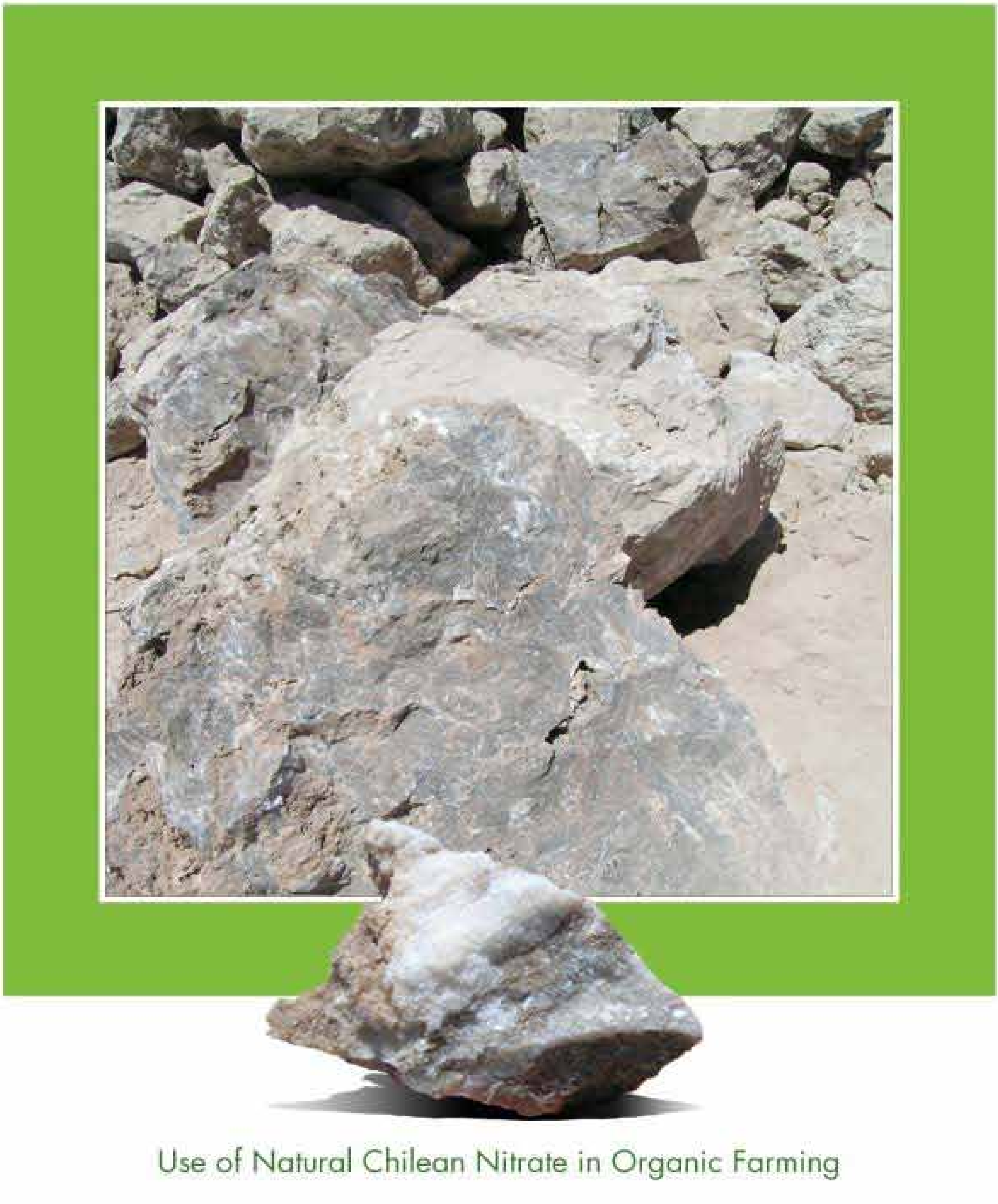
# NATURAL NITROGEN
## NITROGENOUS ROCK



Use of Natural Chilean Nitrate in Organic Farming

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H. Opdebeeck *Agr.Ing., M.Sc.*

G. Verhelst *Agr.Ing., M.Sc.*

E. De Marez *Agr.Ing., M.Sc.*

H. Tejeda *Agr.Ing., Ph.D.*

M. Van Hyfte *Agr.Ing., M.Sc.*

*"It's amazing what is not known"*
*Colin Tudge, 2003*

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- **Basic Principles of Organic Agriculture**

- **Basic Principles of Organic Agriculture**

# Foreword

The purpose of this document is to evaluate the use of Natural Chilean Nitrate, as a source of nitrogen (N), in accordance with the criteria and principles of organic agriculture.

It is a more extended version of the document to be presented to the Codex Alimentarius Committee on Food Labeling at its 32nd session in Montreal (May 2004).

The document and summary are structured according to the IFOAM "Criteria to Evaluate Additional Inputs to Organic Agriculture", as presented in appendix 3 of the "IFOAM Basic Standards for Organic Production and Processing" document, which was approved by the IFOAM General Assembly, Victoria, Canada, in August 2002.

## Natural Chilean Nitrate is Essential and Necessary

Natural Chilean Nitrate is a natural fertilizer containing 16% nitrogen (N). It is the only natural source of nitrate N.

The sole use of current approved organic N sources is insufficient to obtain acceptable crop production in terms of yield and sometimes even quality. Sub-optimal quantities of available N released by soil microorganisms and its lack of synchronization with the uptake of growing crops are the main reasons for these un-satisfactory results.

Because Natural Chilean Nitrate has an available form of N, it is a complement to organic N sources that need time and favorable ecological conditions to be transformed by soil microorganisms. By synchronizing soil N availability with plant needs, Natural Chilean Nitrate contributes to optimal qualitative yield.

When temperature, humidity and pH, the major factors influencing N mineralization, are close to optimal, an organic amendment with a high humus building capacity will only be able to supply the necessary amount of plant available N if applied in very high doses (up to several LAE/ha for demanding crops). When pH is low, this N supplying capacity will be even lower due to diminished mineralization. When now also temperature and humidity are unfavorable the already low N generation capacity will then be even more out of phase with the plant needs.

Humification is an important and beneficial aspect of soil amendments of vegetative origin. Unfortunately the humus production process reduces the N supply capacity of the humified substance (and this more than proportional to its final N content). Natural Chilean Nitrate used as a complementary N source can overcome this by supplying available N in synchronization with plant needs, by stimulating microbial soil life through increased vegetative production and, in acid soils, through pH increase thus avoiding excess organic amendment input which in itself is in conflict with organic agriculture principles.

Consequently, with the right dosage and correct timing, Natural Chilean Nitrate will work in a constructive and life enhancing way with the natural systems and cycles.

Just as organically authorized S fertilizers contribute to the closing of the on-farm S - cycle, Natural Chilean Nitrate, correctly timed and with the right dosage will do the same for the (similar) N - cycle in a constructive and life enhancing way.

Typically for a natural product, Chilean Nitrate also is an important source of trace plant nutrients, distinguishing it clearly from synthetic nitrate. Moreover, several crops benefit from the sodium present in the product.

Even if some authorized alternatives may exist, all of them are organic N sources. Most are based on protein compounds and need microbial transformation – dependent on favorable environmental conditions – to release the plant available nitrate nitrogen (even though they do not produce humus).

Some of them also represent potential hygienic problems (meat meal, blood meal, etc).

## Natural Way of Production of Chilean Nitrate

Formation of the Natural Chilean Nitrate today present in the Atacama Desert dates back to 200,000 years. The Atacama Desert is the driest desert on earth with less than 2 mm of rainfall per year. There is no soil on the surface of the Desert, nor any soil formation process, trace of life or biological life precursor, to the point that for NASA it is similar to the inert surface of Mars. The origin of the Natural Nitrate is supposed to be atmospheric.

Natural Nitrate is obtained from the Caliche ore in the Atacama Desert by mechanical and hydraulic processes, where the sunlight plays an essential role as source of energy. The caliche ore, a “nitrogenous rock” only undergoes physical processing at low temperatures similar to those of the surrounding environment. During processing, not even ion exchange takes place, which is unique among refined mineral fertilizers included those used in organic agriculture. No liquid effluents leave the mining facilities. All solutions are recycled and water is lost only to the atmosphere in the solar evaporation system, a very important component of the mining process.

The total energy input (mostly for rock crushing, ore conveying and evaporation) is 44GJ per ton of N of which 57% comes from directly capturedsolar energy i.e. at 19 GJ per ton N total non renewable energy, its energy score is much more favorable than for synthetic N fertilizer that consumes on average 40 GJ per ton N non-renewable energy. There are plans for the near future the improve this energy balance even more.

## Considerations on the Impact on the Environment

There is no indication that, when used properly, Natural Chilean Nitrate would have a negative effect on the soil structure and aggregate stability. A better plant growth caused by an improved synchronization between N availability and plant needs implies a larger organic matter input returned to the soil through more abundant crop residues, which should have a positive influence on soil organic matter and consequently on soil structure.

Any fertilizer that increases controllability, i.e. N-availability and N-efficiency, in harmony with current organic practices will reduce the impact on the environment. In this context, Natural Chilean Nitrate represents a valuable contribution.

Natural Chilean Nitrate as macro-nutrient fertilizer contains only N and no P and K. Therefore it will minimize accumulation of these macro-nutrients by avoiding excess input of organic fertilizers in order to satisfy N needs.

Few specific long-term trials have been carried out in order to determine the influence of different farming systems on the microbial biomass in particular and on biological cycles in general. Even then, it is difficult to use these studies to extrapolate the specific influence of different fertilizing systems or individual fertilizers and this because of “confounding variables”.

Only 2 parameters; soil organic matter and pH, have been shown to clearly affect the microbial biomass. Natural Chilean Nitrate positively affects both soil organic matter and pH and therefore microbial biomass.

Soil fauna and flora similarly are not expected to be negatively affected. This can be explained by the fact that the nitrate and sodium soil concentration will remain well within their natural range when Natural Chilean Nitrate is used as intended.

Natural Chilean Nitrate is one of the least contaminant among the natural sources of fertilizer nitrogen. As said, when Natural Chilean Nitrate is applied, it is possible to exert a high degree of control over the timing and the level of available nitrate in the soil, minimizing leaching. Heavy metal content is negligible and lower than in average manures.

## Human and Animal Health and Quality

By providing available nitrogen during critical growing stages, Natural Chilean Nitrate improves the quality of crops mostly through increased protein and micro-elements content. When used as intended, and as part of a “system approach”, nitrate levels in crops will not be affected.

Iodine in Natural Chilean Nitrate contributes towards maintaining the level of this essential element in human and animal food. Sodium has a positive effect on its content in pastures, benefiting animal health because this element is essential to farm animals, in particular for milk production (Heintze, 1992).

## Socio Economic Aspects and Values (Ethics)

Complementary use of Natural Chilean Nitrate will allow the organic farmer to optimize production. This and the access to a more economic source of N will give the organic farmer a competitive advantage in the market place and will contribute in maintaining rural communities.

The judicious use of Natural Chilean Nitrate respects and supports the cyclical precautionary and nearness principles dear to the organic agriculture community. It supports expressions of value and ethics such as: “self-reliance”, “biologically robust”, “high general standard of nutrition”, “enlightened agriculture”, “ecology, sensible balance”, “excellence in husbandry”, “productivity together with sustainability”, “maintaining rural communities”, “shorter supply chain”, etc.

Natural Chilean Nitrate, as an essential but most natural plant food, has proven to be a valuable contribution to the success of organic agriculture in that it will allow organic agriculture to improve in a significant way its productivity, sustainability, its potential to produce fresh food of best quality and to fulfill the logistical requirements to offer a fair deal for consumers and promote local labor intensiveness by shortening the supply chain and promoting national self reliance.

Its judicious use is part of common sense agriculture and reflects biological reality. Before the introduction of synthetic nitrogen, when the entire world agriculture was basically organic, farmers already used this nitrogenous rock to maintain soil fertility. Natural Chilean Nitrate was used as organic fertilizer before organic agriculture became a world movement.

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# Introduction

- **Basic Principles of Organic Agriculture**

In order to allow the reader to brush up and have a good understanding of what organic farming is, the basic principles according to different organizations are herewith listed.

***IFOAM*[1]'s *Basic Standards:*** *"Organic agriculture includes all agricultural systems that promote the environmentally, socially and economically sound production of food and fibers. These systems take local soil fertility as a key to successful production. By respecting the natural capacity of plants, animals and the landscape, it aims to optimize quality in all aspects of agriculture and the environment. Organic agriculture dramatically reduces external inputs by refraining from the use of chemosynthetic fertilizers, pesticides, and pharmaceuticals. Instead it allows the powerful laws of nature to increase both agricultural yields and disease resistance. Organic agriculture adheres to globally accepted principles, which are implemented within local social-economic, geographical-weather and cultural settings. As a logical consequence, IFOAM stresses and supports the development of self-supporting systems on local and regional levels."*

*IFOAM*, 2003

*IFOAM's* "Standards" document highlights the following **objectives:**

1. To produce food of **high quality** in sufficient **quantity.**
2. To interact in a **constructive** and **life-enhancing** way with natural systems and cycles.
3. To consider the wider **social** and **ecological** impact of the organic production and processing system.
4. To encourage and enhance **biological cycles** within the farming system, involving microorganisms, soil flora and fauna, plants and animals.
5. To develop a **valuable and sustainable aquatic ecosystem.**

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[1] International Federation of Organic Agricultural Movements

6. To maintain and increase **long term fertility** of soils.
7. To maintain the genetic diversity of the production system and its surroundings, including the protection of plant and wildlife habitats.
8. To promote the healthy use and **proper care of water, water resources** and all life therein.
9. **To use, as far as possible, renewable resources** in locally organized production systems.
10. To create a harmonious balance between crop production and animal husbandry.
11. To give all livestock conditions of life with due consideration for the basic aspects of their innate behavior. (NA[2])
12. **To minimize all forms of pollution.**
13. To process organic products using renewable resources. (NA)
14. To produce fully biodegradable organic products. (NA)
15. To produce textiles which are long lasting and of good quality.
16. To allow everyone involved in organic production and processing a quality of life which meets their basic needs and **allows an adequate return and satisfaction from their work**, including a safe working environment.
17. To progress toward an entire production, processing and distribution chain which is both **socially just and ecologically responsible.**

***USDA*:** "*Organic farming is a production system **that excludes the use of synthetically manufactured fertilizer,** pesticides, growth regulators and livestock feed additives. The system relies on crop rotation, **crop residues, animal manures, legumes, green manures, off-farm organic wastes, mechanical cultivation, mineral bearing rocks** and aspects of biological pest control to maintain **soil productivity and tilth, to supply plant nutrients** and to control insects, weeds and other pests.*"

*USDA*, 1980

A more recent definition has been given by the USDA National Organic Standards Board (NOSB, 1997):

*"Organic farming is an ecological production management system that promotes and enhances biodiversity, biological cycles, and soil biological activity. It is based on minimal use of off-farm inputs and on management practices that restore, maintain, or enhance ecological harmony. The primary goal of organic agriculture is to optimize the health and productivity of interdependent communities of soil life, plants, animals and people."*

Some of the **BIO SUISSE organic farming definition highlights:**

1. Taking on responsibility
   Organic farmers are aware of their responsibility with respect to the **natural fundamentals** of life, and try to bring their work into **harmony with the cycles of nature.** Being a human

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[2] NA: Not Applicable in case of fertilizers and soil conditioners

activity, **farming is always an intrusion into nature.**

2. Active soil
   In the long term, only an **active soil** will bear fruits. **Therefore the maintenance and increase of natural soil fertility** by appropriate cultivation practices is of central significance. Everything that works against this goal is to be abandoned. Most especially, **synthetic chemical fertilizers are forbidden.**
3. Producing quality
   Production of quantity may not be achieved at the expense of intrinsic quality.
4. Maintaining quality
   Maintenance of quality, and especially of valuable constituents, should also be considered during further processing of produce from organic farming.
5. In the interest of the consumers
   Organic agriculture offers foods that **contribute greatly to health**, along with the **greatest possible preservation of the environment,** and thus it is fully concerned with **consumers' interests and their health.**
6. Consideration of value
   In turn, it is expected that **consumers** appreciate the value to their health and are **prepared to pay an acceptable premium for these products.**

The General Assembly of BIO SUISSE is responsible for the issuance and **amendment of the standards.**

- Interpretation of the standards
  Any interpretation of these standards must be based on an understanding of the concept of nature involved in organic agriculture as defined in the rules for production.
  The manner in which the standards are to be interpreted is incorporated into the instructions where necessary.
- Relationship of the standards and the law
  Should legal regulations on processing, storage or specifications of foods conflict with these standards, the BUD-label may not be used[3].

The following appendices are integral parts of these standards concerning **permitted aids for fertilization and soil conditioning**.

- Fertilization should promote life in the soil. Nitrogen is given exclusively in the form of organic fertilizers. **Mineral supplements are given on the basis of local needs, soil analyses, observations on the farm as well as the nutrient balance of the whole farm,** and they should be kept to a minimum.The use of **synthetic chemical nitrogen fertilizers,** easily soluble phosphates and **concentrated fertilizers containing chloride or pure potassium** is forbidden in organic farming.

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[3] Bud-label: the most important organic label on the Swiss market is the Swiss Bud label (Knospe) of BIO SUISSE.

Fertilizers are listed in Appendix 1 and also in the annually updated list of auxiliary inputs of the FIBL (Research Institute for Organic Agriculture; Hilfstoffliste für den biologischen Landbau, 2003).

- Organic inputs, compost and earth brought in from outside must not contain any ingredients that are not allowed under the general standards. Particular attention should be paid to anything which could result in contamination by (heavy metals, antibiotics, residues of chemical pesticides etc.). If there are doubts, the necessary analyses must be carried out or requested.
- Moreover, the amount of fertilizer given must be adjusted according to the **site** and **climatic conditions.** The **quantities of all nutrients employed per hectare should, under optimum conditions,** not exceed the amount in the droppings from **2.5 Large Animal Equivalents (LAE)[4],** one per hectare in low land areas (plains). This is to be adjusted according to altitude and growing conditions using the following model:

| Altitude | Use as fodder | Max. no. of LAE/ha Under | |
|---|---|---|---|
| (m above sea level) | (no. of applications) | good conditions | poor conditions |
| 400-600 | 4 to 5 | 2.5 | 2.0 |
| 600-900 | 3 to 4 | 2.0 | 1.5 |
| over 900 | 1 to 2 | 1.5 | 1.0 |

To calculate the average stocking rate of a farm, the average stocking rate (intensity) of the various areas need to be taken into account.

**EUROPEAN UNION:** The first regulation of the European Union on organic farming [Regulation EEC N° 2092/91] – related to organic production of agricultural products and indications referring thereto on agricultural products and foodstuffs - was drawn up in 1991 and implemented in 1992. Organic farming differs from other farming systems in a number of ways. According to the EU regulation **organic farming favors renewable resources and recycling, returning to the soil the nutrients found in waste products.** Where livestock is concerned, meat and poultry production is regulated with particular concern for animal welfare and by using natural foodstuffs. Organic farming respects the environment's own systems for controlling pests and disease associated to raising crops and livestock and avoids the use of synthetic pesticides, herbicides, **chemical fertilizers,** growth hormones, antibiotics, and gene manipulation. Instead, organic farmers use a range of techniques that help **sustain ecosystems and reduce pollution.**

One can conclude that most of the definitions of the different organic agriculture authorities are closely related and are mostly addressing the same topics, although some different interpretations exist.

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[4] Large Animal Equivalent : in Europe considered as a 500 kg bovine

**Street interpretation:**

Views and beliefs are sometimes based on perceptions that are not necessarily based on reality. Furthermore, in the case of organic agriculture they may reflect conflicts between producers and consumers, between local products and imported products. Also some terminology and definitions are different for different people.

Some opinions heard on the street:

- "The goal of organic agriculture is to produce **highly nutritive foods,** and it is **obvious** that organic farmers respect the environment and avoid all pollution".
- "Organic farmers use **exclusively in-house** organic animal derived fertilizers. In this way the **perennial fertility of soil** is guaranteed".
- "Practically all forage is produced organically (on-the farm); purchased forage is only considered as a **complement"**.
- **"Artificial"** fertilizer is prohibited".
- "Fertilizers aim to **fertilize the soil**; A fertilizer is not intended to **"fortify"** a plant".
- "Organic food is more expensive because it is **healthier, natural and of high quality.** And the plant grows **naturally"**.

- **Document set-up and criteria to evaluate additional inputs to organic agriculture**

This document: "Use of Natural Chilean Nitrate in organic farming", is structured according to the Criteria to Evaluate Additional Inputs to Organic Agriculture, found in the IFOAM Basic Standards - Appendix 3.

Out of 6 criteria ( ① Necessity, ② Nature and method of production, ③ Environment, ④ Human health and quality, ⑤ Socio-economic aspects and ⑥ Ethical aspects - Animal welfare), the first 5 will be addressed in 5 corresponding sections together with some ethical aspects (animal welfare is not relevant in fertilizer use).

At the end of each section a score has been given reflecting how well the product stands up to the criteria dealt with in that section (0 = poor, 3 = good).

