- Fresh crop residues or solid manure were applied before planting;
- A below average yield is expected;
- The nitrate content of the edible part of the plant has to be limited;
- The nutritive quality of the plant (sugar or vitamin C content) has to be improved;
- Better disease resistance is required;
- The plant leaves are not the marketable vegetable product.

Fertiliser N may be increased where:

- Precipitation during the previous winter was high;
- Precipitation during the spring was high;
- Precipitation came late in the growing season;
- The date of planting is early in the growing season;
- An above-average yield is desired;
- The plant leaves have to be kept in good health (e.g.: carrots);
- A dark green colour is required.

The use of mulch in cropping practices has no specific effect on nitrogen requirements and does not change recommendations of quantity of N fertiliser to be applied.

3.1.2 Observation of plant colour

By investigating the colour of the crop foliage farmers sometimes judge the need for nitrogen fertiliser. Using a colour chart that is available for some crops allows improving the efficiency of this method. But based on local differences, this approach is still only a rough estimation. Darwish et al. 2003 observed that in the Bekaa valley, Lebanon the colour of the crop foliage and consequently the yield of potatoes is more affected by water deficiency than N deficiency. Since, water shortage is the rule rather than an exception within the Arab region, the investigation of crop foliage colour may be misleading, and should therefore be handled with care.

3.2 Calculation-based methods

A producer or agronomist who wishes to refine the estimate of the required nitrogen may use different tools such as tables, expert systems or simulation models. Tables contain recommendations based on solid, agronomic research. Expert systems and simulation models are computer programs that estimate nitrogen fertiliser requirements using parameters of the nitrogen balance. The difference between expert systems and simulation models lies primarily in the type of user. The former are available for producers and farm advisers, while the latter are intended for researchers.

3.2.1 Expert systems

Calculating a nitrogen balance based on figures from tables can be very tedious. A separate balance should be calculated for every field, and the more components are included, the more time consuming the process becomes. Moreover, in some places supermarket standards require that fertiliser management complies with established procedures and producers are therefore obliged to maintain a field log. Computer programs have been developed and are available on the market to help producers formulate efficient fertiliser recommendations and keep accurate records while reducing the amount of time devoted to fertiliser management. They frequently offer a user-friendly interface designed especially for agricultural producers and advisers. They generally produce recommendations for less nitrogen than producers would otherwise apply. Many of the software packages that have been developed to estimate the nitrogen fertiliser requirements are cost-effective investments (Tremblay et al. Internet pub.).

3.2.2 Simulation models

Mathematical models for the dynamics of nitrate in the root zone, the vadose zone and in groundwater can be valuable tools for groundwater protection or improved nitrate efficiency provided that they are properly applied. They are especially useful as a planning instrument since they

- are portable:

    Models are adaptable to different situations after adjusting the model parameters accordingly.

- allow prognosis:

Only models allow the future prediction of effects resulting from measures taken to either improve nitrate efficiency or to protect the groundwater. It is also possible to define future goals and then to use the model to estimate what measures should be taken at present to eventually reach these goals.

- allow a deeper understanding of the system:

They permit the identification of sensitive input parameters and their influence on nitrate efficiency and groundwater leaching. The interdependency of the relevant processes become more transparent.

Main Problem - uncertain data: Usually spatial data is not available in a density and quality that is needed to set up a numerical model. Methods exist to tackle this problem such as Geostatistics, stochastic modelling or sensitivity analysis. In general these methods are part of the data preprocessing.

3.2.3 Applications of Models

For the investigation of the following processes models may be very useful:

- Nitrate budget in soil and nitrate transport through the unsaturated zone or a combination of the two.
- Nitrate transport and transformations in groundwater.

Use of a **nitrate budget model** allows the calculation of leaching, uptake and transformation of nitrate depending on climate and cultivation on the local or sub-regional scale. The main purpose of these models is the optimisation of plant growth with regard to a minimised fertiliser usage.

Groundwater models can be used for decision making because they allow to model changes in the groundwater system in advance. Depending on a sufficient data base, a good description of groundwater flow is possible that allows a detailed water balance for the whole as well as certain subsystems. Based on the flow model it is possible to run a transport model that allows nitrate mass balances. As a result priority areas within an investigated region can be defined that require special measures with regard to nitrate pollution.

3.2.4 Principles of modelling

Budget models

This model type is usually 1-dimensional. Several sub models for water transport, nitrate transformation and plant growth are usually coupled on the scale of a soil column.

- The sub model water transport provides information about water content and water transport from climatic, soil and groundwater table depth data.
- The sub model nitrate transformation describes mineralisation, immobilisation, nitrification and denitrification depending on environmental conditions.
- The sub model plant growth calculates nitrate uptake based on the processes of photosynthesis, respiration and plant development.

Up to the plot scale budget models perform quite well in fitting measured data. The quality of the model output depends heavily on the quality of data and the applicability of the model approach to the environmental situation. Sensitivity to input data such as soil mineral nitrogen (N_{min}) or soil type is usually strong. Uncertainty may therefore be quite influential on the model results.

The two main results of budget modelling are the estimation of nitrate supply to the plant and the amount of nitrate leaching to groundwater. The first result allows the optimisation of fertiliser application with regard to a minimum input of nitrate without reducing yield while the second result is an important figure for groundwater protection. A scenario analysis allows the assessment of effects of variable land use situations on nitrate concentration in groundwater or of variable nitrate input on plant growth. These are the main advantages of nitrate budget modelling indicating that these models are valuable tools with regard to land use planning.

Groundwater models

Groundwater models may be helpful in identifying the fate of nitrate within an aquifer. The quality of the model results is highly dependent on data density and quality. Especially the following data should be available in a sufficient spatial as well as temporal resolution:

- hydrogeological underground information, stratigraphy
- hydraulic parameters (e. g. conductivity) of the different substrates
- historical hydraulic heads in a high temporal resolution (if necessary in overlying aquifers)
- interactions with surface water bodies
- historical data on water extraction through wells

- irrigation data
- data on present and historical land use including records of fertiliser input on plot scale

This enumeration shows that only intensively investigated watersheds are suitable for the application of groundwater models. Spatially variable parameters such as conductivities may be collected during model development while temporal data must be gathered well in advance (Figure 8). It is important to note that the practical application of groundwater models is currently limited to porous media.

The evaluation of model results requires knowledge of its limitations with regard to predictions. An instrument allowing the exploration of these limitations is a sensitivity analysis where the reaction of a system on parameter changes is evaluated (Figure 4).

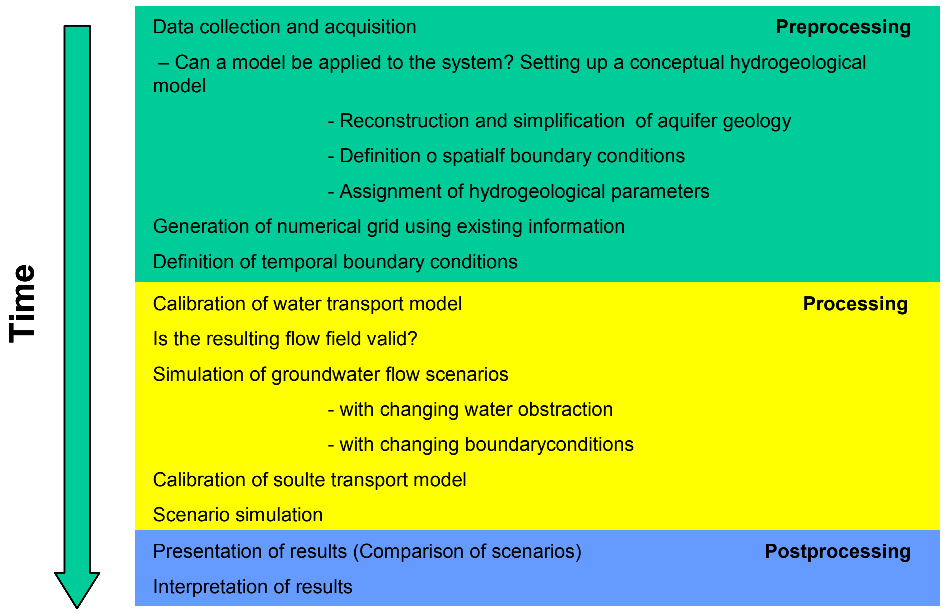

Figure 4: Steps towards a groundwater flow and solute transport model

3.3 Methods based on soil and plant analyses

Using soil and plant analysis nitrogen fertiliser needs can be determined. The measurement of N_{min} in spring and the continuous monitoring of N_{min} (CMN) within the vegetation period are two methods to determine fertiliser needs based on mineral soil nitrogen measurements. Nitrogen measurements in plant tissue using sap tests, chlorophyll readings and total nitrogen analysis are used to determine nitrogen fertiliser requirement. Most often a soil mineral nitrogen test in spring is used to determine nitrogen fertiliser requirement. For some plants, plant tissue test may give results as good as soil tests, and in some situations even better ones. When choosing a method, farmers should be aware that the different methods have advantages and disadvantages in different situations.

3.3.1 Nitrate soil tests

A nitrate soil test measures the total amount of nitrate bound nitrogen in soil. It is the most important nitrogen management tool currently available, because its results correlate very well with crop response.

It is crucial that soil is tested for nitrate up to the current rooting depth of the crop (Table 8). A representative soil sample is a mix from at least 15 cores. For a rooting depth of 90 cm, it comes in three bags, one containing the mixed samples of the 0-30 cm surface layer, the others the mixed samples of the 30-60 cm and 60-90 cm subsoil layers.

Once a sample has been collected, it must be cooled down quickly to prevent any changes in the nitrate content before analysis. In order to be able to compare the results of different samplings, it is important that a single method is used for the determination of soil mineral nitrogen. The soil-testing lab may also analyse the samples for phosphorus, potassium, and other nutrients.

Table 8: Rooting depth of some vegetable crops

Root zone		
0-30 cm	30 - 60 cm	60 - 90 cm
Kohlrabi	Beans	Asparagus
Lettuce, head	Broccoli	Brussels sprouts
Lettuce, iceberg	Cabbage, early	Cabbage, late
Peas	Cauliflower	Cereals
Radish	Celery	Corn
Spinach	Endive	Rape
	Leek	
	Potato	

(Tremblay et al. Internet pub.)

N_{min} method

When applying the N_{min} (for mineral nitrogen) method the measured soil mineral nitrogen is used in the calculations. The concentration of mineral nitrogen is determined from a soil sample collected early in the season, before seeding or transplanting takes place. This concentration is subtracted from a plant specific target value to give the final fertiliser recommendation. Soil sampling and nitrate analysis should be carried out with care and precision. The target values are based on local experiments. The N_{min} method results in relatively precise recommendations for the individual field. Under these conditions, the N_{min} method is more exact than using average-value tables or approximations based on observations. The three main principles of the N_{min} method are summarised below (Tremblay et al. Internet pub.).

Principles

1- Soil sampling depth must correspond to the rooting depth of the crop.

2- Nitrogen in the soil must be quantified because it is an effective contribution to the total crop needs. The more nitrogen the soil contains, the less must be applied.

3- For each crop, a specific target value must be available that is based on the site-specific maximum yield.

The target value is determined experimentally, and is the sum of nitrogen already in soil and nitrogen supplied by the application of fertilisers. Target values for Germany are given in Table 9. They may also apply with some restrictions to the Arab region.

Table 9: N_{min} method fertilisation target values for some vegetable crops

Crop	Target value	Nmin target value category
Asparagus; Carrot; Chicory; Peas	80-100	Very low
Beans, dwarf; Beans, pole; Lettuce, Iceberg; Lettuce, leave; Radicchio	130-150	Low
Endive; Kohlrabi; Onion; Spinach; Radish	160-200	Average
Beets; Brussels sprouts; Cabbage, Chinese; Cabbage, early; Celery; Leeks; Radish, Japanese; Rhubarb	220-250	High
Broccoli; Cabbage, late; Cabbage, processing; Cauliflower	300-350	Very high

(Tremblay et al. Internet pub.)

The N_{min} method improves fertiliser management because the nitrogen supply is close to the actual crop need. The method is highly recommended in areas with intensive vegetable farming (like the Bekaa valley in Lebanon or the Ghouta in Syria), particularly for farms located near drinking water sources, where the danger of pollution is high. Unfortunately, sampling and analysis are not always practicable. Farms may be located at considerable distance to a laboratory, and farmers often manage multiple crops, each requiring an additional sampling and a separate analysis. A simple solution to this problem is, however, on the way. The development of a nitrate quick tests allows farmers to apply the N_{min} method more easily. A complete method for a soil nitrate quick test is included in Appendix I and III.

Using the "target value" approach

The total amount of nitrogen that must be supplied to the crop for optimal yield is represents by the N_{min} target value. Assuming soil mineral nitrogen content of zero before cropping, the resulting fertiliser recommendation would be equal to the target value. In reality, however, the soil usually contains a significant amount of nitrate. The recommendation must therefore be less than the target value. Exceeding the target value leads to over-fertilisation and an increased risk of environmental pollution. Target values integrate the capacity of the soil to release nitrogen from the mineralisation of humus throughout the growing season. Environmental effects, soil characteristics and cropping practices that affect this mineralisation vary considerably from region to region; therefore the N_{min} target values should be based on local experiments.

CMN method

The N_{min} method is used to decide how much nitrogen should be applied at the beginning of the season. It does not consider the varying plant needs throughout the season. This is an advantage of the CMN (Continuous Monitoring of soil mineral Nitrogen) method which - although relying on similar principles - allows a decision on how much of the recommended nitrogen should be applied at planting and as top- or side-dress applications during the growing season. Instead of just one target value, the CMN method uses target values that differ throughout the season. Any number of supplementary nitrogen applications can be made based on date-specific target values and soil mineral nitrogen tests prior to top or side-dressing. The CMN method offers the following advantages: sampling can be flexible (in terms of dates); data collection can be spread throughout the season, which is an advantage for the laboratories, because they often have too much work in the period preceding planting or transplanting; information can be obtained on mineralisation (speed, quantity).