- **Natural Chilean Nitrate: brief product functionality description**

Natural Chilean Nitrate[5] is a natural[6] fertilizer derived from caliche, a **nitrogenous** rock found in the Atacama Desert in Northern Chile. It contains 16% nitrogen as its main plant nutrient and a series of secondary and trace nutrients.

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[5] Natural Chilean Nitrate = natural sodium nitrate

[6] natural: as opposed to synthetic

Synthetic : artificial, man-made, not real, not genuine; Synthesis : combining of separate elements into a complete whole (Encyclopedia Britannica).

It is granulated and can be broadcasted, drilled or used as a side-dress. Natural Chilean Nitrate has been used as a fertilizer for **more then 100 years** and is currently authorized (on a regulated status) in organic agriculture in the USA (NOP (National Organic Program), USDA, National List of Allowed and Prohibited Substances).

## 1.1 Food production of high quality and in sufficient quantity

### *1.1.1 Nitrogen as critical plant nutrient*

Food production of high quality and in sufficient quantity is one of the most important objectives of organic agriculture. The plant nutrient supply affects yield, quality and natural plant health as well as the environment (see also section 3). The supply of plants with mineral elements has a direct impact on the content of primary and secondary compounds and their mineral composition (Haneklaus et al., 2002).

A lot of research has been done to evaluate the differences between the different "conventional" ways of practicing agriculture and organic farming related to quality and quantity.

#### *1.1.1.1 Quality and yield in organic farming*

- **Quality**

The most important quality aspect of organically produced crops is the lack of contamination from synthetic pesticides.

Moreover, nutritional, phenotypic and technical aspects are major criteria for the acceptance of the products by consumers and industry. Plant nutrition plays a key role in organic farming, as a balanced nutrition of the crop is essential not only for producing high quality food and feedstuff, but also for promoting natural plant resistance mechanisms against pests and diseases (Haneklaus et al., 2002). When plant nutrition is inadequate, quality suffers.

- **Yield**

On European organic farms, arable crops yield 20 to 40% less, and forage crops and livestock yield about 20% less than conventionally managed farms (Nieberg & Schulze Pals, 1996; Halberg & Kristensen, 1997). Limited nitrogen supply is often regarded as one of the key limiting factors, responsible for the lower productivity. Also vegetable crop productivity is restricted by a limited quantity of available N during the period of rapid crop growth (Eltun, 1996; Berensten et al., 1998; Torstensson, 1998; Berry et al., 2002).

N balances are often positive (i.e. input > output) for organic farms (Kaffka & Koepf, 1989; Nolte & Werner, 1994). Berry et al. (2002) have calculated that the level of N input for many organically grown crops (cereals, grain vegetables and silage) is similar to those of conventionally managed crops at 150 to 300 kg N/ha. Furthermore, studies have shown that the supply of mineral N from organic matter in organic systems can be even in excess of 300 kg N / ha / yr (Hatch et al., 1991; Gill et al., 1995; Bhogal et al., 2001). This indicates that the problem may be more in **the timing** of N availability than in the amount (Berry et al., 2002).

On the other hand Hilfiker (1998) found that (Figure 1), the N supply on organic pilot farms in the Swiss planes region in 1993 was about 10 kg N/ha below the commonly accepted plant needs. This shortage even reached 30 kg N/ha in 1996.

This is a first indication of **the difficulty in managing N inputs** in organic farming. The nutrient management is further complicated by the fact that most organic fertilizers supply all 3 main plant nutrients, but in **unbalanced ratio's.** Therefore trying to avoid excess supply or accumulation of 1 element (e.g. P) can lead to shortage of an other (N, K) or vice versa.

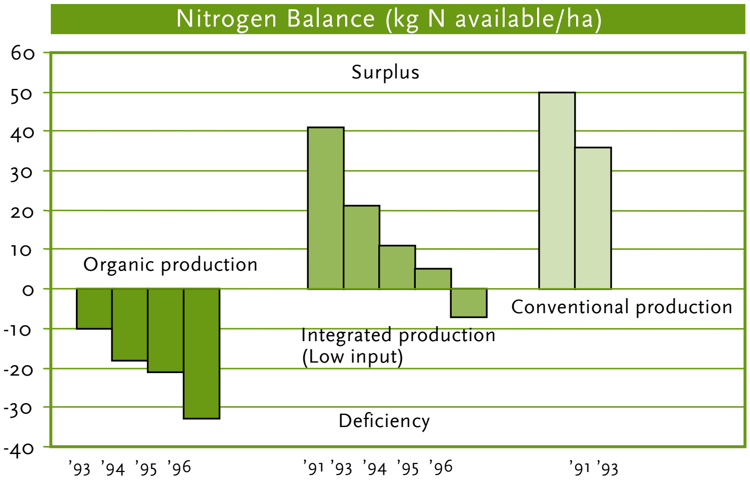

**Figure 1:** Nitrogen balance – contribution of manure minus crop needs – on pilot farms in the Swiss lowlands (Hilfiker, 1998. Rapports FAT, no 518, 1998. Based on Hausheer, Rogger et al., 1998)

### 1.1.1.2 *Results of some well documented trials*

Wheat

- **Yield**

In a long term seven-year rotation experiment including the following crop sequence - clover/grass, clover/grass, potato, winter wheat, cabbage or rape, winter wheat, winter rye, two growing methods were compared: conventional[7] and organic[8]. After completing the third rotation cycle, the average yield of organically grown wheat was only 86% of the yield of conventionally grown wheat. Yield of organically grown potatoes was only 63% of the yield of conventionally (low input) grown potatoes (Dubois et al., 2003).

In another research with different varieties of cereals Menzi and Anders (2003) found that there was a reduction of yield of about 20% in organically grown crops (Table 1). Some researchers found larger differences, others smaller. According to Stopes et al. (2000) organically produced wheat yields are routinely only 50-70% of conventional (high input) wheat production.

**Table 1:**

**Yield and Protein content of conventional and organic grown winter wheat varieties, Switzerland, 2000 and 2001 (Menzi & Anders, 2003)**

| Wheat variety | Grain Yield<br>Conventional | Organic | Difference | | Protein Content<br>Conventional | Organic | Difference | |
|---|---|---|---|---|---|---|---|---|
| | (Mt/ha) | (Mt/ha) | (Mt/ha) | % | % | % | % points | % |
| Arina | 5.81 | 4.89 | 0.92 | 15.83 | 13.6 | 12.1 | 1.5 | 11.0 |
| Tamara | 5.81 | 4.45 | 1.36 | 23.41 | 14.3 | 13.4 | 0.9 | 6.3 |
| Runal | 6.22 | 4.98 | 1.24 | 19.94 | 14.2 | 12.6 | 1.6 | 11.3 |
| Lona | 5.91 | 4.57 | 1.34 | 22.67 | 14.1 | 12.5 | 1.6 | 11.3 |
| Titlis | 6.32 | 5.19 | 1.13 | 17.88 | 14.5 | 12.6 | 1.9 | 13.1 |
| Taneda | 6.56 | 4.81 | 1.75 | 26.68 | 14.0 | 12.9 | 1.1 | 7.9 |
| Levis | 7.14 | 5.31 | 1.83 | 25.63 | 13.0 | 11.4 | 1.6 | 12.3 |
| Pegassos | 7.52 | 6.62 | 0.90 | 11.97 | 11.8 | 9.9 | 1.9 | 16.1 |
| **Average** | **6.41** | **5.10** | **1.31** | **20.41** | **13.7** | **12.2** | **1.5** | **11.1** |

- **Quality**

The most important effect of the organic treatment is not the reduction of yield but the reduction of protein content (11.1%; Table 1) and Zeleny test figures (11.4%; Table 2).

The **compound effect** of yield and protein content causes a very significant decrease of protein production per hectare (0.26mt/Ha or 29.6%; Table 2).

Similar trends are observed in 19 other studies (Woese et al., 1995).

The decrease in both, the protein content and the Zeleny sedimentation test figures, have an

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[7] Conventional: in this case organic and conventional mineral fertilizer

[8] Organic fertilizer

## Table 2:
## Protein Yield and Sedimentation Zeleny Test of conventional and organic grown winter wheat varieties, Switzerland 2000 and 2001 (Menzi & Anders, 2003)

| Wheat variety | Grain Yield | | | | Protein Content | | | |
|---|---|---|---|---|---|---|---|---|
| | Conventional | Organic | Difference | | Conventional | Organic | Difference | |
| | (Mt/ha) | (Mt/ha) | (Mt/ha) | % | % | % | % points | % |
| Arina | 0.79 | 0.59 | 0.20 | 25.1 | 54.3 | 50.8 | 3.5 | 6.4 |
| Tamara | 0.83 | 0.60 | 0.23 | 28.2 | 71.3 | 64.5 | 6.8 | 9.5 |
| Runal | 0.88 | 0.63 | 0.26 | 29.0 | 62.5 | 57.5 | 5.0 | 8.0 |
| Lona | 0.83 | 0.57 | 0.26 | 31.4 | 66.3 | 58.0 | 8.3 | 12.5 |
| Titlis | 0.92 | 0.65 | 0.26 | 28.6 | 67.5 | 59.5 | 8.0 | 11.9 |
| Taneda | 0.92 | 0.62 | 0.30 | 32.4 | 65.9 | 62.3 | 3.6 | 5.5 |
| Levis | 0.93 | 0.61 | 0.32 | 34.8 | 60.4 | 51.8 | 8.6 | 14.2 |
| Pegassos | 0.89 | 0.66 | 0.23 | 26.1 | 54.6 | 41.2 | 13.4 | 24.5 |
| **Average** | 0.87 | 0.62 | 0.26 | 29.6 | 62.9 | 55.7 | 7.1 | 11.4 |

important negative effect on **the baking quality** of the flour, and **this should be reflected in the price** the organic farmer is being paid for his wheat (Menzi & Anders, 2003).

Although in the case of cereals there may be sufficient nitrogen for the production of the grains, it is insufficient to keep a reasonable level of protein inside the grains, resulting in some problems, baking quality being the most important (Menzi & Anders, 2003; Von Pettersson, 1977).

Similar conclusions were drawn by Berry et al., (2002). Besides productivity the low N content in organically grown cereal grain confirmed that lack of available nitrogen restricts protein content. Indeed Figure 2 shows that under a certain threshold of mineral N, grain quality (N-content[9]) is seriously affected and **that N content of grains (quality) and yield are correlated** (and depend on the level of N fertilization).

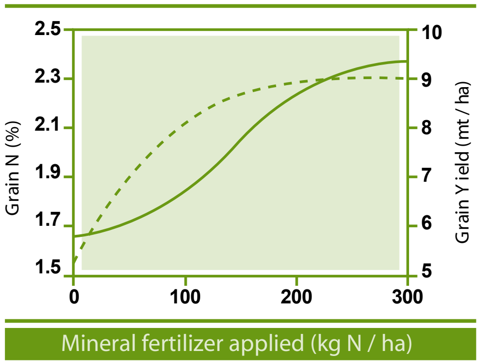

**Figure 2**: Relationship between amount of applied nitrogen in spring and grain N% in 100% dry matter ( ___ ) and grain yield at 85% dry matter (- - -) for 17 crops of milling winter wheat on clay soil (Berry et al., 2002).

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[9] N content in grains is a good indicator for protein content (quality) and yield. Crude protein (content) = 6.25 x N content (Fertilizers and Fertilization, Arnold Finck, page 393).

It is a fact that the percentage of Switzerland's internal supply of organic wheat suitable for bread making has **fallen from 45% in 1991 to 25%** in 2000 (Steffen, 2003; Swiss import statistics).

Also, for the consumer of organic products, the importance of organic wheat as an additional source of vegetal proteins is being substantially diminished (Menzi & Anders, 2003).

Potato:

- **Yield**

In the same long term seven-years rotation experiment mentioned on page 29, yield of organically grown potatoes was only 63% of the yield of conventionally grown potatoes (Dubois et al., 2003).

A multi-variety potato trial cultivated under organic and low input systems during the four seasons from 1997/1998 to 2000/2001 (Hebeisen et al., 2003) confirmed the results by Dubois et al., (2003). The results of these trials are presented in Table 3.

The average yield over the four seasons for all potato varieties in the trials cultivated under the conventional **(i.e. low input)** system was 34.4 Mt/ha whereas the average yield under the organic system was 18.9 Mt/ha. It is also important to note that despite the normal yield differences that **should be expected among varieties and seasons,** the yield under the organic system compared to the yield under the low input system remains almost constant **at around 55% for all** four seasons (Table 3).

According to Hebeisen et al. (2003), the yield potential of potato varieties cannot be attained in full under the organic system mainly because of early diseases ("mildew", late blight, *Phytophthora infestans*) and insufficient nitrogen supply, which results in weak development and an early senescence of leaves. However even the blight tolerant varieties did not show a significantly higher yield, which means **insufficient N supply was the key factor.** Indeed, potato has a relatively high need of nitrogen of which a large part must be satisfied in a rather short time period.

According to Walther et al., 1996 and Walther, 1999, quoted by Hebeisen et al., (2003), potatoes absorb 80% of the nitrogen within four to six weeks after emergency.

If nitrogen is not available during this short period, tuberization and maturation will be seriously affected. In organic agriculture, using mainly farm yard manure or compost as a nitrogen source, it is very difficult to synchronize the release of nitrogen with the potato growth cycle and the relatively short period of N needs. It is quite clear that many of the constraints on organic yield arise because soil nitrate is not present in sufficient quantities to permit optimal crop growth when it is needed in springtime (Berry et al., 2002).

No clear differences in the nitrate content of potatoes were found in samples from different origins. There was only a slight trend towards lower nitrate content in organically grown potatoes. The differences in nitrate content are probably due to differences of nitrate availability and explain partially the shortage of nitrogen in organically grown potatoes (Abele, 1987; Woese et al., 1997).

## Table 3:
## Average Potato Commercial Yield from Multi-Variety Trials 1997 – 2001 (Hebeisen et al., 2003) under organic and conventional (low input) production systems

| Year | Variety | Organic<br>T/Ha | Conv.<br>T/Ha | Org/Conv.<br>% |
|---|---|---|---|---|
| 1997/1998 | Marabel | 19.3 | 40.6 | 47.5 |
| | Velox | 21.9 | 33.1 | 66.2 |
| | Sirtema | 23.5 | 38.1 | 61.7 |
| | Bintje | 18.0 | 36.9 | 48.8 |
| | **Average** | **20.7** | **37.2** | **55.6** |
| 1998/1999 | Victoria | 17.5 | 37.1 | 47.2 |
| | Synfonia | 20.2 | 36.1 | 56.0 |
| | Bintje | 18.0 | 29.6 | 60.8 |
| | **Average** | **18.6** | **34.3** | **54.2** |
| 1999/2000 | Naturella | 19.4 | 30.8 | 63.0 |
| | Synfonia | 21.7 | 34.4 | 63.1 |
| | Bintje | 11.3 | 30.7 | 36.8 |
| | **Average** | **17.5** | **32.0** | **54.6** |
| 2000/2001 | Agata | 22.3 | 34.8 | 64.1 |
| | Cherie | 18.2 | 31.5 | 57.8 |
| | Laura | 19.7 | 36.4 | 54.1 |
| | Sistema | 18.7 | 32.7 | 57.2 |
| | Bintje | 14.2 | 32.8 | 43.3 |
| | **Average** | **18.6** | **33.6** | **55.4** |
| **Overall average** | | **18.9** | **34.4** | **55.1** |

Furthermore, if organic fertilizer would have been able to supply sufficient N at the right time, the application at this critical moment would not have been possible because of technical restrictions (Figure 3).

Indeed the crop is already too much developed to allow application of an organic N-source (yellow zone) even though needs are at one of its most critical stages.

- **Lower quality of organic potatoes**

According to the authors (Hebeisen et al., 2003) of the potato experiment mentioned on page 26 the following observations on quality have been made:

- Starch: the starch content was not different between the 2 procedures. Consequently, as the yield was only about 50%, the **starch yield/Ha** was about half of the one under the low input system.
- Physical quality: under the organic procedure more tubers were hollow and the sizes were above the commercial norms. This was due to more precarious availability of nitrogen.

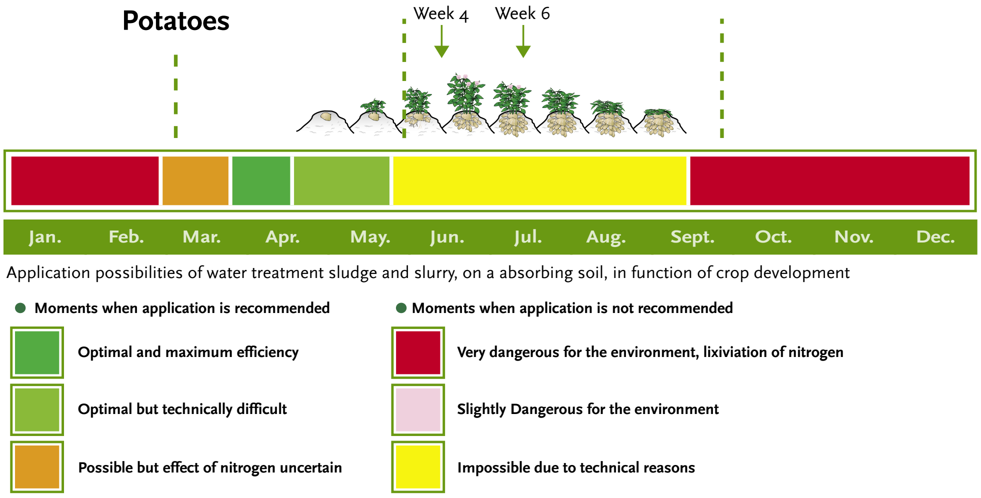


**Figure 3:** Schematic overview of the possibilities in manure supply as a function of potato growth (Revue suisse d'agriculture, 33 (3) p. 58-59, 2001). (Authors translation of legend in English)

- Marketing: since the biologically grown potatoes matured early and consequently came to market earlier than the conventionally grown ones (of the same variety) this upset the logistics chain and was the cause of additional storage expenses.

## Tomato California field trials

- **Yield**

Four crop rotations and management systems were studied in 1994 and 1995 with regards to growth and yield of irrigated processing tomatoes (*Lycopersicum esculentum Mill.*) in the Sacramento Valley close to the campus of the University of California at Davis. The crop rotations were:

① conventional four-year rotations (conv-4);
② conventional two-year rotation (conv-2);
③ low input four year rotation; and,
④ organic four year rotation.

Crops in the two four-year rotations were tomato-safflower-corn-wheat (or oats+vetch)/beans. In the two-year rotation the crops they were tomato-wheat. In the conventional systems N was supplied as mineral fertilizer; in the low input system it was supplied as vetch green manure plus mineral fertilizer; and, in the organic system it was supplied as vetch green manure plus turkey manure. Application rates are presented in Table 4.

## Table 4:
## Rate and source of nitrogen applied to tomatoes grown under different farming systems (Cavero et al., 1997)

| Production system | Applied N (kg ha$^{-1}$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1994 | | | | 1995 | | | |
| | Mineral fertilizer | Cover crop | Manure | Total | Mineral fertilizer | Cover crop | Manure | Total |
| Conventional – 4 | 162 | | | 162 | 173 | | | 173 |
| Conventional – 2 | 162 | | | 162 | 173 | | | 173 |
| Low input – 4 | 95 | 111 | | 206 | 95.0 | 64 | | 159 |
| Organic – 4 | | 103 | 130 | 233 | | 82 | 125 | 207 |

Tomato was direct-seeded in the two conventional systems. In the low input and organic systems it had to be transplanted because of the less complete weed control in those two systems. Tomato yields by years and production systems are represented in Table 5.

## Table 5:
## Tomato yield by year and production system (Cavero et al., 1997)

| Production system | Tomato yield (Mt / ha) | | Mean yield | |
|---|---|---|---|---|
| | 1994 | 1995 | Mt / ha | % |
| Conventional – 4 | 92.9 | 74.5 | 83.7 | 100 |
| Conventional – 2 | 83.0 | 67.2 | 75.1 | 90 |
| Low input – 4 | 62.6 | 80.3 | 71.5 | 85 |
| Organic – 4 | 54.6 | 64.5 | 59.6 | 71 |

In 1995 tomatoes grown in the low input and conv – 4 systems had similar yields, which were higher than in the conv – 2 and organic systems. The lower yield with the organic system in 1995 was caused by a Nitrogen deficiency related to low level of mineralized N in the soil and to slow release of mineral N from the cover crop + manure. A high proportion of the N from the vetch green manure but only a low proportion of N from the turkey manure was mineralized during the season. The low level of available N in the soil under the organic system was reflected in the low concentration of nitrate N measured in the petioles of tomato leaves at three different stages of plant development (Table 6). (These results are similar to the results of the wheat trials (Berry et al., 2002), where the low concentration of N measured in the grains reflects the low availability of N in the soil).