3.3.2 Using soil and sap nitrate measurements

A common cause of over-fertilisation is the lack of consideration of the plant available nitrogen in the soil. Reducing a fertiliser recommendation by the amount of nitrogen supplied by the soil and irrigation water is a key to efficient fertilising. It is important to note that monitoring sap nitrate provides essentially the same information as soil nitrate testing. Sap nitrate can be correlated to nitrogen supply from the soil which means that fertiliser recommendations can be adjusted using the principles of the N_{min} method.

Plant nitrate tests

Like in soil nitrate concentrations in plants are far from being homogeneous. Therefore, one sample should comprise tissue from at least twenty plants collected throughout a field. Generally, the youngest newly expanded leafs are selected from each plant, because nitrogen moves from old tissues to younger ones within a plant.

Various measurements of nitrogen can be made from plant samples. Some tests are destructive like sap nitrate tests or total nitrogen analysis which require the leaves to be removed from the plants. The chlorophyll meter, on the other hand, can be used to measure tissue nitrogen of intact, growing leaves.

Sap tests

Sap nitrate tests can be used to monitor the nitrogen status of the plant. Once absorbed by the roots, nitrogen is transported to the leaves where it is transformed and incorporated into the living material. Although part of this transformation may take place in the roots rather than the leaves, nitrate concentration in the aerial part of the plant provides a good indication of whether the plant is receiving an adequate supply of nitrogen. The nitrate concentration is therefore measured in a representative part of the plant in order to identify any deficiencies. The sap from the leaf petioles tends to give the best indication of plant nitrogen status because it is more sensitive to fluctuations in nitrogen supply than the leaf blade extract (Tremblay et al. Internet pub.).

Chlorophyll measurements

The SPAD (Specialty Products Agricultural Division) meter by the Minolta Corporation (Ramsey, NJ) reacts instantly to the chlorophyll in the leaves. The device detects differences in chlorophyll content by measuring the amount of light transmitted through leaves and interpreting the data with respect to the properties of chlorophyll and the electromagnetic spectrum. This information can be used to assess the nitrogen nutritional status of the plant (Tremblay et al. Internet pub.). The device is accurate, sensitive, simple to use and requires no chemicals, preparation or destructive sampling. While chlorophyll content is usually highly correlated to nitrogen content, the chlorophyll level can also vary by the cultivars, the environmental conditions, the growth stage of the plant, disease, pests and cold temperatures. For this reason, farmer without the consideration of these other possible influences cannot use the SPAD meter Some of the effects on the chlorophyll level may not affect the usefulness of the SPAD meter, when assuring that readings from plants in the field to be fertilised are compared with those from an over-fertilised test strip in the same field, with the same factors at play. The SPAD meter is often thought of as an investment because of its relatively high cost.

N Sensor and precision agriculture

The N-Sensor is a control device, developed in Germany by the agricultural research subsidiary Hydro Agri International, for variable-rate application of nitrogen. The N-Sensor operates in "real time," detecting the crop's nitrogen requirements on the basis of reflectance from the plant cover, and immediately translating the measurements obtained into fertiliser applications. In practice, the system is integrated into the tractor and fertiliser spreader, and takes measurements during the application of sidedress applications (Tremblay et al. Internet pub.). As the device detects the nitrogen needs, the spreader is calibrated to the appropriate rate. In Europe, where the N-Sensor was developed for small grain crops, it has proven to be an effective tool; crops produced using the technology had greater, more uniform yields of grain, and higher protein concentration than those produced without it. Lodging was also reduced. In addition, nitrogen use was better managed resulting in a lowered risk of pollution.

Total nitrogen analysis

This method involves determining the total amount of all forms of nitrogen present in plant tissues. In this method, the tissues are dried, finely ground, digested in an acid solution and then quantitatively analysed. As in the case of soil sampling, great care must be taken in tissue sampling. Total nitrogen in the plant is related to both the amount of nitrogen in the sap, and the amount of nitrogen that has already been incorporated into organic compounds, such as chlorophyll, in the plant tissues. Total nitrogen analysis is limited in use when adjusting nitrogen fertilisation mid-season because it may take days or even weeks to receive the results from the laboratory. It is not a test that farmers can perform themselves (Tremblay et al. Internet pub.).

Nitrate measurement in the field

Nitrate test strips and reflectometer

Nitrate can be measured in sap and soil solution using Merckoquant test strips and a Reflefctoquant reflectometer distributed by Merck GmbH (full methodology appears in Appendix

III). Reflectoquant test strips are specially treated to react in the presence of NO_3^- by producing a colour, the intensity of which varies directly with the concentration. This test appears to be universally popular because it combines economy, precision and easy handling. The quick tests are just about as precise as conventional laboratory analysis, and thus are a good alternative. The colour of the strip can be evaluated by visual comparison with a colour chart or better by reflectometer.

Ion-specific electrodes

Another quick test of nitrate sap and soil solution uses an electrode with a membrane porous to a specific ion: in this case, the nitrate ion. There is a high correlation between results obtained using ionspecific electrodes and those obtained in a laboratory.

4 Nitrogen budget

An important method to estimate a nitrogen balance is the nitrogen budget. It accounts for all sources and sinks of nitrogen within a cropping system. The nitrogen balance, which is usually estimated at the beginning of a cropping cycle, can be used for the calculation of an optimum amount of fertiliser that either maximises yield and quality of a crop, or secures that the nitrogen concentration in the leachate does not exceed a certain threshold. The choice between the two strategies depends on the goals of the calculation.

4.1 Managing fertilisation with the nitrogen budget

Before the estimation of a balance it is important to recognise that the significance of the nitrogen sources and sinks differs depending on their relative importance in the nitrogen cycle. The following sources are mandatory in the calculation of a balance:

a) Mineral nitrogen in soil at the beginning of a cropping cycle,

b) mineralisable plant residues at the beginning of a cropping cycle, and

c) nitrogen mineralisation throughout the vegetation period.

Under irrigation an additional source of N may be the amount of nitrate in the irrigation water. Nitrogen input through precipitation is usually neglected.

Sinks to be considered are:

a) plant uptake,

b) the surplus target value - quantity of mineral nitrogen that is present in soil at harvest when optimal yield is obtained, and

c) nitrogen that is immobilised during the cropping cycle.

Nitrate leaching is usually ignored since precipitation in the Arab region is generally low during the cropping season. Exceptions are coastal areas with winter cropping seasons and high winter rains where leaching has to be considered. Leaching may occur due to irrigation, however, considering the scarcity of water in the Arab region, good agricultural practice should warrant that the amount of water irrigated exceeds the amount taken up by the plant only by the leaching fraction for salinity reasons. Denitrification is also ignored as it is compensated by the nitrogen input through precipitation in well drained fields. Also, ammonia volatilisation from calcareous soils was recorded in the region (Ryan et al., 1981).

4.1.1 How to obtain the input values?

In case site data is limited, the necessary values for the sources and sinks can be derived from tables that at best have been developed locally. Since growing conditions can vary greatly depending on the region, tables developed for other areas introduce additional errors. Whenever possible, measurements should be preferred since they are more precise.

Soil mineral nitrogen

Soil mineral nitrogen is usually estimated or measured at the beginning of a cropping cycle. This means that with multiple cropping cycles soil mineral nitrogen has to be estimated or measured several times throughout a year.

If soil mineral nitrogen is measured with a nitrate quick test the procedure is independent of the season, it is only important to assure that the target date is not too far ahead of the cropping period.

In case soil mineral nitrogen is estimated, the calculation differs depending on the time of estimation. Soil mineral nitrogen concentration in spring is calculated by adding soil mineral nitrogen of the previous fall and nitrogen mineralised from crop residues over winter and subtracting nitrogen loss caused by winter denitrification and leaching.

Table 10 allows the approximation of spring mineral nitrogen in soil. It can be seen that the value depends on soil type and precipitation. With increasing precipitation and decreasing grain size the soil mineral nitrogen increases from a minimum of 20 kg/ha to a maximum of 200 kg/.

Although it may be used with care elsewhere it is important to note that this table was developed for conditions in mid Europe. The processes controlling spring mineral nitrogen differ considerably at different locations, so that the creation of such a table is an important future research goal for the Arab region. For example, the measured soil N_{min} in spring from 0–60cm layer of clay soil used for field crops in central Bekaa did not exceed 10 kg N/ha (Darwish et al., 2002). It reached 50 kg under greenhouse conditions between successive crops: tomato and cucumber (Atallah et al., 2002).

In many countries of MENA region, a summer crop succeeds an early spring crop. Between two crop cycles the quantity of soil mineral nitrogen available is equal to that remaining after the previous crop. It consists of the surplus target value and the readily mineralisable crop residue. The effect of precipitation on residual nitrogen during summer is neglected.

Table 10: Example for the estimation of soil mineral nitrogen in spring in 0-60 cm soil depth. This table is adapted to mild winter conditions and should eventually be changed to be used in the Arab region.

	Sand		**Loamy sand**		**Loam**	
Quality of previous crop residue N	Small	Large	Small	Large	Small	Large
Precipitation November to March	Estimated soil mineral nitrogen in spring (kg N/ha)					
100 mm	30	50	80	150	130	200
200 mm	20	30	30	100	80	150
300 mm	20	20	20	50	30	100

(Tremblay et al. Internet pub.)

Uptake by the plant

Plant uptake can be estimated from Table 5. It depends on the crop type and yield and is estimated multiplying the nitrogen uptake per tonne of yield by the expected yield.

Surplus target value

The surplus target value for various crops is listed in Table 6. They vary considerably from crop to crop.

Plant residues

When inputs of residues from previous crop or mineral fertilisers are high, mineralisation tends to exceed immobilisation and has to be considered when estimating soil mineral nitrogen in spring. In Table 2 the mineralisable nitrogen content of the incorporated crop residues is listed depending on the previous crop type. In spring this value has to be corrected by a factor of 0.25 to account for the reduction of fall crop residues due to mineralisation over winter. The final value is further multiplied by 0.7 to account for the 70% of nitrogen that is likely to be mineralised during the season. This gives the final value needed for the nitrogen budget.

Humus mineralisation

A simple calculation can be used to calculate the mineralisation of humus. The amount of nitrogen is estimated by multiplying an assumed mineralisation rate of 5 kg N/ha in the root zone per week by the duration of the vegetation period.

Nitrogen immobilisation

Immobilisation by microorganisms or by ammonium fixation is responsible for an approximate reduction of soil mineral nitrogen by 15 to 20%.

Irrigation water

Unless 30 to 40 kg/ha of nitrogen are not exceeded, nitrogen from irrigation needs not to be included in the nitrogen budget. A decision to include nitrogen from irrigation requires the monitoring of nitrate in the irrigation water. It is not possible to predict this value.

Leaching

Leaching is an important process over winter in several areas of the Arab region. When soil mineral nitrogen is measured in spring it is implicitly included in the value. The same holds for values derived from tables. During the growing season it is assumed to be negligible, except for irrigation mismanagement where it could be significant.

Denitrification and precipitation

Loss through denitrification is usually compensated by nitrate input from precipitation and therefore not considered.

4.1.2 Sample calculation

Setting up a nitrogen budget for optimum crop quality and yield

Tables 11, shows how to estimate a nitrogen balance either in spring or for a second or third crop. A positive result indicates that the soil contains enough nitrogen to make fertilisation redundant. In case the result is negative the addition of fertiliser should equal the estimated balance. In case a second or third crop is considered the surplus target value of the first crop should still be available in the soil and can readily be used as an input for the second crop. A better alternative, however, is to measure soil mineral nitrogen instead. Also note that mineralization from crop residues is calculated differently for second or third crops leading to a differing nitrogen balance compared to the spring crop.

Table 11: Example of a quality and yield optimised nitrogen budget for carrot either as a spring crop or as a second or third crop. The preceding crop is Lettuce

Present Crop Carrot	**Text reference**	**Preceding Crop Lettuce**
Growing season (weeks)		24
Inputs	**2.1**	
Soil mineral N (kg/ha) spring estimate (or measured in spring or for second crop)	2.1.1 (3.3.2) Table 9 (Annex I)	15
Crop residues (In spring: kg N/ha*0.7*0.25) or (second crop: kg N/ha*0.7)	2.1.2 Table 1	5 (20)
Mineralisation (5 kg N/ha per week*weeks)	2.1.2	120
Total inputs		**140 (155)**
Outputs	**2.2**	
Plant uptake (kg N/ha)	2.2.1 Table 4	160
Surplus target value (kg N/ha)	2.2.1 Table 5	25
Immobilisation (uptake+surplus target value)*0.15 (kg N/ha)	2.2.2 Table 6	28
Total outputs		**213**
Nitrogen Balance	**4.1**	**-73 (-58)**

(Tremblay et al. Internet pub.)

Setting up a nitrogen budget for optimum groundwater protection

An alternative approach is a design of the nitrogen budget where the leachable amount of nitrogen is below a certain limit to ensure that the concentration in the leachate does not exceed the groundwater threshold for Nitrate (Niedersächsisches Landesamt für Ökologie 2001).

This approach is somehow different, but to give an idea on how it could be achieved, Table 12 shows a sample calculation for a single crop within one year. Of course choosing this approach is associated with an economic loss for the farmer that should be compensated to warrant the farmer's readiness to cooperate.

Table 12: Example of a nitrogen budget optimised for groundwater quality. The current crop is carrot. The preceding crop is Lettuce.

Present Crop Carrot	**Text reference**	**Preceding Crop Lettuce**
Growing season (weeks)		24
Inputs	**2.1**	
Total soil mineral N - Soil specific tolerance = 10 kg N/ha	2.1.1 3.3.2	5
Crop residues (kg N/ha*0.7*0.25)	2.1.2	5
Mineralisation (5 kg N/ha per week*weeks)	2.1.2	120
Total inputs		**130**
Outputs	**2.2**	
Nitrogen removed with yield (kg N/ha)		140
Allowable leaching (kg N/ha)		25
Immobilisation ((N removed with yield)*0.15) (kg N/ha)	2.2.2	21
Total outputs		**186**
Nitrogen Balance	**4.1**	**-56**

Adapted from Niedersächsisches Landesamt für Ökologie 2001

In this approach it is needed to specify the site specific nitrogen content of the yield, the maximum allowable amount of nitrogen leached and a soil specific tolerance that is subtracted from soil mineral nitrogen because it neither leaches nor is taken up during the whole year. The value of the soil specific tolerance depends on soil type and field capacity. It is high in loam and low in sand.