**Table 6:**
**$NO_3$-N in tomato petiole at different stages of growth (Cavero et al., 1997)**

| Production system | $NO_3$-N (ppm DM) | | | | | |
|---|---|---|---|---|---|---|
| | 1994 | | | 1995 | | |
| | Bloom | One inch fruit | First color | Bloom | One inch fruit | First color |
| Conventional – 4 | 14,275 | 9,225 | 775 | 7,920 | 7,653 | 240 |
| Conventional – 2 | 14,850 | 11,095 | 1,225 | 7,770 | 6,968 | 587 |
| Low input – 4 | 1,373 | 2,327 | 233 | 8,580 | 5,630 | 80 |
| Organic – 4 | 4,267 | 845 | 50 | 1,022 | 690 | 60 |

Other plant measurements and analysis not shown in this report confirmed the low levels of available soil N (Cavero et al., 1997).

During 1994 yields were higher in conventionally grown tomatoes because a virus in the nursery infected the transplants used in the low input and organic systems. However tomato plants under the low input and organic systems were also subject to reduced levels of soil available N during the 1994 season. This is indicated by the low levels of nitrate N in the petioles (Table 6) as well as by other determinations.

Direct measurements of the ($NO_3^-$- N + $NH_4^+$- N) in soil samples taken at 0-30 cm and 30-90 cm, respectively, also confirmed the low levels of available N in organic soils (Cavero et al., 1997).

- **Quality**

In this research on California tomato, no effects on tomato quality were described.

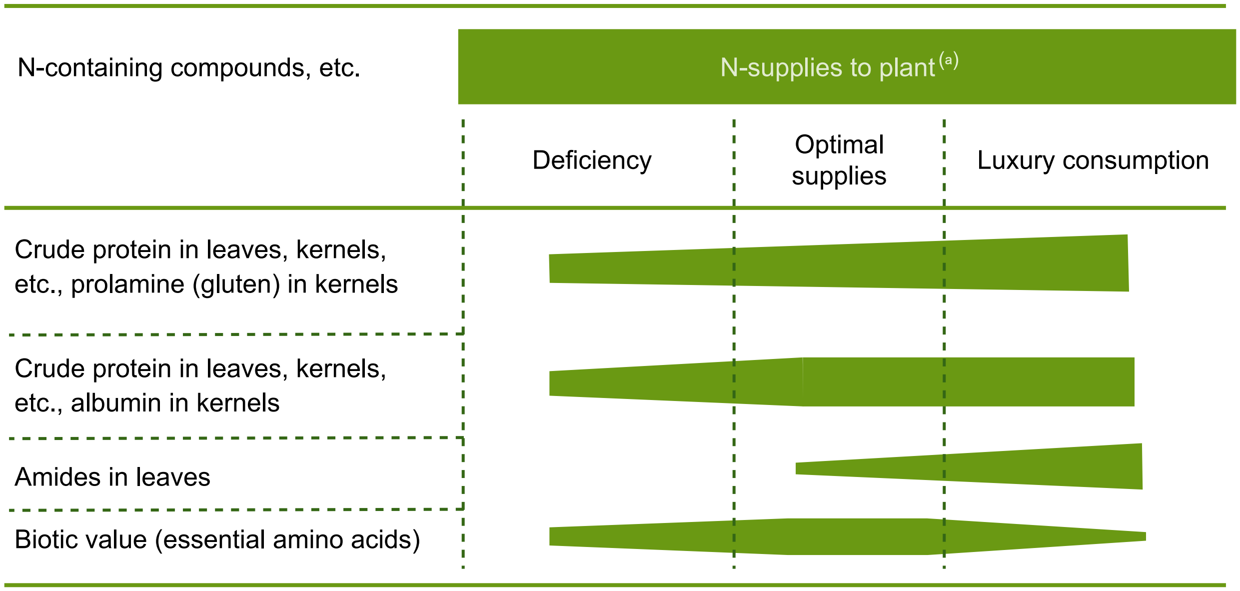
### *1.1.1.3 Proposed solution*

The mineralization of organic manures depends largely on the meteorological conditions and the nature of the soil. As there are no real alternatives ( see § 1.4) acting fast enough to bridge periods of critical nitrogen needs, Natural Chilean Nitrate would be a very valuable complement. Indeed Natural Chilean Nitrate complements all sources of organic nitrogen by providing efficient available $NO_3^-$ nitrogen during critical growing stages or under adverse weather conditions **synchronizing availability** with crop needs and **limiting losses** (more on this in § 1.2 and § 3). In its complementary but critical role, Natural Chilean Nitrate targets only one principle nutrient, avoiding excess accumulation of other elements like P and K. Natural Chilean Nitrate intervenes at that specific time when the current organic nitrogen fertilizers are shown to be inadequate to produce optimal yield at the desired quality. Above first 2 trials (wheat/potato) showed the negative effect on quality of insufficient nitrogen availability.

Nitrogen influences the quality considerably and in many ways, especially through its effects on (Finck, 1979):

- protein content and value
- contents of other valuable substances (containing N or not)
- contents of quality-reducing substances

The health (resistance) of the plant and the quality of its descendants are also influenced. Some important quality changes, caused by fertilization with N are illustrated in Figure 4.



(a) Widening signifies increase

**Figure 4:** Quality Characteristics influenced by N-supply level (Finck, 1979)

### 1.1.2 *Natural Chilean Nitrate source of secondary and trace elements*

### 1.1.2.1 *Supply of secondary and trace elements*

In organic farming, synthetic fertilizers and pesticides are banned.

When both natural and synthetic fertilizers contain the same macronutrients in the same chemical form, the main difference between them lies in the absence or presence of other nutrients in small amounts.

***"An essential difference between many natural and synthetic fertilizers is the degree of their purity.*** *Farmyard manure contains not only nitrogen but also provides all necessary plant nutrients; Natural Chilean Nitrate contains many admixtures in contrast to synthetic sodium nitrate that is essentially a pure chemical. The trend to increase the purity of fertilizers is no justification at all for considering them to be harmful. But it* ***does represent a potential danger to food quality*** *because of a possible one-sidedness in fertilization. On the other hand a greater purity also ensures smaller amounts of possible detrimental admixtures"* (Finck, 1979).

**Other natural fertilizers**, allowed in organic farming, like rock phosphate and rock potash, mineral potassium/sodium salts (kainite, sylvinite), calcium carbonate of natural origin, mined sodium chloride, etc **contain some additional nutrients**, and possible detrimental elements, and are **authorized fertilizers in organic agriculture.**

Table 7 shows that for S, Mg, B, Fe and Mn, Natural Chilean Nitrate provides a substantial contribution. Also Cu and Zn are present in significant amounts. In fact a sufficient supply of other plant nutrients is relevant for N-fertilizer efficiency. S, K, Mg, Cu, Zn and B deficiency may result in a real N-fertilizer efficiency of 19-32% compared to 74% under optimum conditions (Schnug, 1991).

In an application of, for example 50 kg N/ha (319 kg Natural Chilean Nitrate), half of the average boron, over 30% of the manganese, 10 to 20% of the copper, 1,5 to 3% of the sulfur and magnesium needs (average plant needs as indicated in Table 7) are supplied to the soil. An amount of iodine, important for humans, (see § 4.1.1) is also available for plant uptake.

### *1.1.2.2 Ion competition and synergism: nitrate-N vs. ammonium-N*

In many plant species organic anion accumulation in the plant can largely be attributed to charge transfer from $NO_3^-$ assimilation (Dijkshoorn et al., 1968). Increasing the level of $NO_3^-$ nutrition thus stimulates organic anion synthesis and hence cation accumulation (Kirkby & Knight, 1977). In contrast, plants supplied with $NH_4^+$-N often contain lower concentrations of inorganic cations ($Ca^{2+}$, $Mg^{2+}$ and $K^+$) (Table 8). It was also noticed that nitrate fed plants had higher concentrations of organic acids. These organic acids act as natural complexators and promote trace element uptake (Ullrich, 1987).

In other words, besides supplying several secondary and trace elements, Natural Chilean Nitrate, as a nitrate fertilizer, also could help overcome **nutrient stress periods** of the plant in an easier manner, **by stimulating the absorption of those elements already present** in the soil.

### *1.1.2.3 Sodium*

- **Effect on yield**

For many years it has been known that there are crops that respond favorably to the application of sodium (Lehr, 1953; Lunt, 1966; Marshner, 1971). All of these crops respond to sodium when there is insufficient potassium at their disposal, but some of them respond even if there is ample

## Table 7:
## Contribution of Natural Chilean Nitrate

| Secondary elements | Dosage of 50 kg N / ha<br>Natural Chilean Nitrate (g/ha) (c) | Average Plant needs of most plants |
|---|---|---|
| Ca | 13 | 55 000 – 70 000 (b) |
| Mg | 639 | 9 000 – 1 800 (b) |
| S | 671 | 20 000 – 40 000 (b) |
| Na | 83 387 | 10 000 – 60 000 (a) |
| Trace elements | | |
| Mn | 172 | 500 (b) |
| B | 224 | 50 – 500 (a) |
| Fe | 9 | 1000 – 2000 (b) |
| Zn | 0 | 100 – 300 (b) |
| Cu | 13 | 60 – 100 (b) |
| $SiO_2$ | 3 | NA |

(a) Finck, A. DUNGER UND DÜNGUNG, 1979; Verlag Chemie Weinheim New York p.103, 217.
(b) André Gros, 1979, ENGRAIS Guide pratique de la fertilization, 7th edition. Firmin-Didot, Paris; ISBN 2-7196-0013-X
(c) Data provided by SQM (Sociedad Quimica y Minera de Chile; mining company)

## Table 8:
## Influence of the form of N-nutrition on the cation-anion balance in white mustard leaves (Kirkby, 1968)

| | Cations | | | | | Anions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $Ca^{2+}$ | $Mg^{2+}$ | $K^+$ | $Na^+$ | Total | $NO_3^-$ | $H_2PO_4^-$ | $SO_4^{2-}$ | $Cl^-$ | Org. | Total |
| | (me/100 g DM) | | | | | (me/100 g DM) | | | | acids | |
| $NO_3^-$ | 107 | 28 | 81 | 5 | **221** | 1 | 26 | 25 | 25 | 162 | **239** |
| $NH_4^+$ | 72 | 22 | 40 | 7 | **141** | 1 | 25 | 25 | 31 | 54 | **136** |

supply of potassium, because of particular physiological effects of sodium (Marschner, 1986). In all of these crops, sodium is capable of replacing part of the potassium in a proportion that varies according to the crop. As such, crops can be classified in 4 groups according to their response to sodium (Marschner, 1986):

(A) Sodium itself makes an important direct contribution in raising yields and it also substitutes a high proportion of potassium.
(B) Sodium itself contributes moderately to raising yields and substitutes potassium at a lower rate.
(C) Sodium slightly substitutes potassium without directly contributing to increased yield.
(D) Sodium neither substitutes potassium nor has any effect of its own on yields.

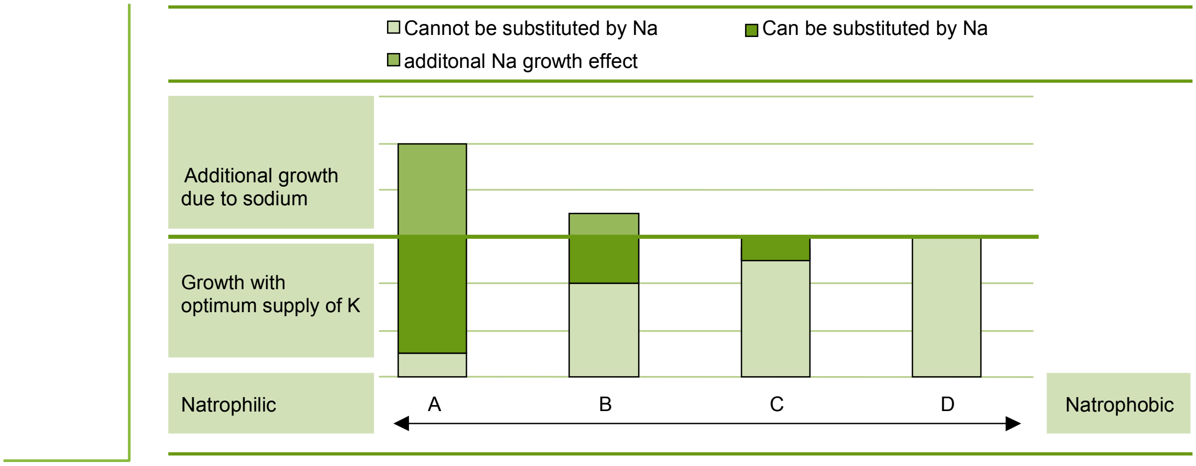


**Figure 5:** Schematic crop classification diagram according to: 1) their direct yield response to Na, 2) their potash substitution capacity (Marschner, 1986)

Marschner (1986) designates those crops, which benefit from sodium as "natrophilic". Those which benefit little or not at all from this element are called "natrophobic". He found that in natrophilic plants, this element is easily transferred from the roots to the rest of the plant, which is not the case for natrophobic plants where Na accumulates in the roots. Examples of crops with a high response to sodium, even in presence of sufficient potassium are sugar beet, celery, swiss chard, turnips, and spinach (Lunt 1966). Van Burg et al., (1983), even consider sodium as an essential secondary nutrient for beets, without which it is impossible to obtain good yields.

- **Effect on quality**

Sodium has also positive effects on the quality of some crops. In a field test in Curacavi, Metropolitan Region, Chile, the use of Natural Chilean Nitrate in tomato and cantaloupe produced fruit with greater firmness at harvest and post harvest, and less dehydration (Suárez, 1989).

Indeed, experiments with different cations in diverse crops have indicated that a high absorption of metallic alkaline cations, particularly sodium, induces **high turgidity** in plants (Black, 1968).

Various physiological effects of sodium on plants have been studied in **sugar beet.** The growth stimulation caused by sodium is related primarily to an increase in the size of the leaf cells and better fluid balance in the plants (Marschner, 1986). The replacement of potassium by sodium increased the above-ground dry weight, the foliar area, the thickness of the leaves, and their succulence i.e. it improves their water balance by accelerating the closing of the stomata under fluid stress (Hampe & Marschner, 1982).

The substitution of potassium with sodium also affects the activation of certain enzymes. Starch synthase has an activation rate three or four times lower with sodium than with potassium. Because of this, the content of soluble carbohydrates, particularly sucrose, is much greater in plant leaves with high sodium content, the starch content being much lower (Hawker et al, 1974). Also sodium is more effective than potassium in stimulating the accumulation of sucrose in the storage tissue of sugar beets (Marschner, 1986). Therefore sodium raises the level of stored sucrose in the roots (Jennings, 1976).

Furthermore, replacing potassium with sodium should increase the recovery of sugar during root processing. Both have the same negative influence on sugar recovery, but the accumulation of potassium in the roots is several times greater than that of sodium (Kirkby et al., 1987).

Natural Chilean Nitrate could ultimately be the trigger for successful organic sugar beet production.

The potential ecological impact of sodium related to soil structure and aggregate stability is discussed in section 3 ( § 3.1.2.2). The potential positive effect of the use of sodium in pastures on animal health is discussed in section 4 ( § 4.1.3).

### *1.1.3 Summary: nutrient supply related to crop yield and quality*

Nitrogen deficiency is one of the most important nutrient disorders in organic farming. Nitrogen is often limiting crop performance (quality and yield) when N is supplied exclusively by organic manure and legumes in the crop rotation. If nitrogen is the limiting element, under current organic farming practices, Natural Chilean Nitrate can be a very valuable complement to bridge the short periods of critical nitrogen needs.

Natural Chilean Nitrate complements all sources of organic nitrogen by providing efficient available $NO_3^-$ nitrogen during critical growing stages or under adverse weather conditions synchronizing availability with crop needs.

In its complementary but critical role, Natural Chilean Nitrate targets only one main nutrient, avoiding excess accumulation of other elements like P and K. Natural Chilean Nitrate intervenes at that specific time in which the current organic nitrogen fertilizers are showing to be inadequate to produce optimal yield at the desired quality.

Typically for a natural product, Natural Chilean Nitrate provides an important source of trace plant nutrients distinguishing it clearly from synthetic nitrate.The yield and quality of other crops also benefit from sodium.

## 1.2 Interaction in a constructive and life-enhancing way with natural systems and cycles.

### 1.2.1 *On-farm nitrogen cycle: balancing losses and gains*

In all systems, conventional and organic, there is a need for increased fertilizer input-efficiency. No doubt, new crops and cropping systems as well as changing management practices have an influence on the flow of nitrogen. The N cycle cannot be isolated from other physical, chemical and nutritional conditions in agricultural production (Van Cleemput, 1999). Organic farming aims at closed nutrient cycles (see also § 3), but an adequate supply of essential plant nutrients and organic matter is indispensable in order to maintain crop productivity and soil fertility (Haneklaus et al., 2002).

Not all N applied to the soil is immediately available. Organic matter needs mineralization (and urea needs hydrolysis). Even if the N fertilizer is in mineral form it might not be immediately available. Processes such as sorption and desorption, immobilization and mineralization, transformation into gaseous form or translocation out of the root zone are in competition with the plant uptake. To increase fertilizer efficiency, synchronization and synlocation are very important parameters (Van Cleemput, 1999).

Table 9, shows that for example in Switzerland, agriculture in general is responsible for almost 50% of all N losses.

**Table 9:**

**Emission of the most important nitrogen components in 1000 tons nitrogen per year (1994) after data from SRU 273 (Biedermann & Leu, 2003)**

| Nitrogen emissions | Total | From traffic, households, industry and trade | | From agriculture | | From natural sources | |
|---|---|---|---|---|---|---|---|
| | | In air | In water | In air | In water | In air | In water |
| NOx | 43 | 43 | | | | | |
| $NH_3$ | 55 | 4 | | 51 | | | |
| $N_2O$ | 11 | 2 | | 8 | | 1 | |
| N in surface waters | 46 | | 37 | | 3 | | 6 |
| $NO_3^-$ in groundwater | 46 | | | | 34 | | 12 |
| Total | 201 | 49 | 37 | 59 | 37 | 1 | 18 |
| Overall total | 201 | 86 | | 96 | | 19 | |
| Year 1990 | 250 | 110 | | 107 | | 33 | |

Losses of N out of the root zone can occur through ammonia volatilization, formation of $N_2O$ and $NO_x$ and leaching (Van Cleemput, 1999). On the other hand part of these losses can be recovered through on-farm fixation by legumes.

### 1.2.1.1 *On-farm N losses*

- **Three main on-farm N-losses can be distinguished:**

① Ammonium volatilization losses
② Losses through oxidized gaseous N compounds
③ Nitrate leaching and run-off losses

The first and third type of losses are by far the most important and represent for example over 85% of overall farm N losses that occurred in Switzerland during 1994 (Table 9).

① **Ammonia volatilization**

From all the nitrogen components emitted in the environment, ammonia gasses are the major part of the nitrogen losses. In Switzerland researchers estimate this to be over **50%** of all losses caused by agriculture (Lehmann and Candinas, 2003; Biedermann and Leu, 2003) (See Table 9).

Already during storing and manipulation of cow manure 10 to 15% of the nitrogen is lost, mainly in the form of ammonia ($NH_3$). Pork manure normally looses 20% of the nitrogen as $NH_3$ in this stage. For chicken manure, losses can be even bigger and reach 30 to 50% (Revue suisse d'agriculture, 1994 and 2001).

After application slurry looses another 50% and manure between 50-70% of its ammonium content (Frick et al., 1997. Rapports FAT, 1997, n° 496).

Mineral ammonium fertilizers and especially urea can loose up to 15% of its N content through volatilization, under unfavorable conditions (calcareous soils, high temperature) (Finck, 1979). **Mineral nitrate fertilizers are not subject to volatilization.**

② **Oxidized gaseous N compounds**

Oxidized gaseous N compounds can be formed via nitrification and denitrification. It has now been recognized that emission of $N_2O$ and NO can be equally important with nitrification and denitrification. Next to $O_2$, moisture level, presence of nitrate, temperature and pH, as well as the quality, quantity and spatial distribution of carbon are extremely important. At several places in the N-cycle $N_2O$ as well as $NO_x$ can be produced. The harmful effect on the ozone layer as well as the greenhouse effect is well known. Within denitrification, marginal aerobic conditions or low rates of denitrification favor the formation of $N_2O$ above $N_2$. Nitrogen fertilization as well as rainfall events especially promote the emission to $N_2O$ above $N_2$. Even urine patches are responsible for $N_2O$ emission, next, of course, to $NH_3$ volatilization (Van Cleemput, 1999).

③ **Nitrate leaching and runoff**

Leaching and runoff depend on the balance between irrigation/rainfall and evaporation/transpiration. This is influenced by soil type, climate and management practices. Leaching can be limited by allowing shorter periods of bare soil, better timing of N fertilization and not ploughing old grassland or woodland. Not only nitrate, but also nitrite should be considered as potential groundwater pollutants (Van Cleemput, 1999).

- **N leaching comparison between farming systems**

In several studies, which compare organic and conventional farming, mean concentrations of nitrate-N in leaching water, as well as nitrogen loads were lower in the former. This fact has often been put forward as a proof for the superior environmental stewardship of organic farming systems. However, a scientific evaluation requires that influencing parameters which are highly different between systems should be taken into account, in order to be able to make a correct comparison, (Colin Tudge in his book "So shall we reap" calls it "confounding variables", see section 5).