The tables 11 and 12 show that the nitrogen balance and thereby the amount of fertiliser needed is reduced by 17 kg N/ha in the approach of a nitrogen budget optimised for groundwater quality (table 12) compared to the approach crop quality and yield optimised nitrogen budget (table 11).

4.2 Conclusion

Using a nitrogen balance to determine the amount of fertiliser that should be applied is a great improvement in fertiliser management compared to recommendations from a general fertilisation guidebook or values based on rules of thumb and imprecise observations. The use of actual measurements as input values for soil nitrate, nitrogen concentration and crop residues may allow an even more precise nitrogen balance than using tabular values in the calculation.

5 Nitrogen management - prevention of nitrogen leaching

Some governments (Switzerland, Finland, Austria and Belgium) limit either the maximum amount of nitrogen allowable in one application, or the total nitrogen supply to a crop in an effort to reduce nitrate pollution of surface- and groundwater. The loss of nitrogen through leaching is not only of environmental concern, but also a money sink for the farmers. Regulations that simply limit nitrogen applications may not encourage farmers to consider other aspects of fertiliser and water management to prevent nitrogen leaching and save water. Understanding the factors that influence leaching can help farmers save money and at the same time prevent groundwater pollution.

5.1 Improved fertiliser management

A fertilisation management that is deliberated is the best way of reducing nitrate leaching. The farmer has the power to decide about the quantity of fertiliser, when and how to apply it. All three factors will influence the risk of nitrate leaching in the field.

5.1.1 Fertiliser source

Many different nitrogen fertilisers are available. Price, availability of the fertiliser material, the application equipment, and the crop to be grown will influence the selection.

Anhydrous ammonia

It is usually the least expensive nitrogen source, although it has handling and application requirements that must be followed for safe and effective use. Anhydrous ammonia should be knifed into moist soil to a depth of 15-20 cm. Following the application, the knife openings should be covered. Anhydrous ammonia readily combines with water in the soil to form ammonium ions which tend to remain as ammonium for a longer time than other sources of ammonium (e.g. urea). Anhydrous ammonia may not be suited for some crops like potato, because the ridges make side-dress application difficult. Because anhydrous ammonia slows the conversion of ammonium to nitrate by creating an environment hostile to nitrifying bacteria, it performs better than other nitrogen sources, especially on sandy soils.

Urea and urea-containing materials

Following surface application, these materials should be incorporated to prevent the loss of nitrogen through ammonia volatilization. Ammonia losses following surface application of urea-containing fertiliser can be controlled by incorporation or by at least 5 mm of precipitation or irrigation within 48 to 72 hours of application. Injection below the soil surface is also a satisfactory method of reducing nitrogen loss from ammonia volatilization. Ammonia volatilization is encouraged by warm weather, high levels of crop residues and high pH. Under favourable conditions losses can reach more than 20 %.

Other sources of nitrogen

Ammonium nitrate, calcium nitrate and ammonium sulphate are often used on speciality crops and potatoes. These materials are usually more expensive than anhydrous ammonia or urea on a cost per kg of nitrogen bases, but they are easier to apply and they supply other plant nutrients. Specialty fertilisers such as calcium nitrate and potassium nitrate are sometimes used to supply calcium or potassium during the growing season. It should be avoided to use these products as the sole nitrogen source. Instead, materials should be included that contain nitrogen in the form of ammonium, especially for early-season applications.

5.1.2 Nitrogen application rate

The decision on N application rates and its split-applications are the most important nitrogen management decision.

If the nitrogen application rate is greater than crop needs, excess nitrogen will remain in the soil and be susceptible to leaching. If the application rate is too low, nitrogen deficiency and yield reductions will result in economic losses. To determine the correct rate a nitrate soil or sap test should be applied and credits for manure and legumes should be considered (as described in sections on nitrogen requirements of crops and on nitrate soil and sap tests).

5.1.3 Yield goal

Nitrogen requirements of the plant are tied directly to the yield goals. So setting the "correct" yield goal is essential when determining the proper nitrogen application rate. Yield goals should represent the expected yield for a given set of soil and environmental conditions. The higher the yield goal, however, the less likely will it be reached and the more likely it is that excess nitrate remains in the soil after harvest.

5.1.4 Timing of nitrogen application

The longer nitrate is in soil prior to cultivation, the greater the opportunity for water to move it below the root zone. Timing nitrogen applications close to the time of major crop needs is especially critical on sandy and/or irrigated soils. In soils where the downward movement of water is unlikely during the cropping period delaying or splitting nitrogen applications does not reduces potential for nitrogen losses.

5.1.5 Placement

Nitrogen fertilisers can be applied by several methods depending on nitrogen source, equipment availability, and time of application. Application methods include sidedressing, knifing, banding, broadcasting, slow-release fertilisation, incorporating by ridging, and the application with irrigation water.

Sidedress applications

Sidedress applications of nitrogen fertilisers are often made by surface banding followed by cultivation or incorporation by irrigation. This practice prevents nitrogen loss through volatilization from urea-containing materials. Care should be taken to avoid root pruning where anhydrous ammonia or other fertilisers are injected. Crops with restricted root systems, such as snap beans, should have nitrogen placed near the roots. Another form of sidedressing is used for crops grown in ridges or hills. Usually the fertiliser is applied near the row and is incorporated into the soil when ridges and furrows are formed. Fertiliser nitrogen that is applied in the furrows is more likely to be lost from the root zone. This occurs because the crop canopy acts like an umbrella and directs water into the furrow. Research shows that about three times as much water flows through the soil in the furrows than through the ridges.

Knifed applications

Through knifed applications a concentrated band of fertiliser is placed within the root zone. The high concentration of ammonia or salt slows the conversion of ammonium to nitrate. Delayed conversion is most likely with anhydrous ammonia.

Broadcast applications

In broadcast applications fertiliser is distributed uniformly before planting. Preplant applications on sandy soils are often less effective than those made after crop emergence. Broadcast applications of dry materials at high rates over growing crops involve the risk of foliar salt burn. Leaf burn can be severe when crops catch fertiliser pellets, such as in the whorl of corn, or when leaves are wet at the time of application. Application of nitrogen-containing solutions can also cause foliar injury. These applications should be limited to less than 40 kg/ha of nitrogen and should be made in the evening when relative humidity is high and dew will dilute salts.

Slow-release fertilisation

A slow-release fertiliser is one that releases its nutrients, particularly nitrogen, at a predetermined rate after application. Slow-release fertilisers serve the same purpose as split-applications; they provide nitrogen as required by the plant. One of the benefits of using this slow release fertiliser is that it saves time. The fertiliser can be applied at once, at the beginning of the season. The risk of loss due to leaching is reduced, and the farmer does not need to return to the field repeatedly to fertilise again. Slow-release fertilisers also have a number of disadvantages: they may require special equipment; they are more costly than conventional fertilisers; nitrogen release may not coincide with crop requirements; nitrogen contribution through mineralisation is not factored into the initial amount of fertiliser applied; and soil analysis becomes more difficult to interpret. The sellers of this type of fertiliser are able to provide the specific characteristics that are needed for a proper application (coated, polymerised, concentrated, with nitrification inhibitors, relatively water soluble or water insoluble).

5.1.6 Fall nitrogen application

Fall nitrogen application will expose nitrogen in soil for a long time prior to crop use. For areas with low rainfall and heavy soils, this may not create a high risk for leaching. On coarse- textured soils and irrigated fields, however, the possibility of leaching is high. Fall nitrogen applications should be avoided in these situations. The same holds for areas where water accumulates or which may be flooded.

Cold soils act as nitrification inhibitors by stopping bacterial action. The application of nitrogen in fall should be retarded until soil temperatures are below 10°C. This will stop nitrification by keeping nitrogen in the form of ammonium and prevent possible leaching until soils warm up in spring.

5.1.7 Fertigation

The application of chemicals through the irrigation system became a common practice in modern irrigated agriculture (Papadopoulos, 1988). Fertilisers followed by herbicides, fungicides, nematicides and other chemicals have been continuously injected into modern irrigation systems. This practice made possible the placement of these chemicals at concentration required by crops or other soil treatments through the irrigation stream in the root zone (Darwish, 1995). As a result, salinity hazards are reduced (Atallah et al., 2000).

Principals of Fertigation

A prerequisite for applying fertigation is the use of modern irrigation systems with high water use efficiency. Other principals are: the use of soluble, zero residue, compatible fertilizers or chemicals and the possibility to modify the concentration and form of nutrients according to the plant age, variety and development stage. The stock solution is usually injected into the system using different types of injectors, with a specific dilution factor and no need for additional electrical power. The possibility of emitters clogging in drip system is overcome by water acidification and chlorine addition.

Water application through modern irrigation systems

The low water use efficiency of conventional irrigation, especially when water is scarce and labour is expensive, results in a non uniform water distribution and low crop response. Water use efficiency can be improved dramatically (up to 95%) with microirrigation system (minisprinkler and drip irrigation). This allows water savings, increasing fertilizer recovery, and an extension of the irrigated area with the same amount of available water. Hence, this technique provides a reduction of cost and labour and allows for a more uniform application of fertilizers and other soil amendments. Research from Jordan, Iran, Lebanon, Syria, Cyprus, Turkey, United Arab Emirates and Saudi Arabia proved the importance of the use of modern irrigation techniques for its impact of increasing yield, improving its quality and reducing its cost.

Requirements for dry fertilizers

There are three major factors in choosing dry fertilizer materials for micro irrigation system:

a) Solubility in water
b) Low possibility of chemical reactions with water impurities
c) Interaction with the soil pH

Table 13: Characteristics of Dry Ordinary Fertilizers Usually Used in Fertigation

Nutrient	Form	Solubility (g/l of cold water)	Effect on pH	Global Index of Salinity “ Na NO_3=100% (Odet & Muzard, 1989)	Cautions
Nitrogen	Ammonium Sulfate	-	Lowers	69	Clogging from $Ca(NO_3)_2$ if water is rich in HCO_3 Monitor pH
	Ammonium nitrate	1177	Raises	104	
	Potassium nitrate	132.1	Raises	73.6	
	Calcium nitrate	1020.85	Raises	-	
	Urea		Lowers	75.4	
Potassium	Potassium sulfate	72.06	Neutral	46.1	Combines N and K. It has low solubility
	Potassium nitrate	132.1	Raises	73.6	

Any dry fertilizer used for fertigation must be completely soluble in cold water. The materials have to dissolve completely before injection.
For the preparation of a stock solution, solubility tests - maybe in a bucket of water - are indispensable. Take the measured amounts of the fertilizers in the ratios they will be used, basing the amounts on the solubility. First add and mix the fertilizer with the lowest solubility. Then slowly add - while mixing - the other fertilizers.

5.2 Nitrification inhibitors

Nitrification inhibitors, e.g. Carboxymethyl Pyrazole, slow the conversion of ammonium (NH_4^+) to nitrate (NO_3^-) by slowing down the activity of nitrifying bacteria in soil. By keeping nitrogen in the form of ammonium (which "sticks" to soil) for a longer time period leaching can be reduced. It is important to recognize that without leaching, nitrification inhibitors are of little value. Nitrification inhibitors are, however, very effective in reducing N losses from sandy and/or irrigated soils, especially when the total amount of nitrogen is applied prior to planting.

5.3 Green manures (or trap crops)

Green manure crops are grown for their various soil ameliorating effects and usually incorporated into the soil. Non-vegetable green manures can help to reduce nitrate leaching in two ways: they absorb nitrate and at the same time reduce drainage by taking up water (Tremblay et al. Internet pub.). Some crops, such as oilseed radishes, mustard, and barley, have long root systems that are capable of removing nitrate from deeper layers within the soil profile. Wheat or crimson clover can also be planted as green manures to extract nitrate from the soil. Wheat takes up more soil nitrate than clover does. A green manure crop can be planted immediately after harvesting the main crop even until October and even with low tillage intensity. Timing the incorporation of a green manure is the key to efficient nitrogen use. For the Bekaa plain it was suggested that it should be incorporated late in the season, at low temperatures, and hence low N mineralisation. In spring, as temperature rises, mineralisation will increase. This coincides with the beginning of the cropping season, making the nitrogen available at just the right time.

5.4 Making effective use of crop residues

Concerns that apply to other organic matter amendments also apply to crop residues. There are various methods of incorporating crop residues, but what is most important is working them in as late as possible: Either before winter or in spring. In this way, the risk of leaching is reduced because low temperatures slow down the release of nitrogen. Care should be taken if crop residues are to be ploughed in. Ploughing operations that result in complete inversion of the soil result in very slow rates of mineralisation of crop residues, because oxygen is often scarce where the residues are placed. Operations that cause the ridges to overlap at a sharp angle (not to turn the soil completely) are more suitable because they favour mineralisation. The ridges trap moisture, and allow oxygen to penetrate the furrows. Allowing residues to mineralise efficiently is important in planning fertilisation. Residues can be incorporated using a rototiller, a practice that increases the rate of mineralisation. Mulching residues at the surface of the soil is another approach, with various effects depending on the local circumstances.

5.5 Choice of crop

Particularly in the case of a late crop an appropriate choice of crop can help to prevent nitrate leaching. Late crops with deep roots, such as brussels sprouts, are especially effective in taking up nitrate from deep within the soil profile. Residues of crops such as leeks and spinach release nitrogen very quickly and may increase the risk of nitrate leaching with fall precipitation. In certain countries, producers located near drinking water sources are obliged by law to plant certain crops as a means of reducing the risk of groundwater pollution.

5.6 Irrigation management

When irrigation water is applied in greater amounts than needed by the crop, water will drain below the root zone leading to nitrate leaching. Water management, therefore, is an important part of nitrogen management in irrigation to prevent nitrate leaching.

Irrigation should be scheduled with the aid of devices which indicate the needs for irrigation in order to adjust the desired soil moisture. These tools are particularly important when irrigating sandy soils with its inherent low water retention.

Experiences with irrigation management in the Arab region

Farmers irrigate potato sometimes by furrow, but mainly by macro sprinklers with gradual shift to drip irrigation. Both, surface irrigation and sprinklers with a large radius, have relatively low application efficiency, not exceeding 50%. Therefore, more water is used in case of sprinkler irrigation in comparison with drip irrigation. Due to mismanagement, farmers often exceed the recommended water demands and fertilizer use. Consequently, nitrogen accumulations in the soil may be observed (Table 14). This indicates that the surplus target value should never be exceeded.