In the case of N leaching comparison studies, the following parameters should be considered (Kirchmann & Bergström, 2001):

- The (sometimes) less intensive net **N input** in organic compared to conventional farming practice is one major difference between the systems, and must be taken into consideration when comparing the systems.
- T**he proportion of perennial crops** is another very important factor. It can influence nitrogen leaching from a cropping system, i.e. whether there is a living crop from autumn to spring or whether the soil is bare.
- The last main factor is the **yield level correction.** This can be done by adding an equivalent area of land, which is needed to achieve the same yield as in the system with which it is compared. The additional leaching from an equivalent area of land needed to obtain the same yield has to be added to the measured leaching load.

After making corrections for the above parameters N losses due to $NO_3^-$ leaching can then be compared. Respecting the first principle, Ryser et al. (1998) found that mineral fertilizers do not contribute to higher leaching levels than organic manures, on the contrary (Table 10).

Organic fertilizer (manure and composted manure) accounted for an N input of 1710 kg/ha over 4 years against only 1110 kg/ha mineral N input. However plant usage N was about the same for both organic and mineral fertilizer resulting in a **much higher efficiency** for the mineral fertilizer treatment (97% against 55%) (see also § 3.3). Leaching losses were about 20% lower for the mineral fertilizer treatments (321 kg against around 400 kg /ha for organic fertilizer)[10].

Also Kirchmann and Bergström (2001) found similar results using radioactive labeled nitrogen in different animal manures and ammonium nitrate over 3 years. Use of $^{15}$N-labelled organic and mineral fertilizers enables discrimination between nitrogen derived from those fertilizers and nitrogen released from the existing soil N pool. Different types of poultry manure and ammonium nitrate were applied in spring at sowing according to the following scheme (Table 11).

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[10] This does not mean that 321Kg resp. 400Kg N come from the fertilizer applied during the trial period. Most losses come from the mineralization of the organic matter already present. Only N labeled trials and very long term trials (after complete turnover of all O.M.) can determine the real leaching from the fertilizers themselves (see following trials).

## Table 10:
## Influence of type of manure / fertilizer and time of application on the N-balance. Lysimeter study from 1994 till 1998 (Ryser et al., Revue suisse d'agriculture, 1998)

| Criteria | Types of fertilizer (kg N) | | | | |
|---|---|---|---|---|---|
| | Traditional manure | | Composted manure | | Mineral fertilizer |
| | Autumn | Spring | Autumn | Spring | |
| Organic input | 1000 | 1000 | 1000 | 1000 | 0 |
| Mineral input | 710 | 710 | 710 | 710 | 1110 |
| Total input | 1710 | 1710 | 1710 | 1710 | 1110 |
| **Plant usage** | **991** | **998** | **1010** | **947** | **1066** |
| **Leaching** | **416** | **385** | **407** | **398** | **321** |
| **Losses** | | | | | |
| Difference | 303 | 327 | 293 | 365 | -280 |

## Table 11:
## Treatment setup of lysimeter study (Bergström & Kirchman, 2002)

| Treatments | Manure plots | Mineral fertilizer plots |
|---|---|---|
| Year 1 | 100 kg N / ha applied as manure, labeled as $^{15}$N | 100 kg N / applied as AmNi, labeled as $^{15}$N |
| Year 2 | 100 kg N / applied as AmNi | 100 kg N / applied as AmNi |
| Year 3 | 100 kg N / applied as AmNi | 100 kg N / applied as AmNi |

Uptake and leaching only from the first year treatments (labeled $^{15}$N) were compared and tracked over a period of three years.

Total N – leaching (from first year fertilizers and from existing N-pool) were not significantly different between the treatments (Figure 6).

However leaching from ammonium nitrate was almost an order of magnitude lower then from the organic fertilizers ( a total of 3,5% against an average of 28% over the three years).

85 % of those losses from organic fertilizer occurred in the third year (mild Swedish winter) (Table 12).

These low numbers for mineral fertilizer N-leaching have been found in previous studies were leaching of fertilizer-derived N has been estimated for agricultural cropping systems (Dowdell & Webster, 1980; Dowdell et al., 1984; Bergström, 1988) and by 9 year lysimeter studies carried out by Dressel et al., 1992.

Long term lysimeter studies confirmed again the low leaching load from mineral fertilizers: the lysimeter trials from Limburgerhof/Germany (Ergebnisse von Lysimeteruntersuchungen

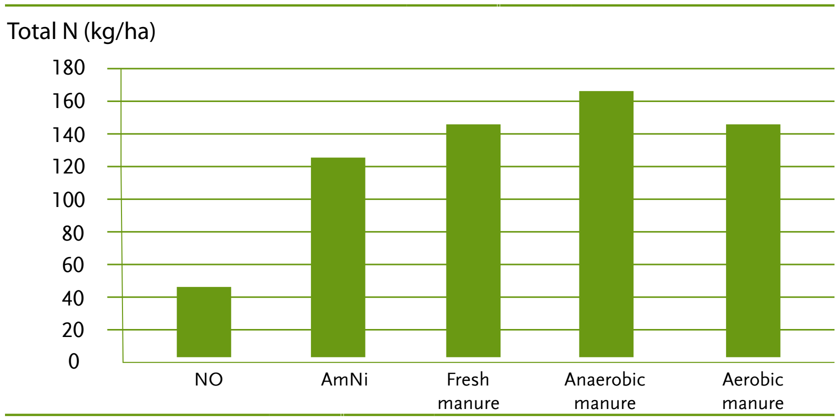

**Figure 6:** Leaching of total N (kg/ha) over 3 years (1992 – 1995) after application of ammonium nitrate and different types of poultry manures (Kirchmann & Bergström, 2001)

### Table 12:

### N – Leaching over a three-year-span (1992 – 1995) when applying 100 kg $^{15}$N-labeled ammonium nitrate and 100 kg $^{15}$N-labeled animal manures (Kirchmann & Bergström, 2001)

| Type of labeled fertilizer applied in the first year | Total N leaching (kg N / ha) | Year 1 (%N) | Year 2 (%N) | Year 3 (%N) | Sum of Leaching (% N) |
|---|---|---|---|---|---|
| Ammonium nitrate | 128 (± 25.7) | 0.9b | 0.4a | 2.2b | 3.5 b |
| Fresh manure | 139 (± 45.4) | 5.6a | 1.1a | 17.9a | 24.6 a |
| Anaerobic manure | 170 (± 31.0) | 3.6a | 1.0a | 27.2a | 31.8 a |
| Aerobic manure | 148 (± 8.4) | 1.4b | 0.2a | 25.8a | 27.4 a |

Within columns, mean values followed by different letters are significantly different at $P < 0.05$ (Duncan's multiple range test and Turkey's studentized range test [HSD].)

in der Grossanlage Limburgerhof, S. Jürgens-Gschwind & J. Jung) took place during more than 50 years from 1927 till 1977 and beyond. With 232 outdoor plots it is probably the largest facility of its kind. From 1927 to 1976 approximately 130 000 samples of percolate were removed and measured and some 1 500 000 analyses of substances in soil and percolate samples carried out and 190 000 analyses of substances in crops.

Concerning N it showed that in general terms: "The nitrogen removed with the percolate is exclusively in the form of nitrate. **Most of this comes from the nitrogen reserves in the soil and**

**only slight amounts from the fertilizer** (Studies 11, 12 and 18). Over a period of 14 or 16 years four different soils under normal agricultural cultivation released only about 6% of the [mineral] fertilizer nitrogen to the deeper layers".

The following are some conclusions from other relevant trials:

- Even in absence of organic fertilizer, in sandy soils, $NO_3^-$ leaching from $NaNO_3$ is limited to 18% (trial n° 3 duration: 8 years).
- As a comparison, $NO_3^-$ leaching from Natural Chilean Nitrate is between 8 and 17 times lower than Na leaching from the same source (trial n°5).
- Contrary to organic fertilizer, little N from mineral fertilizer is leached (trial n° 18, 25 and 26).

Further considerations on potential impact on the environment of the use of Natural Chilean Nitrate will be made in section 3.

#### *1.2.1.2 On-farm N gains*

External input for organic crop production comes either through biological N fixation and/or external organic N input. Leguminous plants can supply nitrogen themselves by symbiosis with N-fixing bacteria. These bacteria live in the root nodules (Finck, 1979). Legume crops grown for N assimilation are common in conventional agriculture and are particularly recommended in organic agriculture. This technique could in principle allow closing an important part of the N-gap, described above, but is in practice only partially satisfactory:

① The percentage of N derived from the air for grain legumes has been found to be in the order of 50-60%, for N fixing trees 55-60% and 70-80% for pasture legumes. Moreover, a high variability has been observed, mainly as a result of a high variability in plant genotypes and bacterium symbionts, ecological as well as management conditions (Van Cleemput, 1999).

② From this again only part of the N will be used by the targeted next crop as shown in Limburgerhof trial n° 6: Legume cover crop (peas) certainly enriches the soil with organic N and diminishes leaching. However only about 30% of the N present in legume crop is taken up by subsequent crop.

Similar results are found in the long-term Agdell experiment at Rothamsted (started at 1848). These trials show a large input of extra nitrogen in the soil by legume cover crops. However grain yield increase of subsequent barley was very limited (Johnstonn, 1991). Also in tropical soils where (low) temperature is not a limiting factor, N production through legume cover crop is not a panacea (Vanlauwe et al., 2002).

③ Further, according to Bergström and Kirchmann (2002), relying on N fixation through legumes for the supply of N to other crops gives very few options for control and thereby little chance of a reduction in leaching loads.

### 1.2.2 *Synchronization of organic nitrogen mineralization with nitrogen uptake by crops*

As demonstrated in chapter 1.1, when using only farm yard manure and crop residues as a source of plant N including crop residues from legumes, the problem lies in the difficulty to match the availability of N in the soil with the plant demand of N in a relatively short period of time.

This has been confirmed by several other sources e.g. Hebeisen (2003) notes that the availability of nutrients in the soil is currently a factor that limits the qualitative and quantitative productivity of organic farming. In some cases, timing or market constrains may limit the use of composting and legume cover cropping and increase the need for fertilizing with sources of readily available nitrogen.

Besides the type of amendment, mineralization of organic nitrogen depends to a large extend on meteorological conditions and soil properties. Contrary to what can be done in conventional agriculture, in organic farming it is not possible to apply readily available nitrogen from an external fertilizer source (Hebeisen et al., 2003), unless it is specifically permitted (USDA, National Organic Program, section 205.602, 2003).

In short the timing of the availability is as important as the total N content of the soil.

The field conditions that influence availability are: ①low soil temperature; ②dry or wet soil conditions; ③wide carbon to nitrogen (C/N) ratio of organic amendments; ④soil acidity or alkalinity; (Brady & Weil, 1999).

#### 1.2.2.1 *N – mineralization in relation to soil temperature*

All forms of organic nitrogen, i.e., from legume cover crops, compost, manure, etc., need to be naturally transformed in the soil into mineral nitrogen forms, mainly nitrate ($NO_3^-$)-N, in order to be taken up by plant roots. Soil microorganisms drive the transformation (Brady & Weil, 1999). With few exceptions, optimum plant growth rate and yield is achieved when plants absorb the majority of the nitrogen as $NO_3^-$ - N and the rest as $NH_4^+$ - N (Marschner, 2002.).

However, during cold seasons – that in many agricultural regions of the world correspond to late fall, winter and early spring – soil microbial activity, including mineralization of N, is very low or almost absent. The temperature coefficient $Q_{10}$ of nitrogen mineralization is 2 over the range 5 to 35 °C. That means that, within this temperature range, for every 10°C temperature increase, the nitrate mineralization rate doubles.

Above 40 °C, the rate of nitrogen mineralization usually drops off, with the optimum commonly lying between 30 and 35 °C (Tisdale, Nelson & Beaton, 1985). At 10 °C the microbial activity may decrease to less than 25% of the maximal rate (Doran & Smith, 1987). In this situation, the concentration of $NO_3^-$ and $NH_4^+$ in the soil, resulting from the slow decomposition of organic substances, is not enough to produce the quantity and quality of vegetables demanded by consumers of organic products (Hebeisen et al., 2003; Havlin et al., 1999; Nat. Organic Standards Board Tech. Advisory Panel Review, 2002; Small Planet Food, 2002).

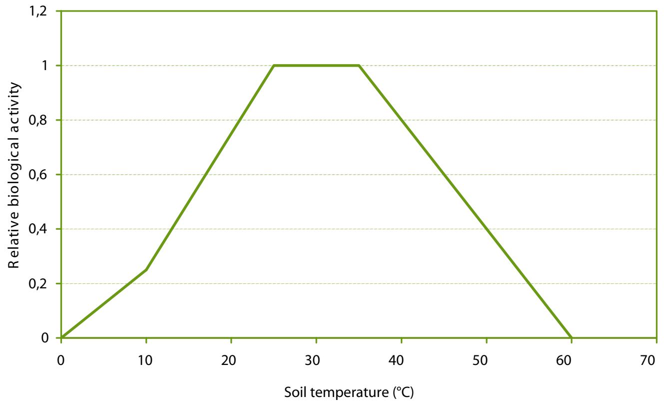

**Figure 7:** Effect of soil temperature on the relative biological activity (Doran & Smith, 1987)

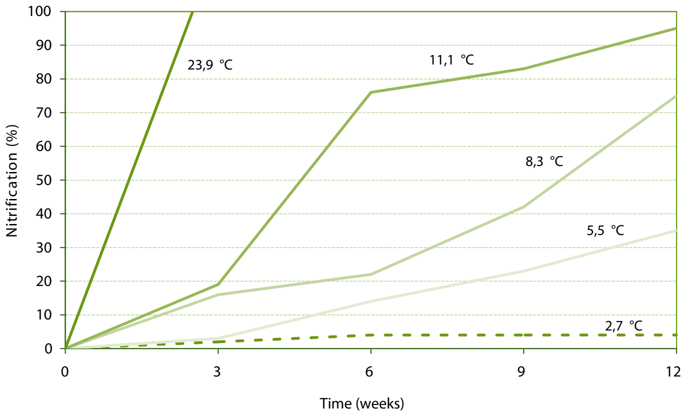

**Figure 8:** Percentage nitrification in function of temperature over time (Source: unknown)

The opposite effect may occur during late spring and summer when mineral nitrogen in excess of crop demand could be released from organic substances. Excess mineral nitrogen could then intervene with the maturation process of the crop, affect soil life or be leached. To limit leaching during autumn and winter, a cover crop should be used, which in turn may affect N availability and synchronization for the next crop.

It is not possible to store plant available nitrogen in the soil for cold and / or wet seasons. Depending on the level of soil moisture, the mineralized nitrogen that remains in the soil after harvesting is either leached to the subsoil, reduced to the form of gas and released in the atmosphere or absorbed by soil microorganisms (Blankenau & Klaus, 2000). In the first two cases, the nitrogen leaves the soil and is no longer available for subsequent crops. In the third case nitrogen absorbed by microorganisms remains in the soil as an organic compound during the cold season until the decaying bodies are mineralized by subsequent generations of microorganisms in the next warm season.

### 1.2.2.2 *N – mineralization in relation to soil moisture*

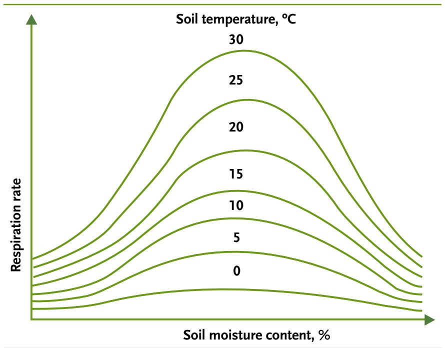

**Figure 9:** Relationship of microbial respiration rate to temperature and moisture (Murphy, 2003).

During wet seasons high water content in soils restricts the level of oxygen necessary for the aerobic microbial decomposition of organic substances - including decaying microbial tissue – restricting the release of mineralized nitrogen (Figure 9) (Tisdale, Nelson & Beaton, 1985). Nitrogen mineralization tends to be slowed down in wet soils.

### 1.2.2.3 *N – mineralization in relation to soil pH*

Soil acidity is another factor that restricts the activity of microorganisms responsible for organic transformations in soils. The pH – range over which nitrification takes place has been given as pH 5.5 to 10 with the optimum around 8.5. But some nitrification takes place in soils at pH 4.5 or lower (Tisdale et al.,1985).

The continuous transformation of organic substances is in itself a factor that increases soil acidity as a result of the hydrogen ions $H^+$ released during the mineralization of the organic nitrogen. One hydrogen ion $H^+$ is released to the soil for each $NO_3^-$-nitrogen that result from the mineralization (Tisdale et al., 1985). Also most mineral N fertilizers acidify the soil although there are a few exceptions of which Natural Chilean Nitrate is the most alkalizing one (for more details see also section 3, § 3.1.4.1.2).

### 1.2.2.4 *N – mineralization in relation to C/N ratio of organic amendments*

Animal manure contains large amounts of decomposable organic material. The mineralizing microorganisms use part of the C and N in the organic material as their building blocks for cells and reproduction. During this incorporation, large amounts of $O_2$ are consumed, which reduces the $O_2$-supply to the soil. The C/N ratio of the organic material determines very strongly if all mineralized nitrogen will be used by microorganisms for cell construction or if (a part of) it can be released in the soil as $N_{min}$[11]. When there is a high C/N ratio (higher than 30), it is possible that the microorganisms **consume** nitrogen from the soil. In that case we have **nitrogen immobilization** leading to a temporary reduction of the plant available nitrogen (Velthof et al., 1998).

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[11] $N_{min}$ = the available mineral N in the soil

## Table 13:
## C/N ratios (Velthof et al., 1998 if not indicated otherwise)

| Crop residue | Incorporation moment | Humification coefficient | C/N ratio | Total N amount |
|---|---|---|---|---|
| Wheat straw | august | 35 | 60 | 25 kg / ha |
| Grain maize | october | 28 | 47 | 110 kg / ha |
| Beet leaves | october | 24 | 15 | 120 kg / ha |
| Dry cow manure | | | 14.8 (a) | 5.20 kg / ton |
| Slurry cow manure | | | 9.63 (a) | 4.12 kg / ton |
| Chicken manure | | | 3.67 (a) | 19.75 kg / ton |

(a): Chadwick et al., 2000a and b; total N amount in kg/ton

The same low availability in mineralized nitrogen occurs when the added organic material has a high humification coefficient[12], since decomposition is limited (Velthof et al., 1998). Different types of farmyard manure tend to have a higher humification coefficient than crop residues.

### *1.2.2.5 N – mineralization in relation to other parameters*

As there is a large variety of manures and legumes, sometimes it becomes quite **difficult to predict** when and how much mineralized nitrogen will be released. Not only the different green manure varieties have different C/N ratio and humification coefficients, but even their maturity stage, their degree of withering and the moment of incorporation can determine the time span and amount of nitrogen that will be released (Figure 10 and Figure 11).

### *1.2.3 Comparison between the Nitrogen cycle and the Sulfur cycle.*

After chronic N deficiencies, S deficiency is widely reported to be the most important and frequent nutritional disorder in organic agriculture (Haglund et al., 2000; Hagel, 2000; Haneklaus et al., 2002). As organic fertilizers provide only a limited amount of S with an average of 0.07 kg S per kg of N and S mineralization is usually low, S fertilization may be the only way to warrant optimal crop productivity in rural areas with low atmospheric S deposition.

On the other hand S and N, as plant nutrients, are very similar in all aspects as shown in Table 14:

The major part of the sulfur is stored in organic form. Its mineralization pathway is similar to the one of nitrogen. Sulfate ($SO_4^{--}$) and nitrate ($NO_3^-$) act in similar ways (Revue suisse d'agriculture, 33 (3), 2001):

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[11] Humification coefficient or iso-humic coefficient indicates which fraction of the added organic material remains after a certain period (around 3 years) of decomposition as "stable organic matter".

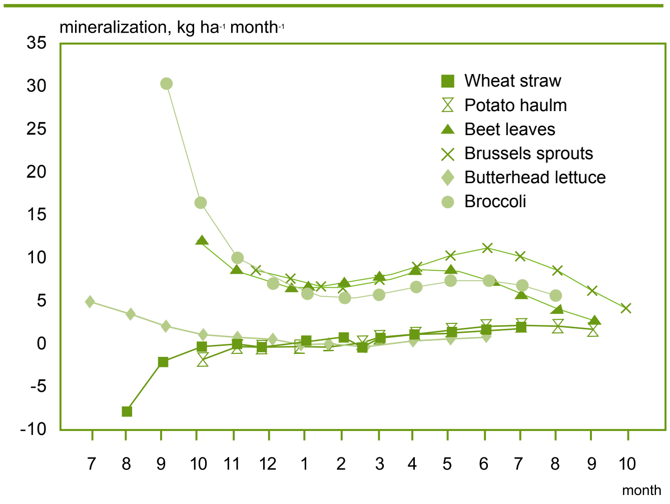

**Figure 10:** Monthly N mineralization from crop residues (Velthof et al., 1998)

① The plant absorbs its needed S (N) preferably as sulfate (nitrate).
② $S_{min}$[13] ($N_{min}$[11]) is a good yardstick for available S (N).
③ Under humid conditions leaching of sulfate (nitrate) during wintertime is the major reason for S (N) losses from the root zone.
④ S (N) losses can only be reduced in as long as biomass production before winter and root development of the crop is promoted (Haglund et al., 2001).
⑤ (Low) S (N) levels in the soil are related to: organic material content, precipitation level (autumn/winter), porosity of soil, application rate of manure, yield level, clay content and cropping intensity.

To compensate the low S supply from organic substances and prevent or correct S deficiencies in organic farming, specific non-organic natural substances like Sulfate of Potash and Calcium Sulfate [and patentkali, Epsom salt and elemental S] can be used (Lampkin, 2002). By the same rationale, Natural Chilean Nitrate should be allowed to compensate the insufficient N supply from organic amendments (see also § 2.6).

### *1.2.4 Summary: interaction with natural systems and cycles*

One of the basic principles of organic agriculture is to encourage and enhance biological cycles within the farming system. As N is an essential, and often limiting, plant nutrient the N-cycle is of major importance. The N-cycle cannot be isolated from other physical, chemical and nutritional conditions when considering agricultural production. N losses, particularly volatilization and

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[13] $S_{min}$, $N_{min}$: amount of mineral S and N available in the soil.

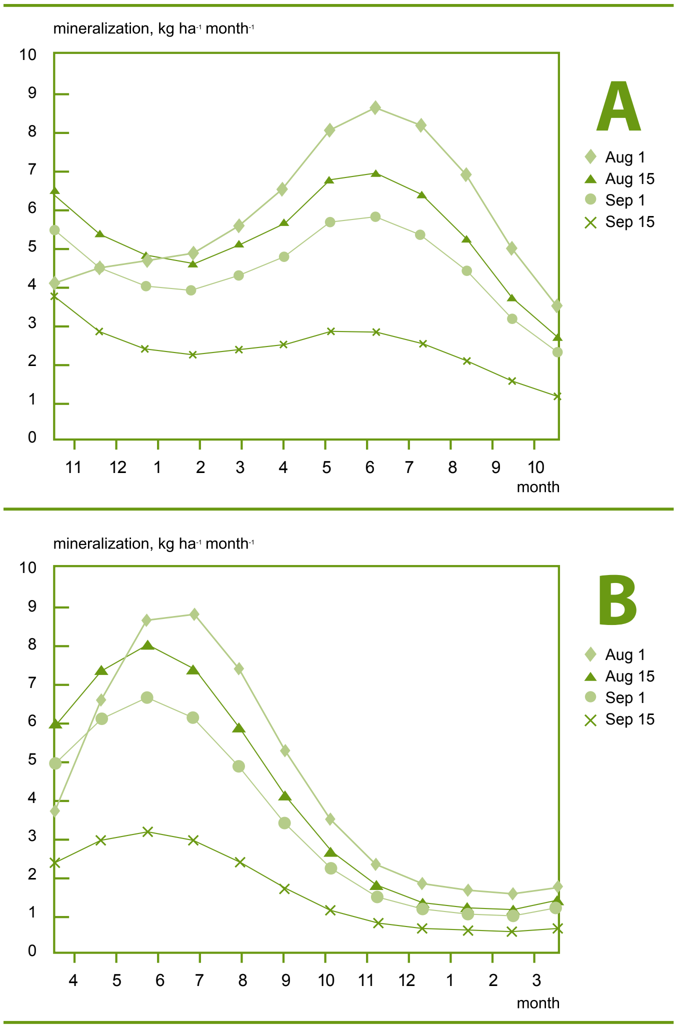

**Figure 11:** Monthly N mineralization after incorporation of rye grass on 31 October (Figure A) and 31 March (Figure B). Rye grass sown on different dates (Velthof et al., 1998).

leaching losses, can be very important when using organic fertilizers. To limit losses (especially leaching) and to close an important part of the N-gap, N-fixation through legume cover crops can be used. But in practice, this technique is only partially satisfactory.

In other words, due to a lack of synchronization and synlocation of the mineralization with some critical growing stages, the N-supply can be insufficient. During those critical stages Natural Chilean Nitrate can compensate for this inherent and natural net loss in the N-cycle in a similar way as prescribed for S fertilization (S-cycle net loss compensation).

To compensate for those losses, only a couple of hundred Kg of Natural Chilean Nitrate can favorably replace tonnes of excess organic fertilizer (farm yard manure and compost) and at the

## Table 14:
## Comparison between nitrogen and sulfur uptake, mineral form and application recommendations (Revue suisse d'agriculture. 33 (3), 2001 p. 72 – 73)

| Element | Form | Characteristics | Recommendations |
|---|---|---|---|
| Nitrogen | Nitrate | - Water-soluble, quick acting<br>- Elevated risk for leaching | - Adapt the application dosage and moment to the short term needs of the plant (use as nitrogen fertilizers) |
| | Organic form | - Slow effect, uncertain mineralization by uncontrollable micro-organisms<br>- Risk of "off -season" mineralization causing leaching<br>- *High volatilization losses* (1) | - Avoid big single quantities<br>- Small repeated applications are preferred<br>- Avoid |
| Sulfur | Sulfate | - Water-soluble, quick acting<br>- Elevated risk for leaching | - Adapt the application dosage and moment to the short term needs of the plant (***use as nitrogen fertilizers*** ) |
| | Organic form | - Slow effect, uncertain mineralization by uncontrollable micro-organisms<br>- Risk of "off season" mineralization causing leaching | - Avoid big single quantities<br>- Small repeated applications are preferred |

(1) Addition of authors of this paper based on Revue suisse d'agriculture, 33 (3), 2001 p. 54 - 55

same time combat acidification of the soil and therefore stimulate further mineralization

Consequently, with the right dosage and correct timing, Natural Chilean Nitrate will work in a constructive and live enhancing way with the natural systems and cycles.

## 1.3 Practical examples: Nitrogen Side-dressing Application system (NSA-system) on several organically grown vegetables

(Optimizing the Nitrogen Supply in Biological Farming, Louis Bolk Institute, Nutrient Management Institute, Wageningen, April 2003)

As previously written and discussed in section 1 the N-availability for the organically cultivated crops depends largely on the mineralization of organic compounds in the soil, from crop residues or from organic fertilizers or legume cover crops.

In practice the N-mineralization is not very consistent and depends on various parameters (rain temperature, pH, soil type, varieties, etc.). In those cases the N-supply is not controllable and can be asynchronous with the plants needs. In short, the shortages can be caused by:
①: insufficient mineralization level compared with the needs
②: wrong timing (too early or too late)
③: intermediate losses.

Decisions that have to be made when side dressing is considered are based on: ① type of fertilizer, ② time of application and ③ plant needs. The tools to help with such decisions of side dressing applications are: NSA-system based on soil analysis; NSA-system based on crop analysis; predictive models analyzing the crop needs, mineralization and losses under specific conditions.

In these approaches the N-reserves are measured on different time intervals in the soil/plant and adapted accordingly. At the start of the season and several times during growing cycle the mineral N is determined. Side dressing application rates are then calculated (Van Dijk, 1999). A buffer capacity of mineral N ($N_{min}$) in the soil guaranteeing an optimum uptake has to be taken into account (Figure 12).

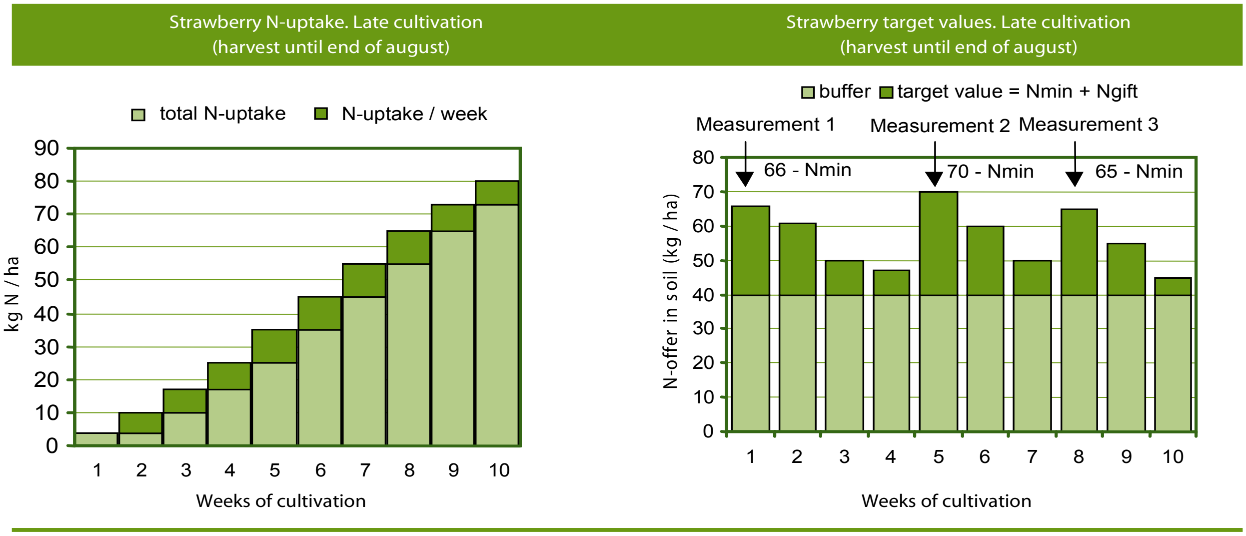

**Figure 12**: Illustration of the NSA system based on soil analysis in organic growing of strawberry (late harvest) (Zanen et al., 2003)

The left graph of Figure 12 shows the uptake evolution during an entire growing cycle. The graph on the right represents the nitrogen supplement needed at three growing stages. Each time the recommended supplement is calculated taking into account:

① The N-uptake until the next supplement,
② The targeted buffer capacity and
③ The mineral N-reserves in the soil.

This means that the fertilization program is continuously adapted and follows the N-losses and the N-mineralization. This way a critical minimum level can be determined, i.e. the moment when the side dressing needs to be applied. Each crop needs to be classified according to its optimal buffer capacity ($N_{min}$) and nitrogen uptake curve. Titulaer (1994) divided several crops into 3 main groups:

Group I: crops that after 3-4 weeks of low N-uptake start a high linear N-uptake of about 6 to 7 kg/ha/day. Most of these crops are being harvested in full growth. Typical for this group are head lettuce, Belgian endive, spinach, cauliflower and broccoli.

Group II: after a few weeks of low N-uptake follows a high linear development with a constant daily uptake. After a month or more the linear development evolves into a reduced N-uptake / ha / day, while the crops come to maturity. Examples are: white cabbage, Brussels sprouts, red cabbage, carrots, onions, leek, red beet.

Group III: crops from this group produce several harvests per year. In the first stage there is a vegetative growth (N-uptake is linear). Starting from the first harvest, the uptake by vegetative growth decreases and stays constant for a few weeks. The total N-uptake of the crop keeps growing in a linear way. Fruits take up the difference. Examples are cucumber, gherkins, beans, pod fruits.

The precision application of side dressing of nutrients in organic growing is only partially attainable and depends on crops and plant varieties, the rotation system, soil cultivation practices, etc. All these parameters should be carefully monitored. Using the NDICEA (Nitrogen dynamics In Crop rotations in Ecological Agriculture; Habets, 1993; 1998) a few examples of side dressing fertilization schemes are given.

### *1.3.1 Group I crop example = Lettuce*

Figure 13 shows the results of a model study with different fertilizing scenarios for early lettuce on sandy soil, with an average gross yield of 25 ton and an N-uptake of 65 kg N/ha.

**Solid manure scenario:** The use of 40 tons of manure (240 kg N, 123 kg $P_2O_5$), a few weeks before transplanting, will not supply enough available N and this almost during the whole growing cycle. Also the possible second crop will have insufficient nitrogen.

**Slurry [14] scenario:** With 30 tons of slurry (134 kg N, 54 kg $P_2O_5$), incorporated within 12 hours after application, the early crop can be sufficiently supplied with N. At the end of the growing

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[14] Slurry : in this case the thin fraction separated from pork manure. It contains in average 7 kg N per ton of which 71 % mineral (fast acting). It contains also 1 kg $P_2O_5$ per ton and 6 kg $K_2O$ per ton. According to some organic authorities restricted in usage.

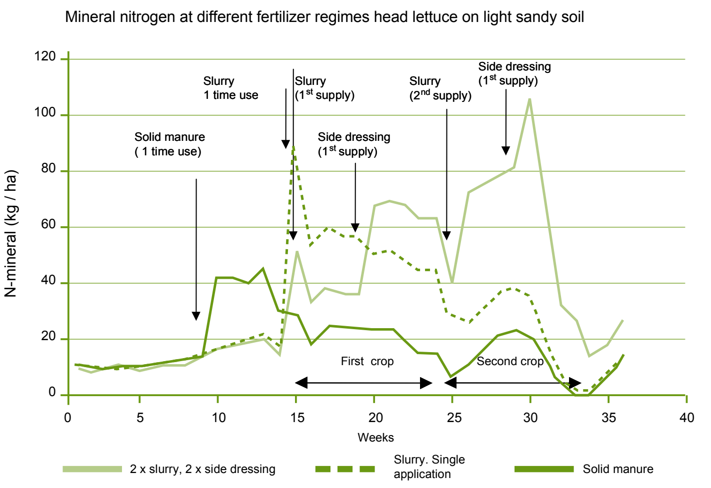


**Figure 13:** Model study (NDICEA) for different fertilization strategies for lettuce

cycle the mineral N drops to a low level. The second crop will probably suffer from shortage in available N.

**Side dressing scenario:** A supply of 15 tons of slurry in the first crop, incorporated within 12 hours after application, combined with a side dressing of 60 kg fast acting nitrogen delivers sufficient nitrogen. Repeating this for the second crop again provides enough nitrogen. Most probably the 2nd side dressing can even be omitted.

Results:

- Unsatisfactory results with 240kg N as manure and 134kg N as slurry both applied in one time as the buffer level of mineral N towards the end of the second crop cycle is not attained.
- Good results with 2 x 67kg N of slurry together with 2x 60kg of quick acting N side dressing (total 250kg N) even though at the time of harvest a low level of mineral N is quickly reached limiting the hazard of losses.

This strategy also limits the risks of excess application rates of other main nutrients (P, K) present in manure and slurry.

**Ideally the solid manure and the side dressing application should be combined to obtain the optimum result.**

### 1.3.2 *Group II crop example = Brussels sprouts*

In results of an NDICEA study on Brussels sprouts on light sandy soil with gross yield of 18 tons and a N-uptake of 180 kg/ha.

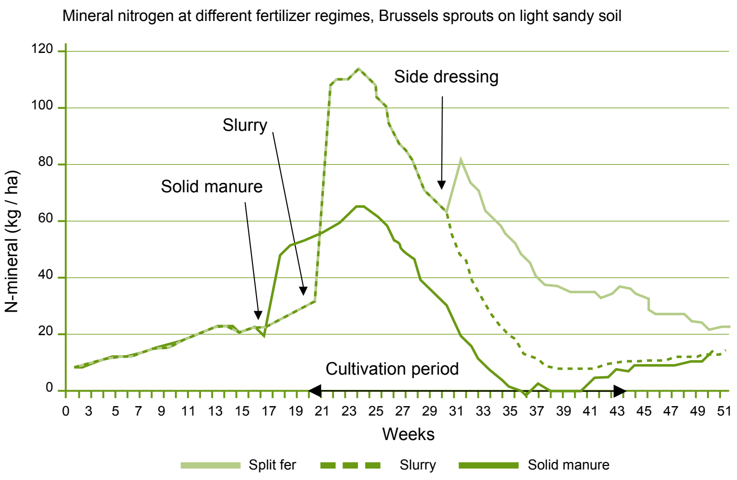


**Figure 14:** Model study (NDICEA) for different fertilization strategies for Brussels sprouts

**Solid manure scenario:** The application of 40 tons of manure (240 kg N, 123 kg $P_2O_5$), a few weeks before transplanting, does not deliver enough nitrogen during the second part of the growing cycle.

**Slurry scenario:** 30 tons of slurry (134 kgN, 54 kg $P_2O_5$), incorporated within 12 hours after application, again does not supply enough nitrogen in the second part of the growing cycle. The losses during cultivation due to leaching and denitrification are 40 kg N/ha. Post harvest losses till the end of March are 15 kg/ha more. Increasing the supply to 60 Mt of slurry delivers enough mineral nitrogen to cover the crops needs at the start. However the losses by leaching and denitrification are considerably higher (85 kg N/ha). The post harvest losses till end March increase to 30 kg N /ha.

**Side dressing scenario:** A side dressing of a faster acting N, half way the growing cycle, after an initial fertilization of 30 Mt of slurry, incorporated within 12 hours after application, provides enough nitrogen. The losses by leaching are reduced to 60 kg N / ha during the cultivation period and to 30 kg N / ha post harvest till the end of March.

**The best solution is a combination of solid manure with a side dressing reducing the losses even further.**

A similar example can be found in Figure 15 for broccoli or cauliflower with a gross yield of 20 tons/ha and an N-uptake of 140 kg N/ha. Growing a cover crop after the main crop can reduce the losses by leaching and denitrification. Due to early harvest of the main cauliflower crop, because the nitrogen supply was sufficient resulting in good growth, the nitrogen uptake of the cover crop can reach 120 kg. This confirms the idea that all parameters and practices need to be integrated and combined with each other in order to reach the ideal organic crop growing.

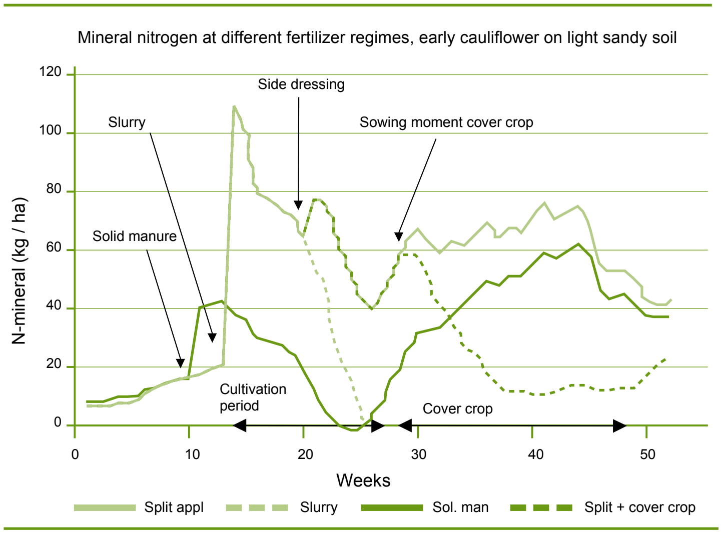


**Figure 15:** Model study (NDICEA) for different fertilization strategies for broccoli / cauliflower

### *1.3.3 Group III crop example = Cucumbers, gherkins etc…*

In the same line of thinking for this group of crops a repeated limited supply of nitrogen by means of a side dressing could help to maintain the linear uptake. To our knowledge, specific scenarios are not available in the literature, but could be developed in the same way as for groups I and II.

### *1.3.4 Summary : Nitrogen Side-dressing Application system*

The practical examples described above show that the possibilities of side-dressing during the growth season currently are limited for organic farming. Complementing with Natural Chilean Nitrate will help to avoid excess organic amendment input even when growing conditions would be optimal. Natural Chilean Nitrate will also assist the OM N supply capacity when these conditions are less favorable, without putting extra stress on the ecosystem, neither by the product itself nor by an unwanted influx of other nutrients that might cause excesses on its turn.

They also confirm again that complementary input of mineral N causes minimum losses and consequently maximum uptake, efficiency and productivity per unit of N.

## 1.4 Approved and trusted alternatives are not available

The possibilities for the organic grower for fertilization under specific unfavorable conditions or as side dressing during the season are limited, because the organic fertilizers that are available in organic agriculture are not suitable for these purposes.

In 1998 about 22 fertilizers rich in nitrogen and approved for organic agriculture, were available, for example in Switzerland. Almost all of them were based on **meat, blood, horn and feathers** (Wyss et al., 1998). All these products, used as side dressing or as sole nitrogen source in organic vegetable growing (Koller et al., 1999), are under question.

Unexpected events such as BSE (Bovine Spongiform Encephalopathy), avian flu, hormone and antibiotic scandals have made the application of these products questionable or at least undermined the confidence of the consumer of organic products. In some countries like Switzerland (FiBL, 2003), the usage of cattle derived fertilizers except horn meal is now prohibited. At the height of Britain's mad cow epidemic in the 1990s, three victims of the human form of mad cow disease were found to be gardeners.

In 1996, the Royal horticultural Society of London released an advisory, cautioning gardeners to wear face masks after it was reported that the dust from the bone-meal could carry the mutated protein (Callimachi, 2003).

In the near future there may be more restrictions of animal derived products (Zanen et al., 2003), as represented in Table 15.

These products are suitable for side dressing purposes because nitrogen is released rather quickly. Generally it is accepted that 100 % of the added nitrogen supplied in this manner is mineralized after 1 year (Zanen et al., 2003). In practice this happens within one or a few weeks depending on the time of the year. Table 15 also includes a ranking according to their mineralization rate (Hilfstoffliste für den biologischen Landbau, 2003. FiBL; Koller et al., 1999).