High water application and the one dimensional water flow by macro sprinklers resulted in nitrate leaching below the potato root zone (Figure 5). The soil solution showed that the sprinkler-irrigated plots (Ncs) had significantly higher leaching potential and NO_3 content in comparison with the fertigation (N1) using drip irrigation.

Research in some Middle East countries proposes objective alternatives for the low water and nitrogen use efficiency in conventional irrigation methods. For example, Syria showed that fertigation of cotton is a very efficient technique for conserving both water and N fertilizers (Janat and Somi, 1997). Water use for the growing season was 4.900 m3/ha with drip irrigation and 7.600 m3/ha with surface irrigation (Figure 6), i.e., 35.5% of irrigation water saved under drip irrigation.

Table 14: Balance in N input and output (Kg/ha) under different potato fertilization and irrigation practices in Lebanon.

N source and fate	Fertilization and irrigation techniques				
	Drip	Sprinklers	Fertigation		
N rate	0	360	240	360	480
N from water	43	67	43		
Applied N	43	427	283	403	523
N from fertilizer	0	98.6	76.5	109.6	103
N from consumed water	30				
N uptake	156	221	190	224	169
N from Soil	126	92.4	83.5	84.4	36
N build up in the 0-30 cm soil	-113	+206	93	179	354

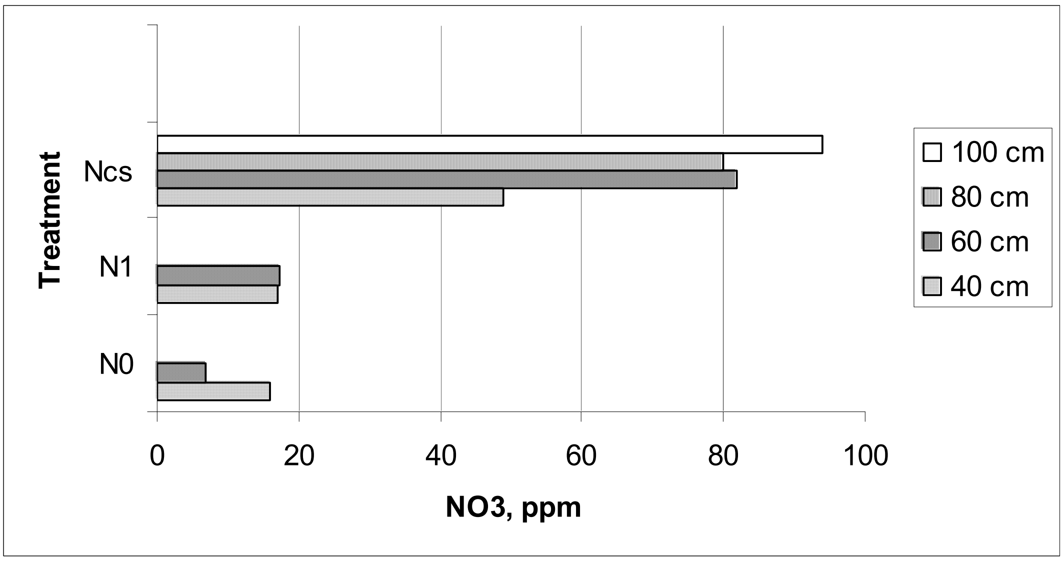

Figure 5: NO_3 concentration of the soil solution removed from tensionics planted at different depth in a potato field in Bekaa, Lebanon.

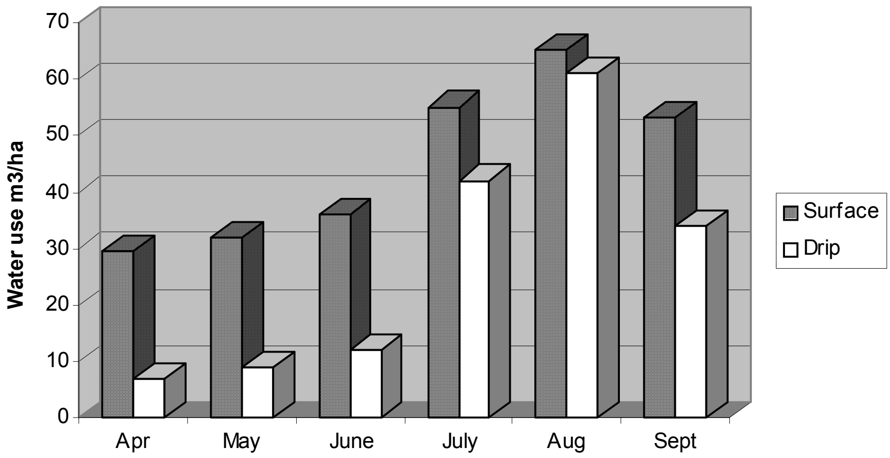

Figure 6: Average daily evapotranspiration (m^3/ha) for cotton under drip and surface irrigation (Janat and Somi, 1997).

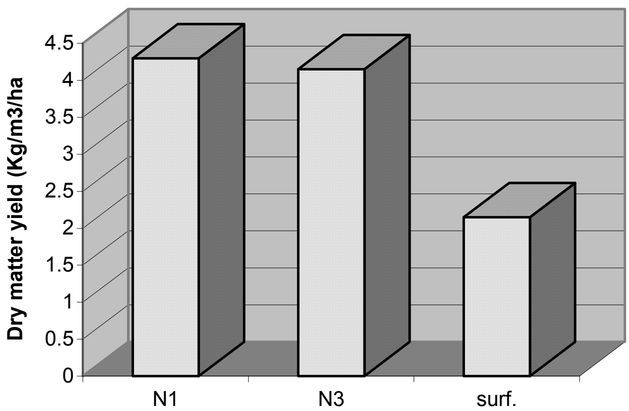

Figure 7: Water use efficiency of cotton under drip and surface irrigation. Nitrogen in fertigated N3 and surface application and irrigation (surf.) were equal (Janat and Somi, 1997).

An increase of 22 % of seed-cotton yield in case of fertigation compared with traditional fertilizer and water management practices was recorded. 93 % for irrigation water use efficiency based on dry matter yield was achieved (Figure 7).

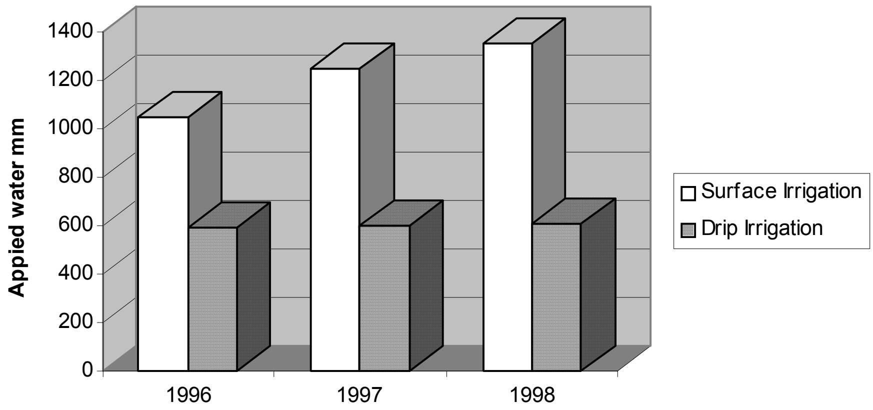

Figure 8: Amounts of irrigation water applied in three successive years (Hobbi and Sagheb, 1999).

In Iran, similar results were recorded for field grown tomatoes (Hobbi and Sagheb,1999). Drip irrigation saved about 50% of irrigation water (Figure 8), with only 5% of N recovery in the surface irrigated plots. Both yield and N utilization increased dramatically under the modern irrigation technique.

In Jordan, interesting results were gained showing the possibility to monitor the water and fertilizer application to field grown tomatoes and potatoes even during **winter**. A comparison of yield parameters, nitrogen and water use efficiency of field-grown tomato and potato, both irrigated by drip, was made. Drip irrigation improved the recovery of nitrogen applied to the soil by potato. The soil application treatments had fertilizer utilization as high as the fertigated treatments and produced total tuber yield not significantly different from that obtained by the fertigation treatment with a similar rate (Mohammad et al., 1999). This experience showed that even when applying nutrients in the soil, improving irrigation practices strenghten the sustainability of agriculture.

As to tomato, fertilizers were also applied to the soil in the furrow irrigated control versus full fertigation. Both treatments received the same amount of water (a total of 500 mm with 200mm from precipitation). In this experiment the conventional fertilizer application gave significantly lower yields than the lowest fertigated rate (Al-Zuraiqui et al., 1997). These trials proved the possibility to manage the concentration of nutrients in the final nutrient solution as a function of the supplemental irrigation requirement to meet the crop nutrient demands, even under a semi-arid climate with frequent torrential precipitations.

Moreover, the crop recovered only 5 % of the surface applied nitrogen during the season, versus 50% in the case of fertigation. This means higher returns from the unit of applied fertilizer.

Many other examples from Cyprus, Turkey, Egypt, Lebanon proved the superiority of fertigation considering higher water use efficiency in the field-grown crops and fruit trees and also under protected conditions.

A Lebanese experience shown here confirms again the possibility of reducing N input in Lebanon with no harm to the production. Considering the additional amounts of N carried by the irrigation water even saves money. Good planning and timely application of N also means less pollution hazards for the high water table in Central Bekaa.

Table 16: Efficiency of the method of potato tuber production.

Treatment	Tuber calibration, %			Water use efficiency	Nutrient use efficiency g DM/g nutrient		
	>60 mm	35-60 mm	<35 mm	kg DM/m3	N	P	K
Fertigation	28.9a	57.6a	14.4a	1.37a	56.80a	68.20a	17.1b
Conventional	17.8b	63.7a	18.4a	0.90b	24.10b	24.10b	24.1a

- Means within the columns followed by the same letter are not significantly different at .05%.

The removed N, P and K were close to values indicated in the literature. Tuber calibration in the fertigated treatment showed significant difference among the elite size (Table 16). This is important for the local market where elite tubers have higher demand. Their price is usually doubled.

Fertigation also led to a water saving of 40%. As to the efficiency of applied N, fertigation proved priority in term of tuber DM produced by one unit of N input (65-g tuber DM/1g. N in fertigation versus 25.4g tuber DM/1g. N under sprinklers). The same significant difference was maintained with the efficiency of applied P.

5.7 Manure management

Organic nitrogen contained in manure will not leach before mineralization. When manure decays, however, nitrogen will be converted to nitrate very rapidly. In this case the nitrate released from manure has the same leaching potential and poses the same hazards to ground water as nitrate from any other source, including fertiliser. In some situations, up to half of the nitrogen in manure will already be in inorganic form and may leach immediately. Because of this, manure must be treated with the same care as mineral fertiliser to prevent nitrate leaching and groundwater contamination.

5.8 Monitoring nitrogen nutrition

Nitrogen deficiencies may occur especially on sandy soils, especially if heavy rains leached nitrogen already early in the season. By the time visual N-deficiency symptoms appear on a crop, nutrient deficiency may be so severe that significant yield losses have already occurred. A better approach is to use a plant analysis to confirm a suspected nitrogen deficiency and to apply nitrogen accordingly. Plant analysis measures the concentration of essential elements to identify nutrient deficiencies. For potatoes, e.g. the petiole nitrate test gives the best evaluation of the crop nitrogen status. Calibration studies have shown that petiole nitrate levels of 1.2% to 1.6% at 50 to 55 days after emergence are needed to optimise yield. Other data should be available with the local extension services.

6 Keys to managing Nitrogen

1. **Apply the recommended rate**. Select the correct rate for your soil based on soil test recommendations. Remember to select a starter fertiliser program that will provide at least 10 kg/ha nitrogen (20 kg/ha nitrogen for potato). Don't subtract this nitrogen from the nitrogen rate unless it exceeds 20 kg/ha for corn or 40 kg/ha for potato. Calibrate application equipment to be certain that the proper rate is being applied. Too little nitrogen cuts profits through yield reductions; too much nitrogen hurts profits through unnecessary fertiliser use and increases the potential for nitrate contamination of the groundwater.

2. **Apply Just before peak crop demand**. Wait until the crop has emerged. There may be an advantage to splitting nitrogen applications, but consider the additional costs, Avoid fall and pre-plant applications of fertilisers.

3. **Select an ammonium-containing fertiliser**. Ammonium-containing fertilisers will provide greater nitrogen recovery and higher yield than sources which contain only nitrate. For corn, anhydrous ammonia is superior in early season applications, but is similar to urea when applied side dressed.

4. **Incorporate materials as soon as possible after application.** Soil incorporation is particularly important when using urea-containing fertilisers.

5. **Use nitrification inhibitors where needed.** Use nitrification inhibitors when pre-plant applying ammonium sources of nitrogen, if side-dressing is not an option. Side-dress applications without nitrification inhibitors are superior to pre-plant applications with nitrification inhibitors in most cases.

6. **Take credit for organic sources of nitrogen.** Legume and manure nitrogen credits are significant and must be taken into account to manage nitrogen efficiently, especially for sandy soils. Take no nitrogen credit for a previous crop of soybeans, snap beans, or peas.

7. **Irrigate wisely.** Use an irrigation scheduling program to provide the water the crop needs without over application.

8. **Monitor crop nitrogen.** Scout fields to evaluate nitrogen status by appearance and monitor nitrogen fertilisation programs by sampling fields for plant analysis. Use the petiole nitrate test to determine supplemental nitrogen needs for potato.

9. **Manage manure wisely.** Manure should be considered as inorganic fertiliser, because it mineralises at a very fast and high rate.

(Adapted from Wolkowski et al. Internet pub.)

7 Success validation

7.1 Introduction

The implementation of a nitrogen management strategy as described in the preceding chapters can lead to a significant reduction of nitrate leaching to groundwater.
However, the efficiency of such a strategy has to be validated - otherwise success or failure of nitrogen management cannot be controlled. It is quite important to describe ways in which such a validation can be achieved. This part of the guideline is a collection of methods and criteria that may be helpful in evaluating the effectiveness of nitrogen management decisions.