Besides these concerns, it may be reminded that organic fertilizers derived from animal waste like horn meal, feather meal, etc. do no contribute directly to humus formation and act in this aspect like a mineral N fertilizer.

Another alternative could be **ricinus cake (castor oil bean).** However, it may create a weed problem in neglected cropland and pasture when not controlled through cultivation and mowing. Of greater concern than its weedy potential is the high toxicity of its seeds, which contain ricin, a water-soluble protein. Hence the protein-rich and nutritious press cake can only be fed to farm-animals after extensive heating. Careless feed preparations, as well as neglected storage of ricinus fertilizers, have repeatedly led to important losses of animals (Swiss toxicological information center, 2003). Even a small amount of masticated seed is likely to cause death. Humans and horses are especially vulnerable. Fatal doses are from 2.5 to 6 seeds for humans and about 6 seeds for horses (CISR, 1972). It is advisable to completely eliminate castor beans from pastures, especially horse pastures. According to Koller et al., 1999 it cannot be recommended on large scale due to the allergic reactions during usage.

**Malt and vinasse kali** are used only just after planting and are not suitable for side dressing because of the difficulty of application or their low nitrogen levels (malt) and slow mineralization rate.

## Table 15:
## Possible nitrogen-rich sources for organic agriculture

| Fertilizer | N content (%) (1)(2)(3)(4) | Characteristics (1)(4) | Usage |
|---|---|---|---|
| Meat meal | 10 | Quick acting | Prohibited in some countries (1) (4) |
| Blood meal | 11-12 | Quick acting | Prohibited in some countries (1) (2) |
| Bone meal | 6 | Quick acting | Prohibited in some countries (1) (2) |
| Horn meal | 12 - 14 | Average to slow acting | Prohibited in some countries (2) |
| Feather meal | 13 | Quick acting | Questioned (3) |
| Ricinus cake | 6 | Quick acting | Questioned (4) |
| Malt | 5 | Average to slow acting | |
| Vinasse kali | 9,5 | Average to slow acting | |

(1) Hilfstoffliste für den biologischen Landbau, 2003. FiBL
(2) Haneklaus et al., 2002
(3) Zanen et al., 2003
(4) Koller et al., 1999

### 1.5 Conclusion and score evaluation

By synchronizing soil N availability with plant needs Natural Chilean Nitrate contributes to optimal qualitative yield. When temperature, humidity and pH, the major factors influencing N mineralization, are close to optimal, an organic amendment with a high humus building capacity will only be able to supply the necessary amount of plant available N if applied in very high doses (up to several LAE/ha for demanding crops). When pH is low, this N supplying capacity will be even lower due to diminished mineralization. When also temperature and humidity are unfavorable the already low N generation capacity will then be out of phase with the plant need.

Humification is an important and beneficial aspect of vegetative organic fertilizers. However this humus production potential is in direct conflict with its N supply capacity. Natural Chilean Nitrate as a complementary N source can overcome this by supplying available N in synchronization with plant needs, by stimulating microbial soil life through increased vegetative production and, in acid soils, through pH increase and by avoiding excess organic amendment input, itself in conflict with organic agriculture principles. Consequently, with the right dosage and correct timing, Natural Chilean Nitrate will work in a constructive and life enhancing way with the natural systems and cycles.

Just as organically authorized S fertilizers contribute to the closing of the S cycle, Natural Chilean Nitrate, correctly timed and with the right dosage will do the same for the (similar) N cycle in a constructive and life enhancing way.

Typically for a natural product, Natural Chilean Nitrate also provides an important source of trace plant nutrients, distinguishing it clearly from synthetic nitrate. Moreover, several crops benefit in yield and quality from the sodium present in the product.

Even if some alternatives may be available and are currently authorized in organic agriculture, all of them are organic N-sources. Most are based on protein compounds that need microbial transformation – dependent on favorable environmental conditions – to release the plant available nitrate nitrogen (even though they do not produce humus).

Some of them also represent potential hygienic problems (meat meal, blood meal, feather meal, etc.).

- **Overall score**

| | Quality | Yield | Secondary and trace elements | Interaction in a constructive and life-enhancing way with natural systems and cycles. | Non-availability of approved alternatives |
|---|---|---|---|---|---|
| Natural Chilean Nitrate | 2 | 3 | 2 | 2 | 3 |

Scale: 0 (poor) →3 (good)

## 2.1 Location of the Natural Chilean Nitrogenous rock

Natural Chilean Nitrate is mined from natural deposits of "caliche". The nitrate ore, "caliche", is found in the Tarapacá and Antofagasta regions , where the extremely arid Chilean desert is located, in a discontinuous strip on the eastern slopes of the pacific coastal range between the latitudes of 19° and 26° (Figure 16). The lack of moisture has prevented the weathering of the surface rocks (parent material) and the development of living organisms (microbial, vegetal, animal, human) two main factors in the process of soil formation and as a direct consequence, no soil development process has ever occurred in the Atacama Desert. **This region is similar to the areas of Mars investigated by the Viking missions** (Navarro-Gonzáles et al., 2003).

**Figure 16:** Location of nitrogenous rock (Ericksen, 1981)

"The Atacama is the only place on Earth (from which) I've taken soil samples to grow microorganisms back at the lab and nothing whatsoever grew" ... (F. A. Rainey in Navarro-Gonzáles et al., 2003).

"In the driest part of the Atacama, we found that, if Viking had landed there instead of on Mars and done exactly the same experiments, we would also have been shut out" ... "The Atacama appears to be the only place on Earth Viking would have found nothing" ...

"During field studies, the team analyzed Atacama's depleted Mars-like soils and found organic materials at such low levels and released at such high temperatures that Viking would not have been able to detect them" (McKay in Navarro-Gonzáles et al., 2003). McKay also noted that the team discovered a non-biological oxidative substance that appears to have reacted with organics – results that mimicked Viking's results.

"It is considered by many that there is no microbial life on the surface of Mars and that the soils there are inhospitable to microbial life" ... "The soils in the core region of the Atacama Desert would seem to fall into this category..." (F. A. Rainey in Navarro-Gonzáles et al., 2003).

The reason Chile's Atacama Desert is so dry and virtually sterile, the researchers say, is because it is blocked from moisture on both sides by the Andes and by coastal mountains. At 3,000 feet, the Atacama is 15 million years old and 50 times more arid than California's Death Valley.

The age and aridity of the Atacama Desert are probably directly responsible for the large nitrate accumulations that are present there. **The nitrates are likely to be of atmospheric origin** (Ericksen, 1981).

## 2.2 Description of the Natural Chilean Nitrogenous rock

The deposits or "Caliche" occur in all types of rock and unconsolidated sediments without showing any systematic variation in mineral content. 98% of the nitrate (saltpeter) deposits are found under the formation of layers or strata. A succession of layers of varied thickness forms the nitrate (saltpeter) deposits.

Most widespread are the unconsolidated regolith, conglomerates of insoluble and barren material cemented by soluble oxidized salts; predominantly sulphates, nitrates and chlorides of Na, K and Mg. Caliche does contain significant quantities of borates, chromates, chlorates and iodates. Apart from this, Natural Chilean Nitrate derived from caliche contains different trace, or minor, elements including iodine, copper, zinc, boron and molybdenum.

As one can observe from Table 16 **many minerals present in caliche are as such already allowed in organic agriculture or at least very closely related to allowed substances.**

In Table 17 a typical analysis of currently mined Caliche is presented.

## 2.3 Geological origin

There are several theories on the formation and origin of the natural nitrogenous rock (Mueller, 1968). Almost all of them are based on bacterial mineralization:

① Production of nitrate through bacterial decay and action of nitrifying bacteria on organic matter of plant and animal remains;
② Leaching of guano on the margins of saline lakes inland arms of the sea, or salars;
③ Nitrification and fixation of atmospheric nitrogen by bacteria in the soil;
④ Deposition of atmospheric saline materials at or near the sites of the deposits.

Their discussion is beyond the scope of this document and the interested reader is referred to Ericksen, G.E. (1981) for a presentation of his own investigations and a well documented discussion of the subject.

Nevertheless, it should be noted that the single most important factor in the accumulation

## Table 16:
## Some of the common saline minerals present in the caliche deposits (Garret, 1983)

| **Halides** | | Formula | Approved for organic farming (reference, Fibl) |
|---|---|---|---|
| | Halite | NaCl | approved |
| **Nitrates** | | | |
| | Soda niter | $NaNO_3$ | Under review |
| **Borates** | | | |
| | Ulexite | $NaCaB_5O_9.8H_2O$ | very close to approved Na-borate mineral (Borax) but less soluble |
| | Proberite | $NaCaB_5O_9.5H_2O$ | very close to approved Na-borate mineral (Borax) but less soluble |
| | Hydroboracite | $CaMgB_6O_{11}.6H_2O$ | very close to approved Na-borate mineral (Borax) but less soluble |
| | Colemanite | $Ca_2B_6O_{11}.5H_2O$ | very close to approved Na-borate mineral (Borax) but less soluble |
| **Sulphates** | | | |
| | Thenardite | $Na_2SO_4$ | approved |
| | Kieserite | $MgSO_4.H_2O$ | approved |
| | Epsomite | $MgSO_4.7H_2O$ | approved |
| | Gypsum | $CaSO_4.2H_2O$ | approved |
| | Anhydrite | $CaSO_4$ | very similar to approved product $CaSO_4.2H_2O$ |
| | Bassanite | $2CaSO_4.H_2O$ | very similar to approved product $CaSO_4.2H_2O$ |

of saline materials in the Atacama Desert has been the extreme aridity of the region which has existed for 10 - 15 million years. But although the climate of the Atacama Desert has been extremely arid throughout late Tertiary and Quaternary time, there have been intervals of climatic change when increasing rainfall greatly modified or destroyed preexisting nitrogenous rock deposits. According to Ericksen G.E. (1981), if the nitrogenous rock deposits were formed during the past 10 – 15 million years and if they have a complex history of repeated deposition and destruction, a rate of deposition whereby the nitrate might accumulate in 200.000 years is reasonable. That would be an estimated theoretical period of time for the formation of the present day deposits, with the added implication that no rainfall with nitrate leaching capacity has occurred during that period.

The nitrogenous rock occurs on a high plateau with essentially zero rainfall (< 2 mm precip. $yr^1$),

Table 17:
Caliche analysis (Garret, 1983)

| Pure Caliche | Analysis Currently mined |
|---|---|
| $NaNO_3$ | 6-10 wt% |
| $Na_2SO_4$ | 6-15 wt% |
| NaCl | 6-10 wt% |
| K | 0.4-1.0 wt% |
| Mg | 0.2-0.8 wt % |
| Ca | 1.0-1.25 wt % |
| $IO_3$ | 0.04-0.08 wt % |
| $B_4O_7$ | 0.3-1.0 wt % |
| $H_2O$ | 1.1-2.0 wt % |

bordered on the east by the high Cordillera of the Andes and on the west by the Pacific coastal range, both these areas catch what little rainfall is available. The high mountain area has about 150 mm $yr^{-1}$ of rain and the coastal range between 10 and 30 mm $yr^{-1}$.

Nitrate rich soils occur locally in other deserts of the world but are nowhere as widespread as those found in the Atacama Desert.

## 2.4 History of Usage

Natural Chilean Nitrate is probably **the oldest single nitrogen fertilizer.** There is evidence that the pre-Inca culture of the Atacamenos employed high grade ores as a fertilizer in the **7th and 8th century.** Tradition ascribes the rediscovery of the fertilizer properties of caliche, in the 17th century, to a priest who was brought “dirt that burns”, by the Indians for analysis, and who then threw the remains onto his garden. Prior to 1800, the extraction of salpeter from caliche was performed by leaching ore in animal skins with cold water. The resultant solution was run into copper pots and concentrated.

In 1805 Tadeaus Haenke, a German naturalist living in Bolivia first identified that the principal nitrate in caliche was the sodium salt.

He developed a process to concentrate and retrieve the nitrates from the ore. Around 1880 when Darwin visited the small nitrate plants called “paradas” he reported the existence of iodine in the caliche. After discovery of the Bosh-Haber ammonia process and the world depression reduced the fertilizer prices the Chilean nitrate was replaced in great extend.

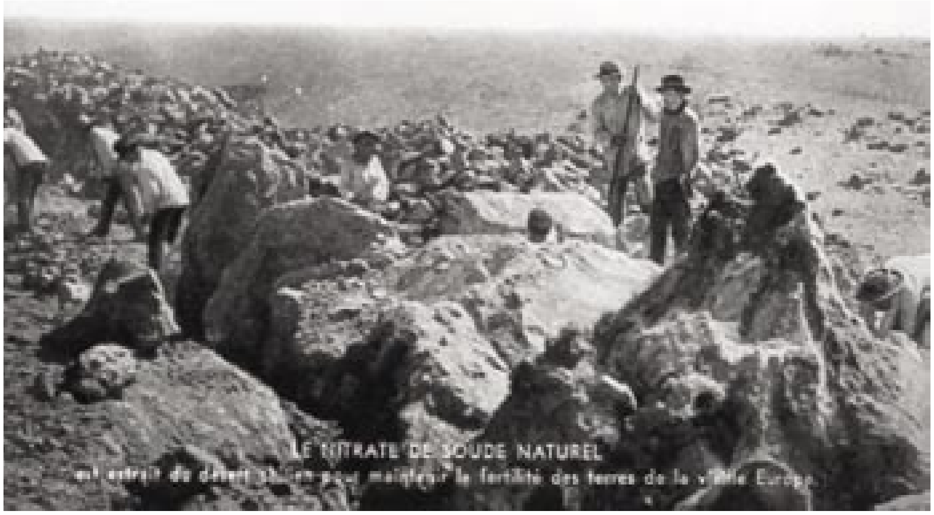


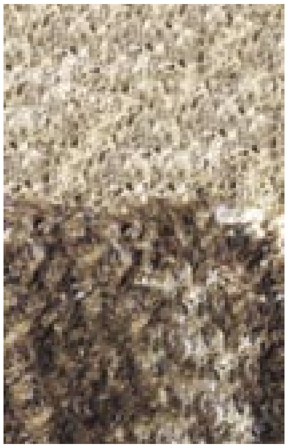
**Figure 17:** Mining of Natural Chilean Nitrate at the beginning of the century

## 2.5 Mining, production process and disposal does not result in, or contribute to harmful effects on the environment

### *2.5.1 Mining method and ore preparation*

The lack of moisture is a critical condition that has permitted the Chilean nitrate to remain in the superficial caliche layer of the desert for more than 200,000 years without a trace of leaching (Ericksen, 1981).

The caliche is mined in open pit areas. Based on general exploration on square grids, areas are laid out and combined to reach and average grade. After blasting and removing the overburden, the caliche is mined. Then the caliche is crushed over 3 stages until the size reached is about 8 mm.



### *2.5.2 Extraction process and crystallization*

**Only nitrate ore (caliche) is needed to produce sodium nitrate of natural origin** (IFDC and UNIDO, 1998. Fertilizer Manual, p. 238). This is in sharp contrast with all potassium and magnesium sulphate fertilizers allowed in organic agriculture (see § 2.6.3).

The Caliche is grounded to a size of 1.0 centimeter and between 75 and 80% of the tonnage reduced to this size is deposited in large 10,000 $m^3$ capacity lixiviating vats. The fine residue from the grounding process is sent to a different leaching system, where iodine is recuperated.

**Figure 18:** Close-up view of caliche rock

Warm 48 °C "weak mother solutions" are circulated through the Caliche particles in the vats, until the solution is saturated in sodium nitrate becoming a "strong mother solution". The strong solution is cooled to 12°C in order to crystallize and precipitate the dissolved sodium nitrate. After recovering dissolved iodine at the iodine plant, the resulting "weak mother solution" is sent back to the leaching vats to a new cycle in the close leaching-precipitation circuit. In the close leaching circuit water may be lost only by evaporation.

New fresh water is not used in the leaching cycle, except when is needed to displace the "strong mother solution" from the refuse. Due to limitations in the quantity of water used to wash the refuse and since this limited volume is not fully efficient in displacing all the "strong solution" the retrieval of the sodium nitrate from the Caliche is only about 75%.

The crystallized sodium nitrate is centrifuged and prilled, being ready to be used as a source of natural nitrate nitrogen in crop production.

### Solar Evaporation System

Through the cooling and centrifugation process, only sodium nitrate and iodine can be recuperated from the Caliche ore.  However, the Solar Evaporation System (SES) permits the retrieval of additional nitrate and other salts from the "weak mother solution" before it is recycled to the leaching vats.  The SES is also used to concentrate solutions produced by "heap leaching" of old refuse piles of caliche ore, that was processed many years ago to extract Natural Nitrate using less efficient processes.

The operation of the SES begins by adding additional water to the refuse wash in the leaching vats.  The water not only displaces additional sodium nitrate that otherwise goes with the refuse, but it also dissolves potassium double salts, borates, iodine, sulfates, magnesium salts and others, which are only partly soluble in the "strong mother solution". After passing through the normal cooling-crystallization stage the new strong solutions are not sent back to the leaching vats to start a new cycle, but instead they are pumped to the Solar Evaporation System to be concentrated.

The Solar Evaporation System consist of a series of interconnected ponds where the solution moves from a first pond having the initial or lowest salt concentration up to the last pond with the highest salt concentration that can be attained through solar evaporation. After reaching the predetermined optimum salt concentration, the Natural Nitrate is recovered from the solutions by cooling and crystallization, and the final weak solution is sent to the vats to start a new leaching cycle of caliche ore.

There are two Solar Evaporation Plants, Coya Sur and Pampa Blanca, with 640,000 $m^2$ and 544,000 $m^2$ of pond evaporating surface, respectively. The average daily evaporation rate for the whole year at each Plant is 4. 5 L $m^{-2}$ and 3 L $m^{-2}$, respectively, this being another consequence of the permanent dry conditions in the Atacama Desert. The total volume of water evaporated from the solar ponds is over 1.5 million cubic meters per year, equivalent to more than one million kWh (kilowatt-hour) per year of solar energy captured by the system.

The total energy input (mostly for rock crushing, ore conveying and evaporation ) is 44GJ per ton N total renewable energy, its energy score is much more favourable than for synthetic N fertilizer that consumes on average 40GJ per ton N non-renewable energy (SQM, 2004; EFMA, 2002).

The Natural Nitrate is not only a natural product but the majority of the energy used in the extraction process is renewable solar energy.

### *2.5.3 Ore reserves/sustainability*

Natural Chilean Nitrate is found principally in a large ore body nearly 800km long and 15 to 25kg wide. Small deposits occur in other areas, e.g. Africa, Australia, Mexico and China (IFDC & UNIDO, 1998. Fertilizer Manuel, p. 239).

Mining has been taking place for over 100 years and according to the mining company, at current output it will last for several more centuries.

The sodium nitrate is mostly obtained as an inevitable by product from the production of iodine and potassium nitrate.

## 2.6 Mining and production process of other mineral organic fertilizers

### *2.6.1 Potassium chloride and sodium chloride*

#### *2.6.1.1 Mining*

Potash ore is extracted from two major ore deposit types, deeply buried marine evaporite deposits that typically range from 400 meters to greater than 1000 meters below the surface, and surface brine deposits associated with saline water bodies such as the Dead Sea in the Middle East and the Great Salt Lake in North America.

Conventional mechanized underground mining operations are the most widely used method for the extraction of potash ore.

Surface brine deposits are exploited using solar evaporation ponds to concentrate and precipitate the potash. The evaporation ponds are extensive, with some operations covering in excess of 90 square kilometers of land area to produce around 8 million tons of potash ore per year (UNEP, 2001).

- **Underground mining**

Large amounts of potash are extracted from underground deposits of potassium minerals in the UK, Poland, Germany, Spain, France, Canada, USA, China and Russia by the conventional room and -pillar mining method (Figure 25) . An updated flowchart is included and shows the usage of the hot leaching and floatation process after the coarse and fine grinding (Figure 26).

**Figure 19:** View of the Atacama Desert

**Figure 20:** Caliche sampling and mining preparation

**Figure 21:** Crushing of the caliche rock before nitrate extraction

**Figure 22:** Closed counter current extraction vats

**Figure 23:** Inside view of the extraction vats

- **Brine mining**

Potash bearing evaporite beds were formed by the evaporation of seawater in inland bays and landlocked surface waters. Similar potash brines are being worked in the Great Salt Lake, Utah, USA and the Dead Sea in Israel and Jordan. An updated simplified flow-sheet of processes and products of the Dead Sea Works (DSW) is depicted in Figure 28. The brines are concentrated in evaporation pans by intense solar radiation and dry winds. In a second series of pans the carnallite is crystallized out and harvested by floating pumps and dredgers. The carnallite is decomposed and the remaining sylvinite is treated in two distinct processes: hot leach and flotation crystallization to produce KCl (Phosphorous and Potassium, 1996)

- **Solution mining**

Solution mining is a process where rock salt minerals are dissolved within a borehole by introducing water or brine, creating a cavity, and pumping out the enriched brine or water-soluble minerals for downstream treatment. The concept of solution mining was expanded to include in-situ leaching; heap and dump leaching. Solution mining is used for mining deep deposits of halite and potash minerals, including carnallite rock. KCl and NaCl are mined and refined according to a solution process (Figure 29) (Phosphorous and Potassium, 1996).

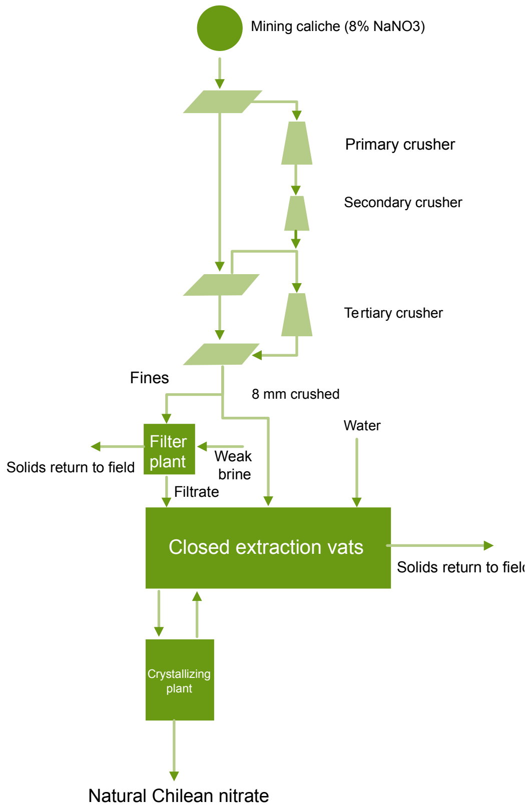


**Figure 24:** Flow process diagram of the recovery of natural nitrates from caliche

### *2.6.1.2 Processing (beneficiation)*

#### *2.6.1.2.1 Beneficiation processes*

Potash ores and carnallite ores, in particular, are very heterogeneous. The ores consist of typical assemblages of halite + carnallite ± sylvite as the main minerals and magnesite ± dolomite ± anhydrite ± polyhalite ± kieserite ± clay as minor constituents in the rock salts.

The soluble potash minerals most extensively mined are sylvite (KCl), carnallite ($KCl.MgCl_2.6H_2O$), and sylvinite (KCl.NaCl) (Phosphorous and Potassium, 1996).

The NaCl is harvested, washed, dried and screened into appropriate size fractions. In case of KCl the process is more complex, because the sylvinite ore contains NaCl and KCl; but they can be separated by using the hot leach, flotation and/or cold crystallization process. After these steps the KCl crystals are concentrated in a thickener, centrifuged, washed and dried.

- **Hot leach**

The hot leach (hot crystallization or thermal dissolution) process is a standard method used in the potash industry for separating sodium and potassium chlorides based on variations in their solubility at different temperatures. The solubility of potassium chloride increases significantly

**Figure 25:** Conventional room and pillar mining underground (K&S, Agricultural advisory department)

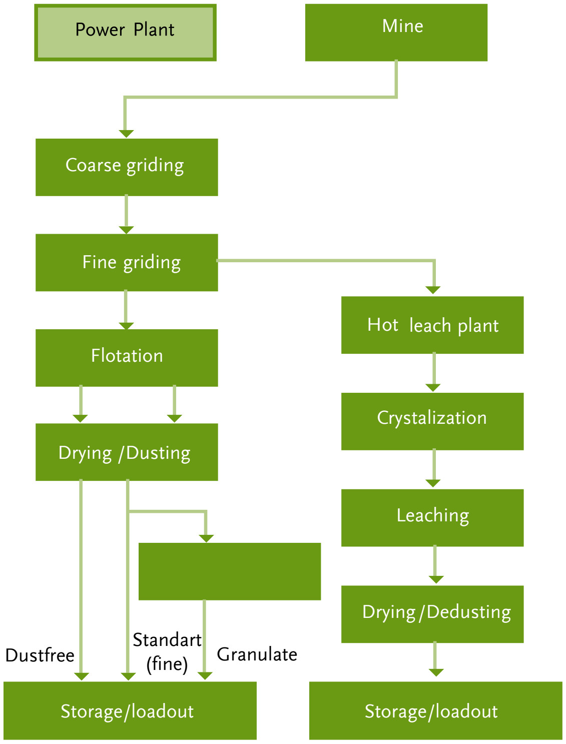


**Figure 26:** Kali und Salz potash plant in Zielitz, process flowchart (Phosphorous and Potassium, 1997)

**Figure 27:** Potash brines, Great Salt Lake, Utah, USA

with rising temperatures while that of sodium chloride does not. The brines are heated to 90 - 110°C and cooled successively to 49°C in a five stage crystallizer system using draft tube baffle vacuum crystallizers. The potash slurry from the final stage crystallizer is partially dewatered in hydro-cyclones and then centrifuged. Then this cake is dried completely in an oil-fired rotary dryer (K&S, Agricultural Advisory Department; Phosphorous and Potassium, 1996).

- **Flotation**

The process of flotation can also be used to make potassium chloride. It relies on the fact that mineral crystals, of sufficient fineness, can be selectively floated from an aqueous medium with the aid of appropriate additives. If air bubbles are introduced with a frothing agent such as pine oil, hydrophobic mineral particles will preferentially attach themselves to the air bubbles at the air/water interface and float to the surface with the froth.

- **Cold crystallization**

The key element of the process is the separation (by recrystallization) of KCl from $MgCl_2$ in carnallite ($KCl.MgCl_2.6H_2O$). Since the presence of NaCl would interfere with this, the carnallite feed from the harvesters must be relatively pure, with less than 5% entrained NaCl (Phosphorous and Potassium, 1996).

- **Electrostatic separation**

This process makes it possible to separate the constituents of a raw salt by a dry route using the specific electric charge of the individual salt constituents (potassium chloride, rock salt and

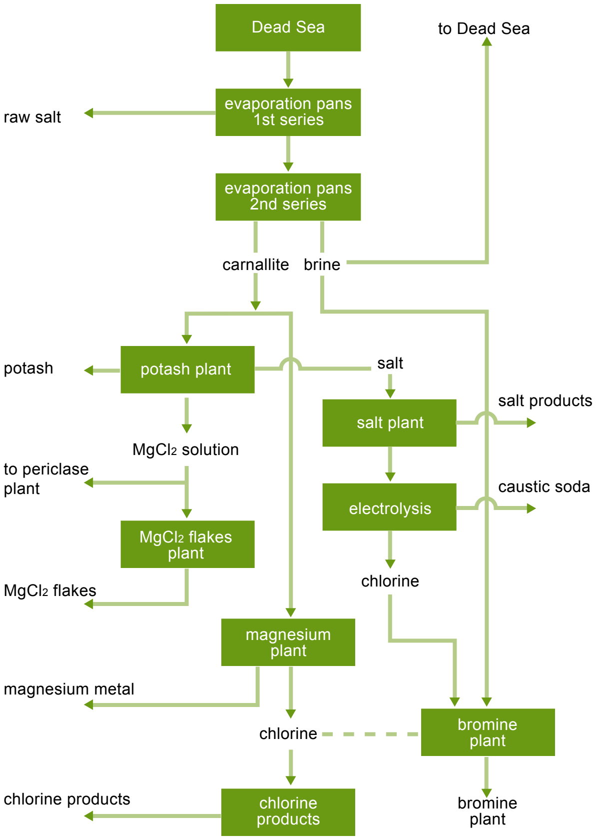


**Figure 28:** Updated block diagram of the Dead Sea Works processes and products (Phosphorous and Potassium, 1996)

kieserite) in an electric field. Finely milled salt (special pretreatment) falls through a free-fall separator across which an electric potential of 120,000 volts is applied. This deflects the raw salt constituents at different angles so that they can be collected separately. During this process, no wastewater is produced (after ESTA® process of Kali und Salz, www.kalisals.de).

### *2.6.1.2.2 Beneficiation waste streams*

Three major waste streams are produced during beneficiation: brines, fines, and salt tailings. A variety of disposal methods are currently used, including (UNEP, 2001):

- Stacking of the salt tailings on the surface;
- Retention of the fines and brines in surface ponds for solar evaporation;
- Deep well injection of brines into confined permeable geological strata;
- Backfilling of mined underground openings with salt tailings, fines and brines;
- Release of wastes to water bodies such as rivers or seas.

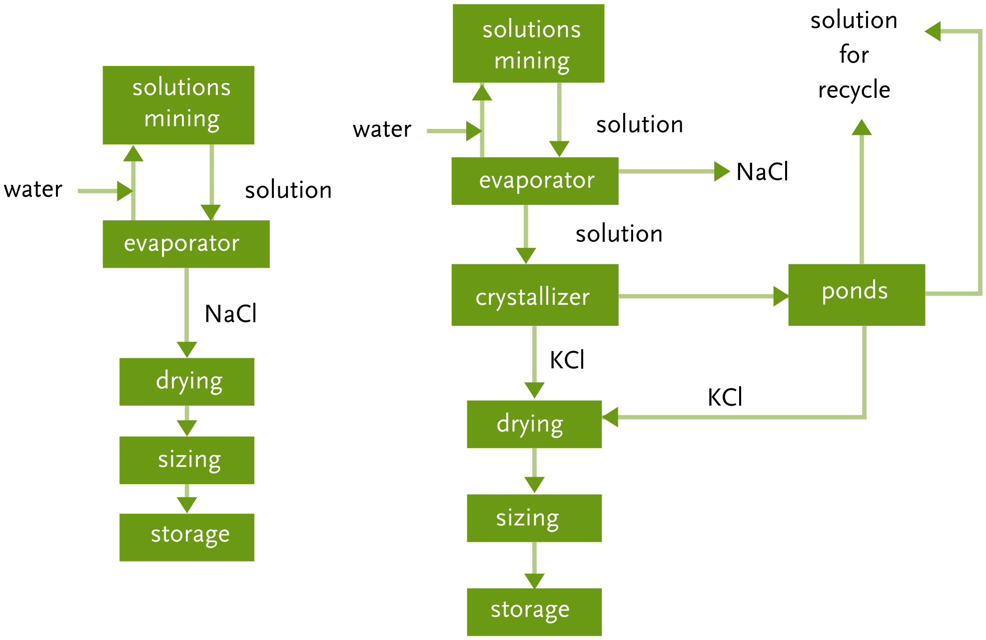


**Figure 29:** Solution Mining of NaCl and KCl (Phosphorous and Potassium, 1996)

### 2.6.2 *Magnesium sulphate*

Next to potassium chloride, potash ores contain also kieserite ($MgSO_4.H_2O$). Pure kieserite is mainly being obtained by an electrostatic process. A flotation process is still used as well.

### 2.6.3 *Potassium sulphate*

Depending on the type of mining, there are two different ways to obtain organically approved potassium sulphate or blends of magnesium sulphate and potassium sulphate (Magnesia-Kainit; Patentkali) (IFDL and UNIDO, 1998).

- **Underground mining and beneficiation (summarized from IFDL and UNIDO, 1998)**

The main natural complex salts that are the source of the potassium sulphate are:

- Kainite ($KCl.MgSO_4.3H_2O$)
- Langbeinite ($K_2SO_4.2MgSO_4$)
- Carpathian poly-mineral ores

The beneficiation process involves the initial conversion with recycled $K_2SO_4$ end liquor of mined kainite or langbeinite.

- **From kainite**

① $2KCl.MgSO_4.3H_2O \rightarrow K_2SO_4.MgSO_4.6H_2O + MgCl_2$
$K_2SO_4.MgSO_4.6H_2O \rightarrow K_2SO_4 + MgSO_4 + 6H_2O$
or
② $KCl + KCl.MgSO_4.3H_2O \rightarrow K_2SO_4 + MgCl_2 + 3H_2O$
or
③ $KCl + MgSO_4.H_2O + 2H_2O \rightarrow KCl.MgSO_4.3H_2O$ (kainite)
and than from kainite to $K_2SO_4$ as in ① and ②.

- **From langbeinite**

$4KCl + K_2SO_4.2MgSO_4 \rightarrow 3K_2SO_4 + 2MgCl_2$: potassium sulphate
$2KCl + 2(K_2SO_4.2MgSO_4) \rightarrow 3(K_2SO_4.MgSO_4) + MgCl_2$: potassium magnesium sulphate[15]

In Germany potassium sulphate is obtained by the chemical reaction starting from kieserite ($MgSO_4.H_2O$) (via Epson salt ($MgSO_4.7H_2O$)) and potassium chloride (similar to reaction ③) by a re-crystallization process (Figure 30) (K&S, Agricultural advisory department).

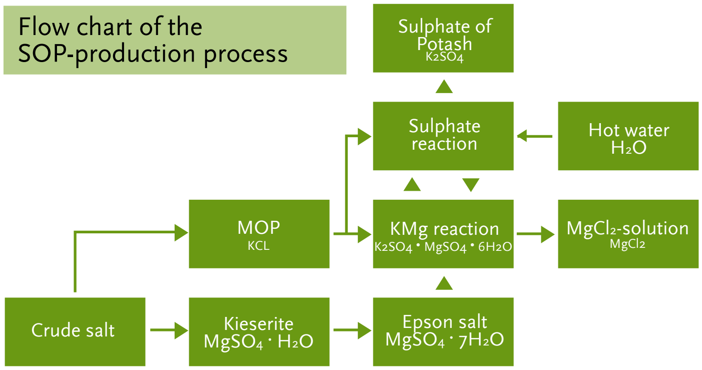


**Figure 30:** Potassium sulphate production process in Germany (K&S, Agricultural advisory department)

- **From polyhalite**

In Russia potassium sulphate is extracted starting from polyhalite. After removal of the NaCl, using calcination processes (heating to 300-400°C) and hot leaching (100°C) potassium sulphate is obtained.

$K_2SO_4.MgSO_4.2CaSO_4 \rightarrow K_2SO_4 + MgSO_4 + 2CaSO_4$

- **"Brine" mining and beneficiation (summarized from IFDL and UNIDO, 1998)**

Starting from brines out of salt lakes, after the potassium chloride is removed potassium sulphate can be gained by using similar techniques as described above in § 2.6.1 . At Great Salt

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[15] Potassium magnesium sulphate is also known in Europe as Patentkali (patented chemical process)

lake, Utah, the potash salts (primarily kainite and NaCl) are harvested and converted to potassium sulfate.

- **Waste streams :**

Similar waste streams are generated as for potassium chloride and sodium chloride (§ 2.6.1).

### *2.6.4 Rock phosphate*

#### *2.6.4.1 Mining*

At present, most phosphate rock is mined using large-scale surface methods. In the past, underground mining methods played a greater role, but their contribution to world production has declined (UNEP, 2001).

**Figure 31:** Surface mining of phosphate rock with bucket wheel (UNEP, 2001 after Office Togolais des Phosphates (OTP), Togo)

The depth of excavations may range from a few meters to more than 100 meters.

Mining methods used to produce direct application phosphate rock can range from highly sophisticated mechanized surface and underground methods, such as those used in North Carolina and Tunisia, to low technology, labor intensive methods. In general, flat lying, thick continuous sedimentary phosphate beds that are not indurate and under shallow overburden are the most desirable to mine.

Beds under thick overburden may require the use of large scale earth-moving equipment (Open pit shovels/excavators).

**Figure 32:** Jordan rock phosphate mining (Phosphorous and Potassium, 1998)

**Figure 33:** Rock Phosphate Mining (Phosphorous and Potassium, 1998)

### *2.6.4.2 Beneficiation*

#### *2..6.4.2.1 Beneficiation Process*

The grade of the ore, feasibility and complexity of upgrading, costs of beneficiation and ultimately the worth of the concentrate dictate if the ore is further processed.

Beneficiation (or concentration) processes are generally used to upgrade the phosphate content by removing contaminants and barren material prior to further processing (UNEP, 2001).

Mines and beneficiation plants generally require fuel, power, and, depending on the process, substantial amounts of water. Grinding to provide the rock in a suitable size range may be necessary to promote dissolution and crop growth response. Particle size separation in fine grinding is usually accomplished by air classification. This means the phosphate rock must be dry prior to grinding. Air drying can be effective under suitable climatic conditions. However drying can be very costly and energy demanding regardless of the method used (Phosphorous and Potassium, 1998).

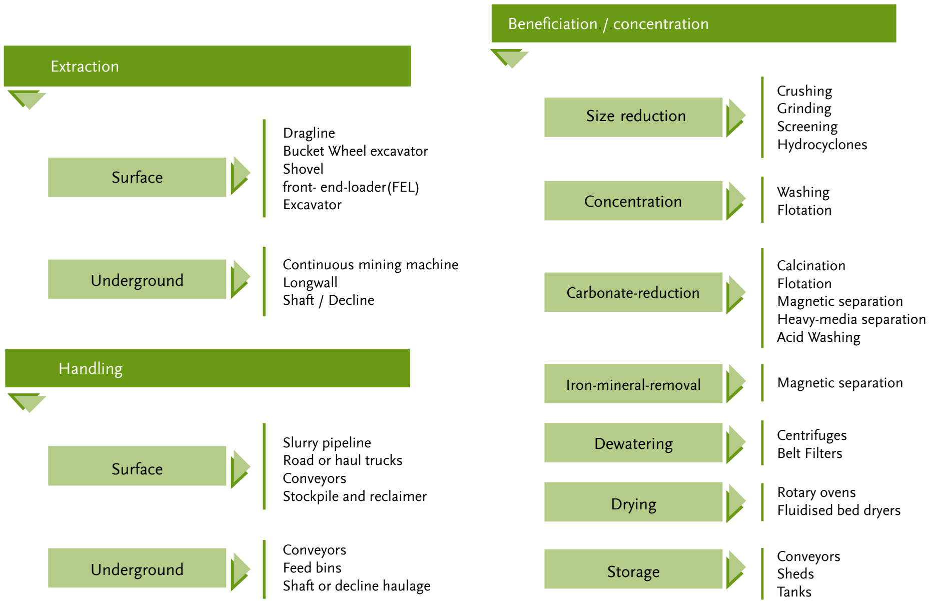

**Figure 34:** Phosphate rock: extraction and beneficiation process (UNEP, 2001)

The presence of carbonates in the form of dolomite and calcite may cause downstream processing problems and may reduce the quality of the end product. They are primarily removed through the use of calcination followed by slaking with water to remove the CaO and MgO produced.

Following beneficiation, the concentrated phosphate rock is stockpiled prior to transporting it to downstream processing plants for the manufacture of phosphate mineral fertilizers. In some instances, phosphate rock with suitable properties may be directly applied to crops as a soil amendment by farmers.

### 2.6.4.2.2 *Beneficiation waste streams*

Generally, the major waste streams produced during phosphate rock beneficiation are clay fines, sand tailings and significant quantities of process water. Magnetite tailings may also be associated with igneous ore bodies. These are disposed to rivers or other water bodies, and disposal to engineered storage dams, or mined-out areas. The process may be recovered and reused (UNEP, 2001).

**Figure 35:** Clay settling pond - Cargill Fertilizers Inc., USA (UNEP, 2001)

### 2.6.5 *Calcium aluminum phosphate*

Extracted aluminum calcium phosphates from Senegal (region of Thiés) are renown for their solubility obtained through heat treatment at 600°C at a substantial energy cost (Gros, 1979).

### 2.6.6 *Environmental Challenges of potassium and phosphate mining*

The activities of the phosphate rock and potash mining industry potentially result in a wide variety of adverse environmental effects. Typically, these effects are quite localized, and in most cases, confined to the mine site.

Environmental aspects that can be affected by mining activities were grouped under 'air', 'water', 'land' and 'social values'. All information in this paragraph is obtained from the study

"Phosphate and Potash mining" by the United Nations Environment Program (2001).

Air quality can be affected by emissions of:

- Dust;
- Exhaust particulates and exhaust gases such as carbon dioxide ($CO_2$), carbon monoxide (CO), nitrogen oxides ($NO_x$), and sulfur oxides ($SO_x$);
- Volatile organic compounds (VOC's) from fueling and workshop activities;
- Methane released from some geological strata.

Large volumes of **water** are typically required by mining and beneficiation activities. This water consumption may lead to a fall in the level of the water table, affecting the surrounding ecosystem and potentially resulting in competition with other users.The **land** surface and sub-surface is disturbed by activities such as:

- The extraction of ore;
- The deposition of overburden;
- The disposal of beneficiation wastes;
- The subsidence of the surface.

**Social goods and intangible values** such as community lifestyles, land values and the quality of the ecosystem in the vicinity of the mine site could be affected by factors such as:

- Modification of the landscape;
- Noise and vibration from activities such as blasting and the operation of equipment;
- Changes in wildlife habitat.

Underground mining methods tend to create fewer environmental problems, the major issue being possible surface **subsidence.** This is induced by the removal of extensive flat-lying ore deposits, followed by the subsequent collapse of overlying rock. Some minor environmental effects may be associated with the disposal of rock removed to access the ore body.