Evaluation methods may either be direct or indirect methods:

Examples for direct methods are:

- Farm balance
- Concentration measurements in soil and seepage water
- Groundwater investigations

Indirect methods are:

- Awareness increase
- Acceptance and participation
- Land-use changes

In the following text the most important direct methods will be described in detail. They will be evaluated with regard to their applicability in validating success.

Table 17 gives an overview on the available methods. It contains information on where to take samples, the spatial entity that is characterized by the sample, the temporal resolution of the results, the temporal "distance" between cause and effect as well as the ability to reconstruct the location of cause for a measured effect. It is clear from the table that the deeper one moves into soil the longer the spatial and temporal distance between cause and effect and the more difficult it becomes to evaluate the methods results with regard to success or failure of a specific management decision. The methods explained in the following section are set italic in the table. Only those methods that are either cheap or easy to apply and therefore the most suitable from a practical point of view will be explained.

Table 17: Properties and significance of the different validation methods. Methods explained in more detail later are set in italic.

Method	**Investigated Media**	**Spatial reference**	**Temporal Resolution**	**Temporal affiliation of cause and effect**	**Retraceability of cause and effect**
Balances: *Farm scale* *Field scale*	*Farmed Area*	*Area:* *Farm oriented / Field oriented*	*Individual year* *Crop rotation*	**short**	**high**
Fall Nmin	*Soil,* *Soil Solution*	*Field scale*	*Individual year*		
Lysimeter	Soil solution	Punctual	Time series		
Deep drill	Soil, Soil Solution	Punctual	Time point, Derived time series		
Shallow observation well	Shallow Groundwater	Punctual / small areas	Time point		
Multi-level observation wells	Depth-dependent groundwater	Small areas, high vertical resolution	Time point, Derived time series		
Drains, Surface water bodies	Seepage water, runoff, groundwater	Drained area, Watershed	Time period		
Withdrawal well	*Groundwater body*	*Watershed*	*Time period*	**long**	**low**

The evolution of seepage- and groundwater quality with time allows monitoring the impact of a continuous exposure to nitrogen and at the same time verification of success of remedial actions.

For groundwater samples from deep aquifers or well water it is very important to keep in mind that a great time delay is likely between exposure at the soil surface and actual quality changes in the well. Additionally it is much more difficult to spatially allocate areas of exposure that can be made responsible for groundwater deterioration because mixing and transport processes have masked the relationship.

7.2 Balancing nitrogen fluxes

This headline here stands for an improvement of nitrogen management with special consideration of groundwater quality.

7.2.1 Farm balance

In a farm balance nitrogen-imports and nitrogen-exports are compared. This includes fertiliser, animal feed, harvest, and animal products. Nutrient fluxes within the farm are not considered.
The area related balance (average nitrogen balance per ha) allows an evaluation of these nutrient fluxes with regard to groundwater protection. Setting up such a balance requires the cooperation of the farmer who is responsible for keeping the necessary data records.

Implementation

To get reliable results the minimum time span of a farm balance should cover 3 years. Nitrogen fixation or release in soil is not considered because an equilibrium condition is assumed. Denitrification is assumed to be more or less compensated by input through precipitation.

Presentation of results

Table 18 gives an overview of the balance elements. The balance is expressed in kg N per ha. The area to which the balance is oriented can only be the area that is actually used for production - unused areas and areas with other uses should be excluded. In addition to a balance a transfer coefficient can be calculated. The transfer coefficient allows a judgement

Table 18: Elements of a farm balance

Elements of balance	**Origin of data base to gather…**	
	Total Input	Nitrogen content
Nitrogen-input through…		
Mineral fertiliser	Book keeping	From manufacturer
Manure import		Empirical values
Compost import		From manufacturer
Seeds		Empirical values
Nitrogen fixation through legumes	Seeded areas, Empirical values	
Nitrogen-output through…		
Harvest	Book keeping	Analysis of customer - Empirical values
Animal products		Analysis of customer - Empirical values
Manure export		Analysis or empirical values

about the efficiency of nitrogen use. It is the ratio of N-Output and N-Input in percent. A sample balance for a farm in Germany is given in Table 19.

Table 19: Areal averaged farm balance for a farm in Germany (mainly animal production)

Balance [kg N/ha]	N-Input			N-Output		Transfer-coefficient
	Mineral fertiliser	Animal feed	Seeds + Legumes	Harvest	Animal products	
203	164	117	4	22	61	29

Evaluation of results

A successful implementation of a nitrogen management strategy should lead to a decreasing nitrogen balance or an increasing transfer coefficient per ha with time. The area related balance is therefore a yardstick for successful nitrogen management.

7.2.2 Field balance

In a field balance nitrogen-imports and nitrogen-exports are compared as well. However here, the balance is an indicator for the nitrogen fluxes that will eventually reach groundwater under the assumption that the field is in an equilibrium condition with regard to nitrogen-fixation and release. The reduction of this balance is a major goal of the nitrogen management. Field balances can be carried out for single or multiple years including cash and cover crops. Averaging over several years will lead to more reliable results. A field balance requires information about fertiliser inputs and harvest outputs for a particular field which is usually supplied by the farmer.

A field balance may be used to inquire about the current state of the field, to evaluate the success of nitrogen management and to plan fertilisation on the particular field with results from past balances.

Implementation

Data base

The balance elements are listed in Table 20. The spatial extent of the balance is the contour of the field. The actual nitrogen contents of the inputs and outputs are calculated as described in the section on the farm balance. When manure is applied it is assumed that only 80 % of the actual N-content contributes to the balance (20 % are lost through ammonia volatilisation).

Table 20: Elements of a field balance

Inputs	Outputs
Mineral fertiliser	Harvest
Manure	Animal Products (Milk or meat in case of pasture)
Compost	
N from legumes	

Numerical analysis

Initially all imports and exports are summed up:

N-Balance = Nutrient-import minus nutrient-export

Using the following formula the potential nitrate-concentration in seepage water is calculated:

Potential NO_3-Concentration = (N-Balance [kg N/ha] * 443) / yearly seepage water [mm]

In addition to the N-balance a transfer coefficient can be calculated that allows the evaluation of fertilizer efficiency. It is defined as the ratio of N-imports and N-exports:

Transfer coefficient = Nutrient-import / Nutrient-export

Presentation of results

To allow conclusions on the regional scale field balances can be aggregated either in space or in time. The resulting distribution of single values can be statistically analysed by calculating averages or by setting up a histogram.

Aggregations in time may cover a single year including cash and cover crop or several years covering a complete crop rotation period. Aggregation in space may be carried out by classifying data into fields where only a cash crop was grown and fields where the same cash crop was followed by a cover crop. Another aggregation could be an aggregation on the farm scale which allows the validation of the farm balance. The sum of the area-averaged field balances should equal the area-averaged farm balance.

7.2.3 Investigation of the root zone – Fall N_{min}

The fall mineral nitrogen content in the root zone is a measure for the nitrogen susceptible to leaching during the winter period. The mineral nitrogen in fall usually consists mainly of nitrate but also some ammonium occurs. It is a good method to control the success of nitrogen management decisions made in the preceding season. For example after a moderately fertilized spring potato season in Lebanon (300 kg N/ha), the concentration of nitrates in the 0.6 m soil had an average value of 40 mg NO_3/kg dry soil. This was equivalent to 50 kg mineral N left for the succeeding crop. If we add the amount of N left with the crop residue (128 kg N/ha), this amount becomes 180 kg N/ha potentially subjected to winter leaching.

Implementation

For practical reasons a subplot of about 60 * 100 m is specified on a otherwise homogeneous field. The measurement of fall N_{min} should be done on the same subplot each year to assure comparability of the results. The measurement usually comprises the first 90 cm of the soil profile with steps of 30 cm. It can be extended to 150 cm in a wet fall when leaching has already occurred. The soil of the subplot is sampled 16 times and the samples are combined and homogenized for each depth. They are analysed for nitrate and ammonium. The water content in percentage of weight should also be recorded.

Presentation of results

The depth dependent content of N_{min} may be visualized in concentration-depth plot. This allows a judgement on the occurrence of leaching if nitrate in the lowest compartment (60-90 cm) is high. This may be verified by comparing the measured water content with the field capacity. Results can also be aggregated in a similar way as described for the field balance.

Numerical analysis

The fall N_{min} and the amount of seepage water can be used to calculate the potential nitrate concentration of the leachate:

(Fall N_{min} [kg N/ha] * 443*EF) / Yearly seepage water [mm] = Potential NO_3-Concentration

EF is the frequency of exchange of pore water which is 1 for locations with an intermediate to high leaching potential and lower for locations with a small risk of leaching.

By rearranging this equation, a maximum tolerable fall N_{min} can be calculated, assuming a maximum allowable concentration of nitrate in the leachate:

(Yearly seepage water [mm] * max. allowable NO_3-Concentration) / (443*EF)
= max. tolerable fall N_{min} [kg N/ha]

The maximum tolerable fall N_{min} can be displayed and compared in a graph with measured fall N_{min} data. It is also possible to aggregate results. This may be done in a similar manner as described for data from a field balance.

7.2.4 Water quality in the withdrawal well

An analysis of water that is actually taken from a production well for drinking water purposes allows an integrated view on groundwater quality in the catchment of this well. Results of the analysis can be used to:

- Evaluate the necessity for treatment measures of pumped water
- Monitor long-term changes of groundwater quality in the catchment

Small scale changes of water quality remain undetected because of dilution. The identification of cause and effect relations with regard to water quality changes is very difficult and sometimes even impossible. It is also important to note that the delay between cause and effect can be extremely long (up to thousands of years but usually less).

Implementation

Investigations of water quality should be done using groundwater from a single production well and not mixed samples. Otherwise problems in the catchments of the wells are difficult to detect. To detect changes in groundwater quality a high temporal sampling density is necessary. Additionally sampling should be harmonized with dates from the vegetation period or the crop rotation cycle.

Evaluation of results

The evaluation of historic and current analyses of the well water should include:

- A consistency check of old and new data
- An investigation of major structural changes within the catchment in the past
- The knowledge of possible transformation processes in groundwater

When evaluating water quality for success validation, several aspects should be considered:

- Time series should be analysed for a presence of a trend and/or periodicity of selected parameters
- The type of groundwater should be classified to draw conclusions on its orgin

- Water quality data should be aligned with withdrawal rates and climate

The evaluation of data has to include the groundwater flow field, structural changes in the catchment, possible inputs or protection measures as well as transformation processes in the groundwater.

8 Course of action in N consulting

The administrative goal within the scope of groundwater protection is to safeguard the supply of drinking water. It is absolutely necessary to ensure that drinking water is available to the population in a sufficient amount and a clean quality.

8.1 Definition of a nitrogen management priority program

Groundwater quality is endangered due to increasing exposure to nitrate but also other substances. Therefore, measures for an area-wide protection of groundwater have to be implemented with a special focus on catchments of production wells. Special protection areas have to be defined for these catchments in which even more strict measures for groundwater protection apply. In addition to the implementation of these measures control mechanisms must be established that monitor the compliance with the regulations. It is therefore very important to develop a priority program involving all stakeholders that serves as framework for the successful implementation of a nitrogen management scheme and increases awareness among these stakeholders.

The long term aim of successful nitrogen management is the conservation or restoration of the natural groundwater state, especially in areas which are designated as resources for the current and future supply of drinking water. To reach this aim the following goals are defined:

- The nitrate concentration of seepage water should not exceed a legal threshold (In Germany: 50 mg/L according to the German drinking water directive).
- Shallow groundwater should contain nitrate below a threshold (50 mg/L in Germany). The production aquifer should contain even less (25 mg/L in Germany).
- Initially water from a production well should contain nitrate below a certain threshold (50 mg/L in Germany), which should be lowered to half the threshold in the long term Additionally thresholds for products of nitrate transformation (such as Sulphate) should be set in case nitrate reduction is an important process within the aquifer.
- Public awareness and acceptance of nitrogen management issues must be increased.

8.1.1 Implementation

Legal framework

One prerequisite for successful nitrogen management is the existence of a legal framework that ensures the protection of groundwater. This guarantees that every citizen of a state who is involved in activities that may release nitrate into groundwater is legally obliged to carefully avoid pollution.

In areas where the extraction of groundwater for drinking water is of particular importance, laws should exist that govern the definition of protection zones based on scientific or technical expertise. These laws must include a legal procedure that regulates the specification of such a zone on request, for example, by the waterworks.

And finally a legal basis for compensation payments should be implemented. Experience has shown that the financial aspect of groundwater protection cannot be overemphasised.

But even with the existence of such laws, nitrate pollution of groundwater is still abundant in many countries, because being obliged does not necessarily mean that people are aware.

Cooperation model

To avoid tensions between agriculture and water supply companies it is of great importance that arrangements between both parties regarding nitrogen management are on a voluntarily base and that the compensation of financial loss is a matter of course. The mediation between these parties requires the establishment of a functioning consultancy system involving:

- An advisory service for farmers with a special focus on groundwater protection, carried out by agricultural consultants. This includes investigations of soil and groundwater as described in the preceding section.
- The assessment of compensation payments through these consultants. The payments should compensate losses based on voluntary agreements concerning nitrogen management measures. Money for these payments should be collected from the water consumer.
- Investigation and monitoring of groundwater and soil pollution by the consultant to asses the necessity for measures.

8.1.2 Conclusion

The prevention of groundwater pollution in order to maintain a steady water quality is the better solution compared to conditioning of polluted groundwater by the water supply company. Land owners, water supply companies and public authorities must collaborate closely. The open and voluntary discussion between all involved parties is generally more fruitful than imposing fines or initiate legal procedures. A focus on how to compensate yield losses financially will speed up the understanding between the different parties considerably.

8.2 N-consulting scheme

Figure 9 shows the principle elements of a N-consultancy system. After a survey of the area in focus, the current state of nitrate pollution is analysed. The results are evaluated according to the management priority program and priorities are set. This is followed by a plan on possible measures toward a better nitrogen management. Implementation and communication of these measures is the next step. Finally the success of these measures is tested. The last three elements are repeated over and over. They are interactively adjusted in case of changing conditions.

8.2.1 Restricted area survey

Ideally consultancy starts by doing a survey of the area in focus. Important properties of the area are recorded and processed to be instrumental in future consulting. This survey is a singular work. However, the data base acquired is continuously updated. At minimum the following information should be acquired:

- Mapping of land parcels and their integration into a GIS
- A compilation of farms and farm information relevant to groundwater protection
- Creation of a detailed soil map
- Evaluation of existing hydrogeological data

8.2.2 Analysis of current state

Results of this analysis are used to:

- Evaluate the area according to the priority program by set up local authorities
- Detect sub areas that have a high priority for N-consulting (setting priorities)
- Validate a successful nitrogen management

The investigation of existing data is an important part of such an analysis. The results supplement the data obtained by using the investigation methods described in the preceding sections

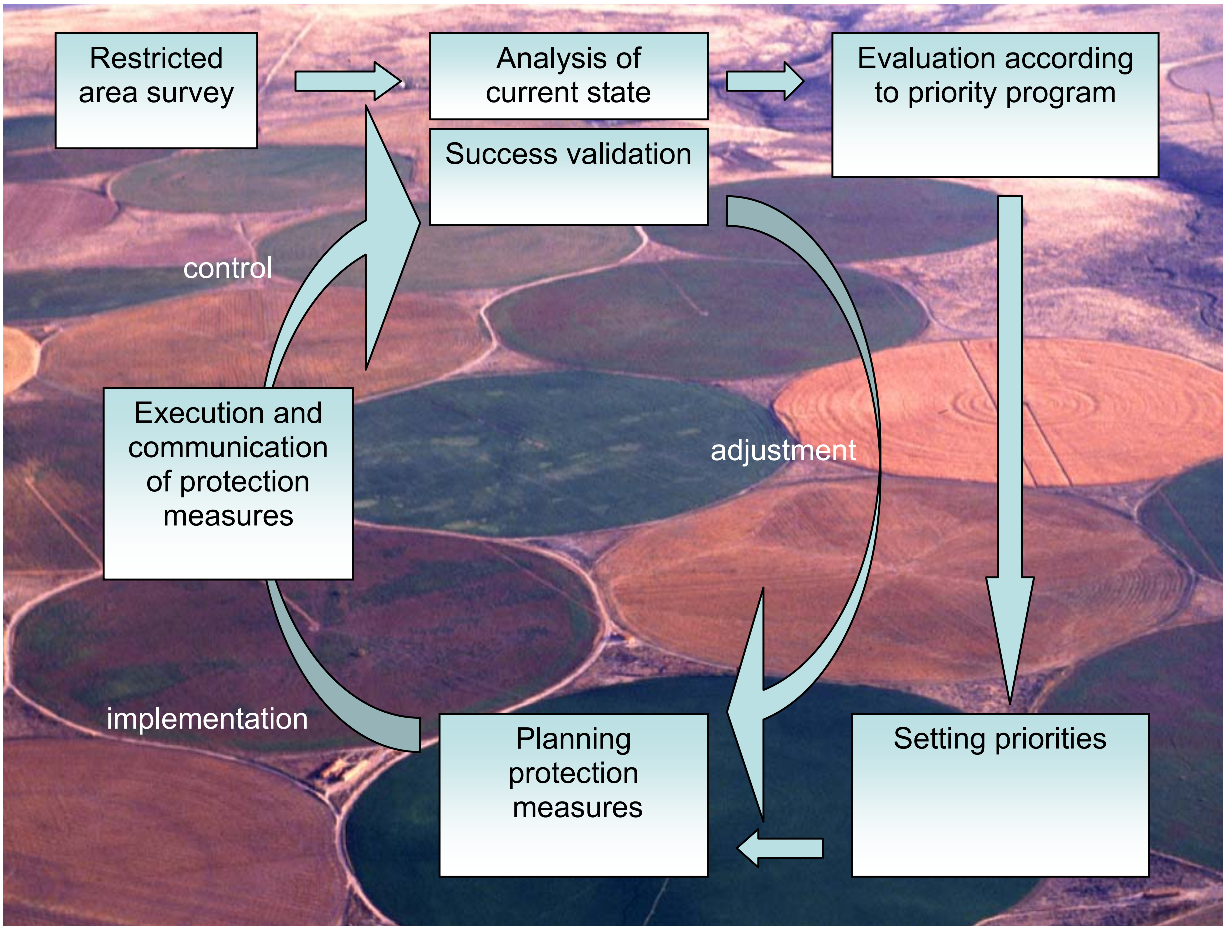

Figure 9: Flow chart of an exemplary N-consultancy system

Evaluation of existing data

This is usually limited to the investigation of water quality data from the production well. The monitoring of water quality is an accompanying measure in drinking water production, so the data should be available. Using time series, trends may be recognised, that allow the identification of anthropogenic N input. It has to be noted, however, that the time lag between a contamination and the resulting effect in the production well can be extremely long so the non-existence of a trend is no proof that contamination is not a problem.

Acquisition of new data

New data may be acquired using all the methods described in the section on methods of success validation. Since the total area is usually large, the investigations have to focus on representative spots including the most important classes of land use or soil type.

8.2.3 **Setting priorities**

Area-related priorities

This part of the N-consultancy system involves the identification of hot spots that are highly susceptible to leaching. The GIS technique may be used to identify these areas by overlaying different geo-information layers. These layers could include,

- Hydrogeology,
- potential for nitrate leaching,
- locations with a high potential for N-release (peat soils or food plains),
- land register information,

among others. The result is a conceptual map where areas with a high priority for measures can be identified.

Farm-related priorities

For an efficient consulting, farms with a high priority for N-consulting have to be discriminated from farms with a lower priority. Possible criteria are,

- the farm balance,
- the animal density,
- fall N_{min},
- technical equipment,
- size of farm,
- fraction of area close to the production well.

The eventual goal is to optimize internal workflow.

8.2.4 **Planning protection measures**

The actual planning of protection measures should account for

- the priorities identified
- the feasibility of measures and the difficulty to put them across to the stakeholders
- the available financial resources that have been set along with the priorities

It is important to remember that arrangements between stakeholders should be made on a voluntary base. The catalogue with necessary measures is defined on a yearly base. Although consulting should take place in the entire area, N-management measures are differentiated according to the priority of the individual sub areas.

8.2.5 Execution and communication of protection measures

The backbone of a working N-consultancy scheme is the legal framework that allows the enforcement of prohibitions and sanctions within the scope of groundwater protection.
However it is at least as important that any arrangement made between different stakeholders is amicable and that the use of force is only a last resort.

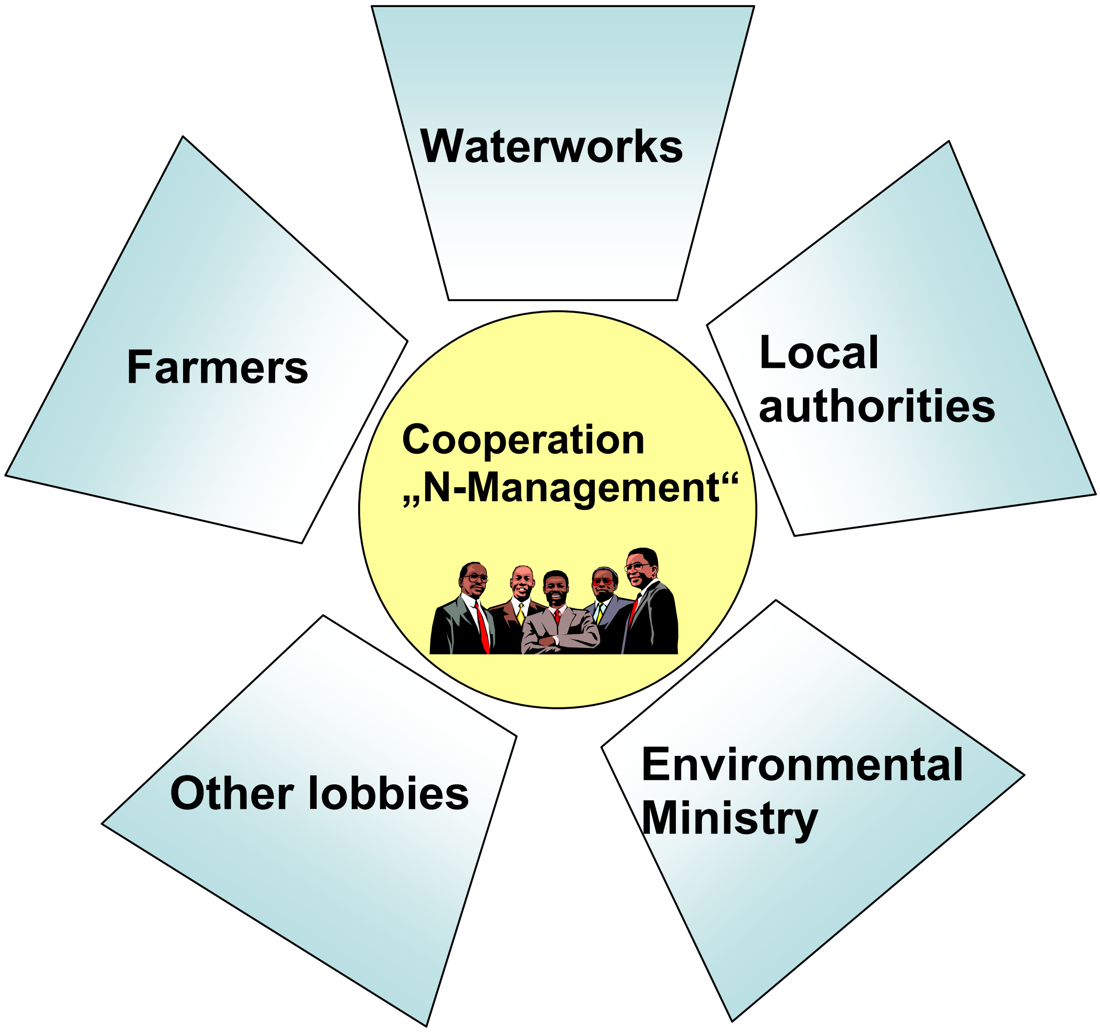

Figure 10: Stakeholders involved in the discussion of N-management.

The cooperation

The board in which concerns of groundwater protection are discussed is illustrated in figure 10. Involved are elected representatives of the farmers, local authorities, ministries, the waterworks among others. The boards task is to discuss and decide on groundwater protection measures,

creation of consulting concepts, choice of consultants, evaluation of consulting reports and recommendation on how to validate success.
It is the task of the consultants to inform the board and adjust groundwater protection measures according to the boards decisions.

Instruments of communication in N-consulting

The instruments of communication are illustrated in Figure 11. They involve newsletters or circulars that are distributed to farmers on a regular base containing information on the current N-situation in the area as well as information on new measures or dates and deadlines. Another instrument is the awareness day for the interested farmer but also the general population where consultants and members of the cooperation get together to communicate their position. Finally the direct or group counselling of farmers is an important tool to convince the farming community about the benefits of their participation in nitrogen management.

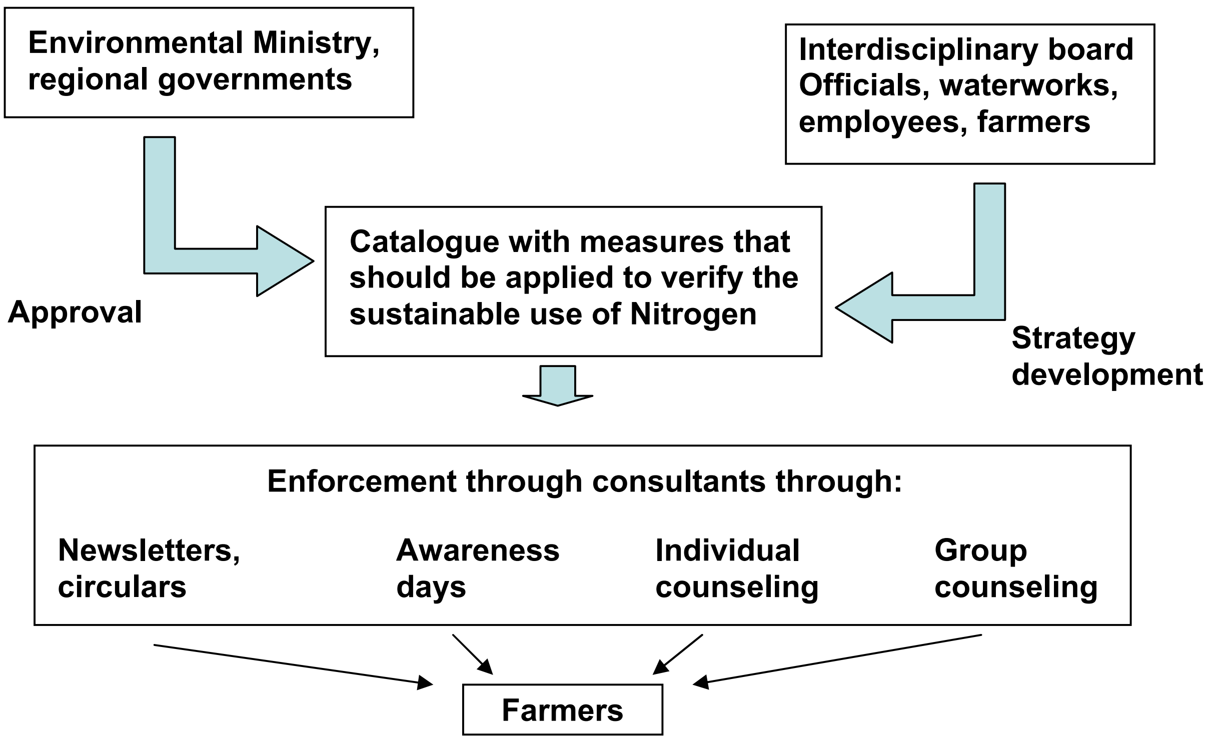

Figure 11: Procurement of groundwater protection measures through consultants

Voluntary agreements

The conclusion of agreements occurs between partners, not antagonists, and on a voluntary base. Partners could be local authorities and farmers or water supply companies and farmers. The content of these arrangements (contracts) include:

- Basics on rights and duties of the partners
- Detail information on the measures agreed upon
- Financial compensation

These arrangements should cover time periods from one to several years

8.2.6 Success validation

The continuous validation of success is central to an efficient N-consulting. During validation the same methods as for the analysis of the current status are applied. However in focus are spots that have been subject to management decisions. Results are reported continuously in reports or presentations through the consultants and serve as a base for future developments in N-management. The three goals of success validation are the motivation of all cooperation members, the revision of N-consultancy and the development of future strategies for groundwater protection.

Success validation is based on four columns:

- Evaluation of field and farm balances:

  Based on good records of N-fluxes, the calculation of decreasing balances are reliable measures of success.

- Control of environmental compartments:

  This is the most labour-intensive part - the methods have been illustrated -. Because it is not practical to validate the success of all measures everywhere in the area, reference spots that are representative should be chosen. There is also a priority to control areas that are highly susceptible to leaching.

- Acceptance:

  Acceptance can be judged by a) comparing the fraction of fields where N-management arrangements have been concluded to the fraction of fields from farmers that are not yet convinced, b) the continuity of arrangements, c) the turnout of stakeholders at events or presentations and d) the demand for N-consulting.

- Costs:

  The cost efficiency can be measured by calculating the ratio of cost and saved N either on the plot scale or for the total area.

9 References

Al-Zuraiqi S., Al-Qawasmei W., Rusan M., And I. Al-Deek 1997. Response of Tomato to nitrogen fertigation using 15N technology. Regional TC Project RAW/5/002 on Water balance and Fertigation. Coordination Meeting. Beirut. 3-6 November, 1997.

Atallah, Th. Darwish, T. and Maroun Moujabber 1997. Cultural Practices and Soil Salinity in Greenhouses in Lebanon. International Conference on "Water Management, Salinity and Pollution Control towards Sustainable Irrigation in the Mediterranean Region". CIHEAM/MAI-B and CEC-DGI. Publications of Instituto Agronomico Mediterraneo, Valenzano-Bari. Italy: 115-123.

Atallah, Th; Darwish, T.; & R., Ward 2000. La serriculture de la cote nord du Liban: entre tradition et intensification. Cahiers d'Etudes et de Recherches Francophones-Agricultures. V.9 (2): 135-140.

Atallah, Th. Darwish T. and M. Moujabber 2002. Modality of fertigation of protected cucumber and nitrogen use efficiency under field conditions. International Atomic Energy Agency IAEA-TECDOC-1266: 41-48.

Brady, N.C. 1990. The Nature and Properties of Soils. 10th edition, Macmillan publisher company, New York.

Cameron, K.C., Di, H.J., McLaren, R.G. 1997. Is soil an appropriate dumping ground for our wastes? Aust. J. Soil Res., 35: 995—1035.

Darwish T. and J. Serhal 1987. Experiment of culture on a municipal compost (Factory of Treatment of Beirut). Lebanese Science Bulletin, V.3 (2), 85-92.

Darwish T. 1995. Implementation and Perspectives of Fertigation in Crop Production in Lebanon. Short Advanced Course on Fertigation. FAO/RNE, CIHEAM/IAM-B and LEBANESE UNIVERSITY. Nov. 26- Dec.3, 1995: 207- 220.

Darwish, T., Atallah, T., Hajhasan S and A. Chranek 2002. Water and N Fertilizer Utilization of Spring Potatoes in Central Beqaa, Lebanon. International Atomic Energy Agency IAEA-TECDOC-1266: 49-60.

Darwish, T., Atallah, T., Hajhasan, S., Chranek, A. 2003. Management of nitrogen by fertigation of potato in Lebanon. Nutrient Cycling in Agroecosystems. Vol. 69: 1-11.

El-Moujabber, M., Atallah, Th., and T. Darwish 2002. Crop modeling and water use efficiency of protected cucumber. International Atomic Energy Agency IAEA-TECDOC-1266: 61-67.

Gerwing, J., Gelderman, R., 1993. Nitrogen Management and Groundwater Quality in South Dakota. www.abs.sdstate.edu/abs/plantsci_pubs/fs864.html

Hobbi M.S. and Sagheb N. 1998. Field evaluation of urea fertilizer and water use efficiency by tomato under trickle fertigation and furrow irrigation. TCP, Raw/5/002 Annual Coordination Meeting, Karaj-Iran, November 1998.

IAEA-TECDOC-1266, 2000. Water balance and fertigation for crop improvement in West Asia.

ISO 11466, 1995. Soil Quality – Extraction of Trace Elements soluble in Aqua Regia.

Niedersächsisches Landesamt für Ökologie, 2001, Anwenderhandbuch für die Zusatzberatung Wasserschutz, Grundwasserschutzorientierte Bewirtschaftungsmaßnahmen in der Landwirtschaft und Methoden zu ihrer Erfolgskontrolle, 1. Auflage, Hildesheim

Janat M. and Somi G. 1997. Comparative study of nitrogen fertilizer use efficiency of cotton crop under conventional and fertigation practices using 15N methodology. TCP, Raw/5/002. Annual Coordination Meeting. Beirut, November 1997.

Kechli A 1999. Determining the rates of N mineralization in Lebanese Soils. Lebanese National Council for Scientific Research. Lebanese Association for the Advancement of Science. The 13th Sc. Meeting. Abstracts, p. 23.

Mohammad M. J., Zuraiqi S. Quasmah W. And I. Papadopoulos 1999. Yield response and nitrogen utilization efficiency by drip-irrigated potato. Nutrient Cycling In Agroecosystems 54: 243-249.

Myamoto,S., Ryan,J., and J.,L., Stroehlein 1975. Sulfiric acid for the treatment of ammoniated irrigation: I. Reducing of ammonia losses. Soil Sci. Soc. of Am. Proc. 39:544-548

Odet, J. and M. Muzard 1982. Memento fertilization dews cultures legumieres. Ctifl, 2nd Edition. Paris, 398 p.

Pansu, M., Thuries, L., 2003. Kinetics of C and N mineralisation, N immobilization and N volatilization of organic inputs in soil. Soil Biology & Biochemistry, in press.

Papadopoulos,I. 1988. Nitrogen fertigation of trickle-irrigated potato. Fertilizer Research 16 : 157-167.

Ryan J, Curtin D and Safi I 1981. Ammonia volatilization as influenced by calcium carbonates particle size and iron oxides. Soil Sci. Soc. Amer. J. 45 (2): 338--341.

Steevoorden, J. H. A. M. 1989. Agricultural practices to reduce nitrogen losses via leaching and surface runoff. In: Management Systems to Reduce Impact of Nitrate. Elsevier, Amsterdam, pp. 72-80.

Thuries, L., Pansu, M., Feller, C., Herrmann, P., Remy, J.C., 2001. Kinetics of added organic matter decomposition in a Mediterranean sandy soil. Soil Biology & Biochemistry, 33, 997-1010.

Tremblay, N., Scharf, HC., Weier, U., Laurence, H., Owen, J. Nitrogen Management in Field Vegetables – A guide to efficient fertilisation. http://res2.agr.ca/stjean/publication/bulletin/nitrogen-azote_e.pdf

White, R. E. 1985. The influence of macropores on the transport of dissolved and suspended matter through soil. Adv. Soil Sci. 3, 95-121.

Wolkowski, R.P., Kelling, K.A., Bundy, L.G. Nitrogen management on sandy soils. www.uwex.edu/ces/pubs/pdf/A3634.PDF

Appendix I

Method for soil nitrate extraction

Introduction: Under normal conditions, 90% of the mineral nitrogen in the soil is in the form of nitrate (NO_3^-). Nitrate should be considered in the decision in the quantity of nitrogen fertiliser application. The use of a rapid test to detect nitrate levels in the soil represents a valuable tool for gaining timely information about the soil about to be fertilised. **Warning!** Rapid tests of soil nitrate contents are remarkably sensitive. The accuracy of the results, however, is directly proportional to the care taken in sampling and performing the analyses. It is important to carry out all the procedures and techniques with great care, and in an identical manner for all samples so that the results from different samples can be compared with one another.

Special care of solutions and test strips: -Ensure that solutions and strips do not become contaminated. -Be careful to not unnecessarily expose either the solutions or the test strips to air and dust. -Store test strips in the cold, and do not use them after their ware dates. -Hermetically seal the test strip storage tubes immediately after removing the strips from them. -Once a tube of strips has been opened, store it in a dry place at room temperature.

Materials: - N_{min} auger set (0-30cm, 30-60cm and 60-90cm) with hammer -Plastic bags -Cooler and freezer packs -Reflectoquant (with 9 V battery) -Merckoquant Nitrate test strips -Extract solution (0.0125 mol/l $CaCl_2$) -Standard solution of 10 ppm Nitrate-N -Distilled water or de-ionised water -50-ml Sarstedt tubes with 5-ml graduation –Sarstedt tube rack -Precision balance -Whatman #1 filters.

Soil sampling (ISO/DIS 10381-1): 1. Take 10 to 12 randomly collected sub-samples per plot. 2. Each sub-sample core should be taken to a depth of 0-30 cm 30-60 cm and 60-90cm depending on the rooting depth of the crop 4. Mix the 10 to 12 sub-samples thoroughly in a plastic bag. 5. Label the bag with the plot number, the depth of the sample, and the date of sampling. 6. Protect the samples from heat and light by placing them in a cooler with freezer packs. 7. Proceed with the nitrate extraction the same day, or freeze the samples as quickly as possible.

Soil sample preparation: Extraction: 1. Pour exactly 30 ml of extraction solution into a Falcon tube. 2. Tare the solution and tube in a beaker. 3. Add 10 ml of sieved soil to the solution by adding soil until the solution reaches the 40-ml graduation. It is important to add well-mixed soil that is representative of the entire sample. 4. Record the weight of soil added using the balance (**A**). 5. Close the Sarstedt tube. 6. Vigorously shake the tube for two minutes and filter the solution using a Whatman #1 filter paper or equivalent at room temperature into a second Sarstedt tube.

Quantification of NO_3^-: Using the reflektoquant see appendix III.

Nitrate concentration: -Take a reading from the sample. Record the result (**D**). If the reading is not within the limits of the meter (5 to 500), increase the dilution of the solution until the reading falls within the range. If the result seems irregular, re-do the extraction using a fresh portion of soil. After 12 samples, repeat the readings of the extraction solution and the standard solution.

Soil moisture: 1. Record the weight of an aluminium weighing dish (**E**). 2. Weigh approximately 30 g of soil into the weighing dish (tar the weighing dish first), and record the weight (**F**). 3. Place the soil and weighing dish in an oven and dry for 16 hours at 105°C. 4. Weigh the dried soil and weighing dish and record the weight (**G**).

Calculations: **Dry weight of soil used for extraction (X)** A* ((G – E) / F) = X **ppm NO_3^--N in the soil** (D-B) * [(30 + A – X) * (10 / C)] / X = ppm NO_3^--N in the soil **Conversion of ppm to kg NO_3^--N per hectare** ppm NO_3^--N in the soil * conversion factor = kg NO_3^--N / ha 58 **ppm to kg/ha conversion factors** **Depth of soil sample Conversion factor** 15 cm 1.98 17 cm 2.24 30 cm 3.96 34 cm 4.48 45 cm 5.94 51 cm 6.72 60 cm 7.92 68 cm 8.96

Appendix II

Method for tissue nitrate extraction

Sampling: Because plant nitrate levels are strongly affected by light, it is best to take samples as early as possible in the morning, before the sunlight is strong. Ideally, sampling should be done before 10:00 am. Samples taken early in the morning are also likely to be saturated with water, which facilitates sap extraction. In broad-leaf crops, the tissue collected during sampling should be the most recently fully expanded leaf. In cereal crops (and other plants in the family Poaceae) the tissue should be the section of stem closest to the ground. Take as many samples as possible, ensuring that they are representative of the whole group of plants to be sampled. When using leaves, remove the leaf-blades and keep only the midribs for the analysis. Place the plant samples in plastic bags and put them in a cool, dark place as soon as possible.

Materials: -Garlic press -Distilled water -Standard solution (100 ppm NO_3^-) -Two small beakers -Reflectoquant meter -Test strips -Two eyedroppers -Knife -Graduated cylinder (5-ml)

Sample preparation: **Extraction of sap:** 1. Slice the plant parts for extraction into pieces of about 0.5 cm. 2. Randomly select several of the pieces and mince them in a garlic-press, collecting the drops of sap in a clean beaker.

Dilution: Unlike soil nitrate levels, which are often too low to be read by the Reflectoquant meter, sap levels are often too high to be read by the meter. In addition, the green colour of undiluted sap can interfere with the reading. Therefore the sap may be diluted, and the calculation should be corrected by the dilution factor. Dilution should be done using distilled or deionised water, or tap water may be used provided a measure of its nitrate level, to be deducted from readings of the sap nitrate levels.

25-fold dilution 1. Using an eyedropper, take two drops of sap from the beaker and place them in a second, clean beaker. 2. Add 48 drops of distilled water. 3. Stir well.

Note: When diluting many samples, it may be more efficient to measure the volume of 48 drops in a 5 ml graduated cylinder and to subsequently add this volume of water to the samples instead of counting 48 drops every time. However, the drop size may vary with different eyedroppers, and can be influenced by atmospheric pressure changes, so when changing eyedropper or if pressure changes are suspected, 48 drops should be re-measured in the graduated cylinder, and the new volume used.

50-fold dilution: If the Reflectoquant meter cannot read the concentration of nitrate after 25-fold dilution, make a 50-fold dilution of the sample. 1. Using an eyedropper, take two drops of sap from the beaker and place them in a second, clean beaker. 2. Add 98 drops of distilled water. 3. Stir well. 4. Be sure to rinse and dry beakers, and rinse the inside of the eyedroppers before beginning a new sample.

Note: The extracts can be frozen for later use.

Nitrate concentration in sap extract: Take a reading from the sample extract Reflectoquant (Appendix III). Record the result (**D**). In the case of triplicate samples, D represents an average of the three readings ($D_1 + D_2 + D_3$ / 3) If the reading is not within the limits of the meter (5 to 500), increase the dilution of the solution until the reading falls within the range.

Calculation: The reading on the display of the meter is a relative measure that must be corrected using the calibration reading and the dilution factor. Nitrate level in sap = (D * 100 / C) * dilution factor (i.e. 25 or 50) 62

Appendix III

Quantification using the Reflectoquant reflectometer

Table of contents

Introduction

To learn using the Rqflex device easily please read the manual carefully. We designed it as readable as possible with many pictures. It is best to actually carry out each step on the Rqflex while reading the manual. Please take a look at the booklet accompanying each Reflectoquant - Test package.

Description of the device

Your Rqflex is a precise and flexible to use measurement device. It is part of the Reflectoquant Analysis system with the following components.

- Measurement device Rqflex
- Reflectoquant analysis strips
- Reflectoquant-plus vessel test
- Test- and lot specific barcode stripe

Following the principle of reflectometry, reflected light from either an analysis stripe or after passing through a vessel is exactly measured. As in classical photometry Intensity differences of entered and reflected radiation are used to quantify concentration of certain compounds.

Display elements / Buttons

Buttons 1

Display 2

To display notes and informations

Data exit port 3

To connect Rqdata (see page 25)

Do not connect electric power hier

Lid 4

Method memory 5

Up to five methods (Nitrate,pH….etc.) may be saved simultaneously. This is independent of the fact that test vessels or analysis strips are used. By reading in a new barcode methods may therefore be overwritten.

Barcode reader 6

Using a barcode all data that is needed for a method is trandsfered to the device. The barcode contains also informations on wave length corrections and lot specific calibration.

All parts of the display are shown for one second after switching the device on. The device is carrying out a self test during this time. Please pay attention that all functions especially the multifunctional numerical display is working correct.

Low battery 1

Clock 2

Date 3

Method dependent symbol 4

Method memory 5

Multifunctional numerical display 6

Device, Test and Barcode stripes are unique so please take care that lot numbers agree.

Technical data…………………………..

Getting started

Please insert the 4 batteries delivered with the device.

Entering the batteries

When?

Either when batteries are low or when device is new

How?

1. Remove battery lid from beneath the device by pushing it with minor pressure in direction of the arrow.
2. Put the batteries with correct polarisation into the lid.
3. Close lid.

Important

When low bat appears for the first time another 20 measurements are still possible. After that the device will not switch on. It is important to replace batteries within approx. 2 minutes, otherwise saved results may be lost.

Entering time and date

When ?

1. The device is new
2. Summer/Winter time
3. After battery exchange

How ?

1. Switch off the device.
2. Switch it on while pressing the MEM-button. The clock and date display are blinking.
3. Pressing START will allow you to switch between international and american time.
4. Pressing TEST will allow you to choose Hour, Minute, Day or Month.
5. Press START to enter Time (Hour, Minute) or Date (Day, Month).
6. After pressing MEM or ON/OFF the procedure is ended. The values set are automatically saved and the clock is activated.

Coding

When?

1. The device is new
2. A new lot of tests is opened.
3. A method is overwritten

How?

1. Take the Barcode from the Reflectoquant package. Some tests may use two barcodes.
2. Switch the device on and open the lid. A display showing F:50 means that 50 memory spots are left.
3. Press the TEST-button until the arrow points on the respective Memory in which you plan to save the coding of the test method.
4. Push the barcode in direction of the arrow through the barcode reader until there is a stop then pull the barcode out.
5. The encoding is done when you see three numbers on the display which agree with the first three numbers of the lotnumber printed on the barcode. A noise will also appear.
6. In case something went wrong, repeat the procedure until the noise appears stating that the code has been read.
7. Put the barcode back into the package in case you may need it again (But do not put it in the Metal container holding the analysis strips)!

Overwriting a method

An existing method already saved will be overwritten when reading in a new barcode.

When overwriting a method all results saved using the old method will be deleted.

A blinking MEM button means that there are still some results saved. In case these values are needed they can be read by pressing the MEM button.

Methods using two barcodes

In case of methods that use two barcodes the lotnumber and the method symbol will be blinking alternately after reading in the first barcode.

As soon as the second barcode is read the lotnumber will appear continuously

It does not matter which Barcode is read first.

Measurement

For an easier use of the manual the description is divided into 5 measurement procedures.

These procedures are different only in the first steps.

A measurement procedure is test specific. Therefore the procedure cannot be chosen freely by the user but is read in via the barcode. Generally methods A-D are used for analysis strips, while method E is used for test vessels. The individual steps of a method are shown within he display.

Make sure that when beginning a measurement procedure the correct adapter (stripe or vessel) is slid into the device.

When doing the measurement also read the booklet contained in the test package.

Procedure A

Here, only the reaction time of the analysis stripe is important. Make sure the stripe adapter is in the device.

How ?

1. Switch the device on!
2. Press TEST until the arrow points to the correct memory spot.
3. Compare the first three lot numbers on the Reflectoquant package with the numbers shown on the display. The numbers must agree.
4. Press START. The reaction time will appear on the display.
5. Dip the analysis stripe into the solution according to the procedure described in the booklet accompanying each Reflectoquant package. At the same time press START. Shake off excessive fluid from the stripe. The stop watch of the device is activated and the remaining reaction time is displayed (Count Down).
6. 5 seconds before the end a humming noise and the blinking method symbol signal that the stripe should be entered into the device until it reaches a stop. It will then be measured.
7. The result will be displayed in the units given on the package (for instance mg/l) and saved to memory.

Procedure B

In addition to the reaction time of the stripe other reaction times have to be considered when using this procedure.

How ?

1. Switch the device on!
2. Press TEST until the arrow points to the correct memory spot.
3. Compare the first three lot numbers on the Reflectoquant package with the numbers shown on the display. The numbers must agree.
4. Press START. The waiting time will appear on the display (e. g. 120 sec.) Work according to the procedure described in the booklet accompanying each Reflectoquant package. Press START again to start the stop watch. After the waiting time has passed the stripe method symbol in addition to the reaction time will appear on the display (e. g. 60 sec.)
5. Dip the stripe according to the description of the booklet into the solution and press START again at the same time. Shake off excessive fluid from the stripe. The stop watch of the device is activated and the remaining reaction time is displayed (Count Down).
6. 5 seconds before the end a humming noise and the blinking method symbol signal that the stripe should be entered into the device until it reaches a stop. It will then be measured.

7. The result will be displayed in the units given on the package (for instance mg/l) and saved to memory.

Procedure C

For this procedure the device will be calibrated to an unused stripe. Make sure the stripe adapter is in the device.

How ?

1. Switch the device on!
2. Press TEST until the arrow points to the correct memory spot.
3. Compare the first three lot numbers on the Reflectoquant package with the numbers shown on the display. The numbers must agree. The symbol tells you that an unused Reflectoquant stripe should be entered.
4. Press START. The device is now calibrated. Continue as described in method A or B.

Procedure D

For this procedure the device will be calibrated to an used stripe. Make sure the stripe adapter is in the device.

How ?

1. Switch the device on!
2. Press TEST until the arrow points to the correct memory spot.
3. Compare the first three lot numbers on the Reflectoquant package with the numbers shown on the display. The numbers must agree.
4. Press START. The reaction time will appear on the display.
5. Dip the analysis stripe into the solution according to the procedure described in the booklet accompanying each Reflectoquant package. At the same time press START. Shake off excessive fluid from the stripe. The stop watch of the device is activated and the remaining reaction time is displayed (Count Down).
6. 5 seconds before the end a humming noise and the blinking method symbol signal that the stripe should be entered into the device until it reaches a stop. It will then be measured.
7. Two alternately blinking lines in the display tell you to remove the first stripe and enter the second.
8. After entering the second stripe, press START. The result will be displayed in the units given on the package (for instance mg/l) and saved to memory.

Procedure E

For this procedure test vessels are used. Enter test vessel adapter.

How ?

1. Switch the device on!

2. Press TEST until the arrow points to the correct memory spot.

3. Compare the first three lot numbers on the Reflectoquant package with the numbers shown on the display. The numbers must agree.

4. Press START. The waiting time will appear on the display (e. g. 240 sec).

5. Work according to the procedure described in the booklet accompanying each Reflectoquant package. Press START again to start the stop watch. After the waiting time has passed the reaction time will appear on the display (e. g. 5 sec.)

6. Enter the vessel with the blind sample into the adapter press START after closing the lid of the device. Accompanied by a humming noise the blind sample is measured. Two alternating vessel symbols in the display tell you that now the vessel with the measurement sample should be entered

7. Press START after entering the vessel and closing the lid. Accompanied by a humming noise the test sample is measured. . The result will be displayed in the units given on the package (for instance mg/l) and saved to memory.

8. Remove the vessel immediately after the measurement is done.

Important

Switching of the measurement procedure (Menu led)

When?

1. In case a measurement was not okay or the stripe has been inserted too late.

2. When doing series of measurements.

How?

After running a procedure once you can immediately do additional measurements after pressing START. For procedure D and E a blind sample and a test sample have to be measured by pressing START before each sample. The order does not matter! The result will be displayed in the units given on the package (for instance mg/l) and saved to memory.

Please Note

In case you like to do more than one Nitrate measurement the following procedure is reconmmended. Since the count down function of the device is not available you need an additional stop watch.

1. Run standard procedure once.

2. Insert analysis strips every 15 sec into the samples, shake off water and collect them close to the device.

3. After the reaction time of 60 seconds for each stripe measure by pressing START. This means you have to enter a stripe every 15 seconds!

Caution

The reaction times have to be precise! Otherwise the result may be erroneous. After 2 Minutes the device switches off when no button is used during this time

Handling Results

When?

1. When saving results
2. When reading results from memory
3. When transfering results to the PC
4. When deleting results

Saving results

How?

All results are automatically saved with date and time of measurement. The device saves up to 50 results per method. When the lot number is displayed, the number of free memory spots is displayed instead of time and date e.g. F:21.

Important

When 50 results are saved, F:00 is displayed. During the next measurement the oldest result is overwritten.

Displaying saved results

How?

1. Switch the device on
2. Press the TEST-button until the arrow points to the chosen method. The lotnumber is displayed.
3. Press the MEM-button. The result which was saved last for this method is displayed. In case no results are saved a humming noise will appear and the display does not change.
4. Continuously pressing the MEM-button allows to display saved results in a descending order with regard to time of measurement. Display of the lotnumber in addition to a humming noise signals that no additional value is saved for the chosen method.
5. By pressing TEST you may chose a different method, for wich you may view the saved results by pressing MEM.
6. The procedure may be ended by pressing ON/OFF or TEST.

Data transfer to the PC

When?

To ensure Data quality and to document measurements

How?

The device is hooked up with a PC using a special Interface. A software is also needed for which additional Information is included.

Deleting Measurements

When ?

1. To delete the last value measured
2. In case a measurement was erroneous
3. To delete all measurements

How ?

While the lotnumber is shown in the display press the MEM button for 3 seconds to delete the last value saved. The value is blinking during this time. At the same time a noise can be heard. When 000 is shown the value is deleted. Press TEST to bring the lotnumber back on the display.

Important

When coding a new method all values saved for the previous method are deleted!

Taking care of the device

To get exact measurements please read this section carefully

Handling the device

1. The device is quite robust. Still you shouldbe as carefull as you are when handling other electronic devices.
2. Don’t expose the device to high humidity, heat or cold
3. To clean the outer parts of the device, take a wet tissue and carefully remove the dirt

Cleaning the test vessel adapter

When?

Cleaning has to take place immediately in case of a spill!!!

How?

1. Switch off the device
2. Carefully pull out the vessel adapter
3. Dry the adapter immediately as well as the optics
4. Insert the adapter into the Device

Cleaning the stripe adapter

When?

Cleaning has to take place in case an error (OPT or ERR) is displayed. A thorough cleaning (Taking apart the stripe adapter in parts) is required regularly. Please also consult the method dependant Reflectoquant booklet.

How?

1. Switch of the device
2. Carefully remove the stripe adapter from the device
3. Take the adapter apart into three pieces.

4. Clean with water or a mild cleanser or even with ethanol. The white area used as a standard may not be cleaned with an abrasive cleanser!

5. Dry all parts and recombine them

6. Insert the adapter into the device

Recalibration

The recalibration set consists of a internal standard (grey plastic part), a calibration barcode and a white calibration stripe.

When?

1. In case of measurements which are not plausible
2. When changing the stripe adapter and or the white standard
3. In case of strong mechanical usage
4. In case of errors (OPT or ERR)

How?

1. Clean the stripe adapter thoroughly. Pay attention that the white standard is not discolored (change on dmand)
2. Store the device at 18-22 degree Celsius for at least 30 Minutes
3. Switch the device on after the stripe adapter has been inserted
4. Insert the calibration barcode and check that it has been inserted correctly. Check if the calbrition stripe is clean!
5. Press START. The device is recalibrated, the CAL-display vanishes and switches off.
6. Store the calibration set very carefully in the original packaging.

Important

In cases of low batteries the calibration barcodeis not accepted. Change batteries!

Recalibration is only possiblewhen the stripe adapter is inserted. In case the white calibration stripe is not inserted a humming noise will appear after pressing START. CAL will be displayed which means that a calibration stripe must be inserted.

Solving problems

In the following table you'll find explanations for error messages and hints on how to avoid erronous measurements. Most problems are based on the following reasons:

Stripe- or vesseladapter were recombined or inserted wrongly

Analysis strips or vessels were not inserted properly into the adapter

Vessels are dirty

Reaction times were not considered properly

The method explained in the booklets accompanying a test was not carried out correctly

Wrong doing whil handling Reflectoquant tests (Cans or bottles were not closed or pH was not correct)

Problem	Reason	Solution
no Display	- no batteries - batteries low	- Replace batteries - Insert batteries correctly
Display LO	Concentration less than measureable concentration range	Write down that value is below lower boundary of measurable range
Display HI	Concentration is bigger than measureable concentration range	Dilute sample. Remember to note down the dilution factor!
Display ---	No saved code	Code device
Display Opt	- Optics or adapter dirty - Adapter assembled improperly - Open lid while measuring with vessels	- Clean optics or adapter, recalibrate on demand. - Check if adapter is assembled properly - Close lid and repeat measurement
Display ERR	- Error with optics - Adapter assembled improperly	- Clean optics or adapter, recalibrate on demand, - Call customer support - Check adapter
Diplay E-1	- Too much light from the outside - Adapter assembled improperly	- Repeat measurement at a darker place - Before switching the device on, close lid
Display E-2	Result not plausible	Repeat measurement