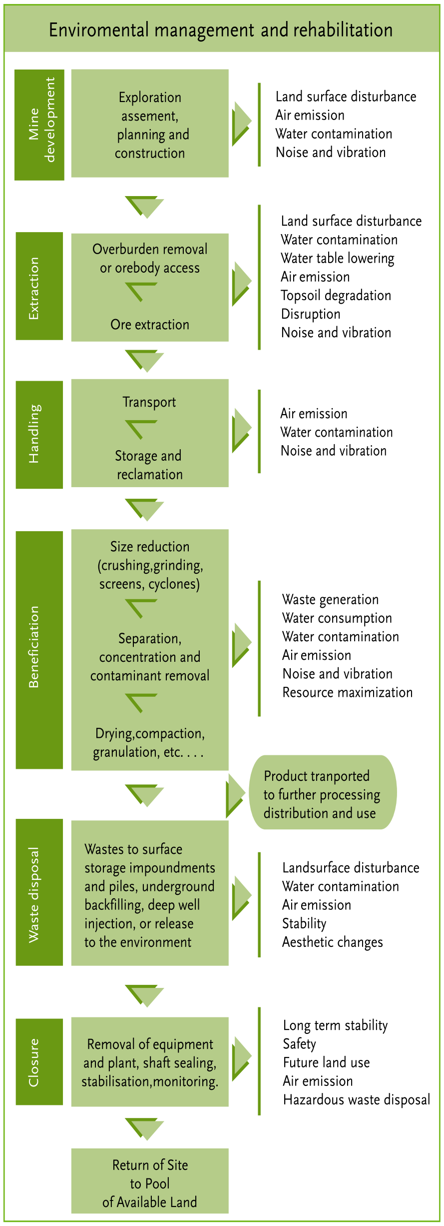

**Figure 36:** Major potential environmental effects that may occur during phosphate rock and potash mining activities (UNEP,2001)

Also, **ground water inflow** into the underground openings may become contaminated or deplete overlying aquifers. Underground mining methods are used to source potash ore from deeply buried marine evaporite potash deposits. A lesser quantity of phosphate rock is sourced using underground methods.

Where subsidence occurs, there is potential for damage to overlying buildings or infrastructure. To avoid safety risks and property damage, close coordination and communication is required between the company and relevant government bodies, other companies and communities.

The phosphate rock ore-body in Togo being extracted by the Office Togolais des Phosphates (OTP) is located near the coast in an **area of intensive small-scale farming**. Surface mining methods are used to remove the overburden and extract the phosphate rock ore. This requires the progressive **relocation of farmers and village communities** as mining occurs.

Solar evaporation ponds used to extract potash from surface brine deposits usually cover a wide area of land, with operations in the region of **90 square kilometers.** The precipitation and build up of salt in the ponds over time presents an issue.

Excavation activities may **contaminate surface water** through the release of fines generated during clearing, blasting and excavation operations, the weathering of overburden contaminants susceptible to leaching and the release of salt from brines and potash ore.

The elevated water table is a prominent feature of the Florida ecosystem. Frequent surface appearance of the aquifer has produced a patchwork of wetlands, streams, rivers and lakes. This is a challenge for the efficient extraction of the phosphate rock deposit by draglines. If the opencast pit contains water, dragline operators have difficulty identifying the boundary between the ore and overburden, potentially resulting in the loss of ore or dilution by barren rock. To maintain dry excavations and an efficient operating environment, **the water table may be depressed** to a level below the ore by pumping from wells or sumps. However, this may lead to negative effects on the surrounding water-sensitive ecosystem.

Brines may potentially contaminate surface or ground waters.

Regulations in Florida to protect watersheds from disturbance have restricted the development of floodplains, streams and rivers. Accordingly, phosphate rock mining operations must establish buffer zones and work around these features. However, on occasions crossings may have to be constructed across them to facilitate access to mining areas.

Water contamination may occur through spillage of ore slurries or brines form pipelines and the mobilization of fines by rain run-off from roads or stockpiles.

The beneficiation of potash produces **wastes** such as:

- Tailings consisting largely of impure salt (NaCl) with smaller amounts of other minerals such as anhydrite;
- Slimes consisting of insoluble fines such as clay and dolomite;
- Brines containing salt or magnesium chloride.

In most countries, wastes are disposed of to specially engineered impoundments such as dams and ponds or released in a controlled manner to the environment.

In New Mexico, the Mississippi Chemical Corporation pipes water from a distant freshwater aquifer to their Carlsbad potash operation. Local groundwater in the vicinity of the operation is high in total dissolved solids and **not suitable for human or livestock consumption.**

Other impacts may include: wind-generated dust from fines tailings; adverse effects on **wildlife;** and the **visual disturbance** resulting from large elevated dams or tailings stacks.

Kali und Salz GmbH operate three potash operations in the Werra region of Germany: Hattorf; Unterbreizbach; and Wintershall. The operations extract a complex mineralized ore 'Hartsalz', that consists of a mixture of sylvinite, carnallite, kieserite, and halite from a deeply buried potash deposit.

The ore is beneficiated using both dry electrostatic separation and wet thermal dissolution separation processes to produce a variety of potassium and magnesium products. For each ton of ore beneficiated, 22% becomes product, while 78% becomes waste. The waste consists predominantly of **salt tailings** and magnesium chloride ($MgCl_2$) brines. The process allows the salt to be largely separated dry from potash, producing dry salt tailings. On the other hand, magnesium chloride can only be separated from potash in solution. This results in **significant quantities of brine being produced.**

The salt tailings are generally conveyed to a **salt stack** on the surface for disposal. Some salt tailings are used to backfill carnallite rooms produced at the Unterbreizbach underground mining operation. Brines are disposed of by either deep well injection into a suitable pervious dolomite formation or discharged to the Werra and Ulster river system.

Brine waste produced at each beneficiation plant is pumped to a series of lined retention ponds from which **discharge occurs to the river system.** The discharge is monitored and controlled using a computer system to ensure that the permitted salt concentration of 2.5 grams per liter of river water is not exceeded as the river conditions and flow rate vary. The system prevents adverse effects on the aquatic ecosystem downstream.

Backfilling of waste into underground openings produced during extraction of the ore is conducted at a few operations. When feasible, this provides a safe and secure long-term disposal method.

The Foskor Ltd. operation at Phalaborwa is located in the semi-arid northeast of South Africa, adjacent to the Selati River and **upstream from the Kruger National Park.**

The processing operation uses 250 million liters of water per day, the majority of which is recirculated. Excess water is transferred to the tailings dam before release to the Selati River. The **tailings water** is high in both total **dissolved solids (TDS) and sulfates.** The sulfates are largely introduced with tailings sourced from the adjacent Phalaborwa Copper mine, which currently supplies about 40% of the phosphate ore feed for the Foskor beneficiation plant.

Surface and ground water contamination may occur through the release or seepage of tailing effluents and brines from dams, ponds and stacks. **Contaminants** might include clay fines, chemical reagents, sulfates, salt and magnesium chloride. In addition, rainfall may dissolve salt tailings or cause erosion and mobilize fines.

Depending on the operation, water releases are required to maintain the water balance of the operations storage facilities. In most countries, this water must meet established water quality standards. To achieve this, excess water is treated through a system of dams and wetlands to clarify and remove contaminants.

Stacking salt tailings – Kali und Salz GmbH. Zielitz, Germany

Pond receiving slimes and brine from the stack – Potash Corporation of Saskatchewan (PCS), Canada

Discharge into clay settling pond (note dragline in back ground) – Cargill Fertilizers Inc. USA

Dry salt tailings pile - Kali und Salz GmbH, Germany

**Figure 37**: Examples of mining activities causing environmental problems (UNEP, 2001)

The construction and operation of surface **waste storage** facilities typically disturbs a significant area of land. Some operations have reduced the area affected by stacking wastes higher. In other cases, wastes are disposed of to mined-out areas, avoiding impacts on undisturbed areas.

The potential for **accidental failure of waste disposal** dams and ponds is of concern. This can cause rapid, extensive and widespread impacts on the surrounding environment.

**Wildlife** may be adversely affected by exposure to contaminants in waste. This is especially the case with **aquatic species** that are sensitive to elevated contaminant levels. In some situations, **water** birds may be susceptible to entrapment on brine ponds due to salting of their feathers.

The Catalão phosphate rock mining and beneficiation complex in the state of Goiás, Brazil is owned and operated by Copebras S.A., part of the Anglo American Corporation of South Africa group. The operation deposits phosphate and magnetite tailings streams in a conventional valley style **tailings dam.** The dam wall has been constructed from compacted clay and coarse phosphate tailings. The dam is inspected about once a year, as part of an ongoing monitoring and audit program. The inspection includes the general condition of the dam and associated infrastructure, including the dam wall, decant facilities, slurry delivery and deposition and monitoring piezo-meters. Information is documented in a comprehensive report with numerous photographs to illustrate the current state of the facility.

Tailingsdam, wall in distance – Copebras S.A. Brazil

Tailings dam seepage water release – Copebras S.A., Brazil

**Figure 38:** Tailings dam, Copebras S.S., Brazil (UNEP, 2001)

In South Africa, Foskor Ltd. has controlled **windblown** dust by ploughing furrows in the surface of dry tailings, perpendicular to the prevailing wind direction. The furrows create eddies that trap dust particles mobilized by the wind reducing air pollution.

Heavy weathering of the overburden and ore-body at the Catalão phosphate rock mine of Copebras S.A. means the pit walls are extremely **prone to erosion creating concerns about the stability of the 80 meter high final pit walls.**

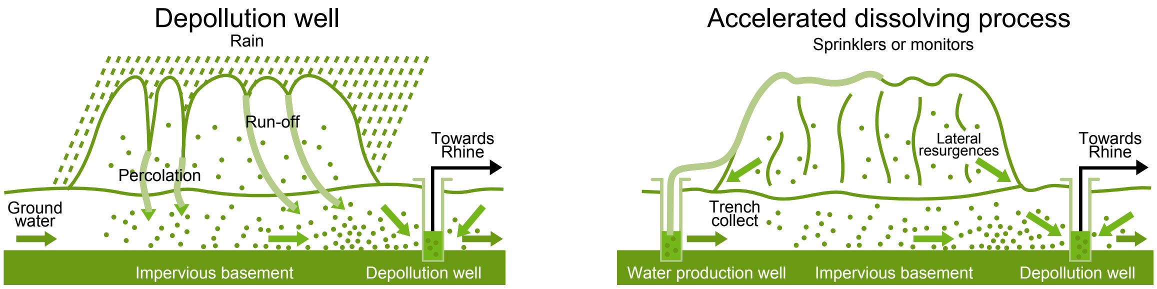

**Figure 39:** Waste piles dissolution schematic (UNEP, 2001 after MDPA, France)

Sorting and crushing demolition ruble – Kali und Salz GmbH, Germany

Placing rubble against salt pile – Kali und Salz GmbH., Germany

Revegetation of magnetite tailings – Foskor Ltd. South Africa

Tree plantation adjacent to mine – Office Chérifien des Phosphates, Morocco

**Figure 40:** Environmental consequences of rock phosphate mining (UNEP, 2001)

## 2.7 Conclusion and score evaluation

As described above, the caliche ore, a nitrogenous rock, is from natural origin and only undergoes physical processing at very low temperatures to extract Natural Chilean Nitrate.

No chemical transformations, not even ion exchanges, are used which is **unique** among mineral fertilizers including those used in organic agriculture.

With regards to the impact on the environment, land disturbance (small overburden, small scale operation), air emissions (no chemical pollution), water and water table contamination (no water bodies and water table) and waste regeneration (see mining and beneficiation process) are minimal.

| | | Natural Chilean Nitrate | Potash/Mg salt | | | Rock-phosphate | | |
|---|---|---|---|---|---|---|---|---|
| 1 | Land surface disturbance | 2.5 | 1 | - | 2 | 1 | - | 2 |
| 2 | Topsoil degradation | 3 | 2 | - | 2.5 | 1 | - | 3 |
| 3 | Air emissions | 2.5 | | 2 | | | 2.5 | |
| 4 | Water contamination | 3 | 1 | - | 2 | 1 | - | 2 |
| 5 | Water consumption | 2 | 1 | - | 2 | 1 | - | 2 |
| 6 | Water table lowering | 3 | | 2 | | | 2 | |
| 7 | Noise and vibration | 2.5 | | 2 | | | 2 | |
| 8 | Vegetation and wildlife disruption | 3 | | 2 | | | 2 | |
| 9 | Waste generation | 2.5 | | 2 | | | 2 | |
| 10 | Hazardous waste disposal | 3 | | 2.5 | | | 2.5 | |
| 11 | Aesthetic changes | 2.5 | 1 | - | 2 | 1 | - | 2 |
| 12 | Stability | 3 | 1 | - | 2.5 | 2 | - | 2.5 |
| 13 | Safety | 3 | | 2 | | | 2 | |
| 14 | Future land use | 3 | | 2 | | | 1 | |
| 15 | Resource maximization | 2.5 | | 2,.5 | | | 2.5 | |
| 16 | Energy consumption | 2.5 | | 2.5 | | | 2.5 | |
| 17 | Dust | 1.5 | 2.5 | - | 3 | | 1.5 | |
| | **Total** | 45 | 31.0 | - | 37.5 | 29.5 | - | 36 |
| | **Average score** | 2.6 | 1.8 | - | 2.2 | 1.7 | - | 2.0 |

Most processing water is recycled and the energy used is almost 60% direct solar energy a much better score than for synthetic nitrate for which production more than double the amount of non-renewable energy is used for the same amount of N. The Chilean company informed us that they have plants to improve even more this already excellent score in the near future. Additionally, since the Atacama Desert “soil” is lifeless (see § 2.1: Mars-like soil) and since the region is uninhabited (except for the mine employees[16]), major potential environmental effects would therefore not have much of an impact.

As shown above potash and phosphate mining and beneficiation are mostly much less environment friendly as such, and furthermore they are always located in more bio intensive areas and even in densely populated regions.

With this in mind and referring to Figure 36 major potential environmental effects are listed together with their scores (1 to 3: 1 = important impact; 3 = little or no effect) and this compared with mining of other (authorized) mineral fertilizers: potash[17] and rock phosphate.

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[16] Mine employees in the Atacama desert receive some of the best salaries in Chile mostly because of their isolation from inhabited regions and competition from copper mines.

[17] Potassium sulphate, kainite, rock potash, sylvinite, patentkali (potassium magnesium sulphate), kieserite, Epsom salt.

# Section 3:
# Considerations and Environmental Impact

## 3.1 Maintaining and increasing long term fertility of soils.

### *3.1.1 Introduction: Nitrate dynamics in the soil.*

Any kind of organic nitrogen in soils, i.e., from crop residues, legume cover crops, compost, manure, etc., is naturally transformed into mineral nitrogen (basically nitrate N) in the soil, to be taken up by plant roots. The transformation is performed by soil microorganism and it is affected mainly by soil temperature, soil moisture, oxygen availability, soil pH, and carbon to nitrogen (C/N) relationship in the organic substances. Hence nitrate nitrogen is a natural substance in soils and it is the main source of nitrogen for growing crops. But as indicated elsewhere in this document (§ 1.2.2), under open field conditions it is not always possible to maintain at optimum levels all those natural factors that control the activity of soil microorganisms. As a direct consequence, the rate of **mineralization** of soil organic nitrogen is not always **synchronized** with the rate of nitrogen **uptake** by crops.

Even if other important natural factors are kept at optimal level, during early critical growing stages the mineralization rate may not be sufficient or sufficiently synchronized to supply the mineral nitrogen needed by a growing crop to produce adequate yield and quality. Conversely during warm seasons, mineralization rate will be high and special growing practices may be necessary to prevent leaching of nitrate nitrogen ($NO_3^-$)-N produced in excess of crop demand.

Winter and early spring are the seasons during which most nitrate leaching occurs in humid temperate and Mediterranean climates (Brady & Weil. 1999) as available nitrate nitrogen ($NO_3^-$) -N cannot be stored as such in the soil profile. Excessive mineral nitrogen produced during the warm season can be stored in the soil by being reconverted into organic nitrogen by soil microorganisms and by crops specifically cultivated for that purpose. This nitrogen will be mineralized again only at the start of the next warm season.

Under the above circumstances, Natural Chilean Nitrate nitrogen ($NO_3^-$)-N can be a complementary source of nitrate to fill the gap in the natural on-farm N-cycle. The Natural Chilean Nitrate was produced by ecological processes at ancient ages and its use is fully analogous to the use of mined bird guano. This mineralized guano was composted[18] by microorganisms at earlier geological ages.

Timely application of split doses of Chilean nitrate synchronized with the uptake of nitrogen by the crop will produce the best results in terms of yield and crop quality as indicated in section 1, but also in terms of ecological impact.

### *3.1.2 Ecological impact related to soil structure and aggregate stability*

#### *3.1.2.1 Nitrate*

There's no doubt about the positive influence of soil organic matter (SOM) on soil structure and aggregate stability. Shepherd et al. (2002) argue that the most important SOM components exert their highest effect within one year [and up to 3 years]. Nevertheless there's long term stabilization of soil aggregates and this has been attributed to humic substances (Haynes et al., 1991), which are relatively stable binding agents.

Because of this important impact within the first years, aggregate stability can change in the short-term, e.g. after ploughing a ley, even though the amount of total SOM is nearly constant (Haynes & Swift, 1990).

It is clear, therefore, that optimal aggregate stability requires the frequent addition of fresh organic matter residues.

Raupp (1995) described a Swedish long-term experiment (1958-1990) comparing biodynamic treatments with conventionally fertilized treatments. There were clear benefits to total SOM from the manure applications, but there were no clear differences in soil structure. Similarly, Alfoldi et al., (1995) reported results from the long-term DOC trial (BioDynamic-Organic-Conventional) in Switzerland showing that, after fourteen years, crop production systems did not show any influence on the volume of total or large-sized pores, bulk density or aggregate stability. According to Alfoldi et al., (1995) this may well have been because the conventional treatment, besides NPK mineral fertilizer, included similar manure inputs albeit at a lower level than the biodynamic and organic treatments.

According to Shepherd et al (2002), it is very difficult to determine from the literature if there would be a difference in soil structure between conventional and organic farms if the conventional farms, while maintaining fertilizer input, had the same organic matter inputs. It is probably not the farming system per se that is important, but the amount and quality of organic matter returned to a soil. Furthermore, soil structure would also be influenced by other practices including stocking rate, grazing management, rotational and tillage practices (Shepherd et al., 2002).

Consequently it can be expected that a complementary use of Natural Chilean Nitrate will have no influence on SOM in first instance. However the rise in yield caused by a better synchronization of N availability and needs implies a larger SOM input through more important crop residues, which should have **a positive influence on SOM and consequently on soil structure.**

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[18] Composted all the way to its ultimate stage so to say.

Indeed the following 40 years experiment (Vuilloud et al., 2003, Changins, Switzerland, 1963-2003, personal communication, to be released shortly), with different organic fertilization systems confirms above reasoning concerning SOM:

- Crop rotation: first 10 years: maize, wheat, wheat
  Next 10 years until 2003: sugar beet, maize, wheat, wheat
- All 3 treatments received the same amount of N mineral fertilizer (between 70 and 140kg N/ha depending on crop and sub-treatments):

  - Treatment A: mineral N only (crop residues exported from the field);
  - Treatment B: mineral N + crop residues;
  - Treatment C: mineral N + 30T FYM every 3 years till 1972 and 40T every 4 years until 2003.

- Results

  - Manure N content had a very slight positive but non significant effect on yields.
  - Soil organic matter content was not significantly influenced by the three fertilization systems before 1993. The last soil analysis indicates, by decreasing order, the following tendency: cattle manure>crop residues>mineral fertilizers only. The higher nitrate fertilization treatment had a positive effect in the "crop residues" and "mineral fertilizers only" treatments and a relatively negative influence in the "manure" treatment.
  - The fertilization system based on mineral fertilizers [only] does not insure soil humus conservation. Humus balance of this system was negative, due to the fact that crop residues are exported.

    The 2 other fertilization systems i.e. with crop residues (with mineral N) and with manure (with mineral N) can be considered balanced.
  - Despite 40 years of experimentation, the soil organic matter level of the three systems is not yet stabilized and continues to decline in all 3 fertilization systems.

The Limburgerhof trial n° 8 (Jürgens-Gschwind & Jung, 1977) also reaches similar results.

So SOM basically does not seem to differ neither significantly between farming systems nor between fertilization systems.

### *3.1.2.2 Sodium*

The elements calcium ($Ca^{2+}$), magnesium ($Mg^{2+}$), potassium ($K^{+}$) and sodium ($Na^{+}$), are held in the soil profile by electrostatic negative charges that constitute the Cation Exchange Capacity (CEC). But these elements are not held with equal tightness. The order of cation adsorption strength, or lyotropic series, is $Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}$ (Tisdale, S.L. et al. 1993. Soil Fertility and Fertilizers. 5th ed. p. 89-90). Sodium is held with the least strength, hence being the easiest cation to be washed by rainfall or irrigation water. This explains why the continued application of sodium salts including Natural Chilean Nitrate for over 100 years in the Rothamsted Classical Experiments (UK) has not damaged the soil (Cooke, W.G. 1982, Fertilizing for Maximum Yield. 3rd ed. P. 158). It is also a fact that Natural Chilean Nitrate has been used in crop production under proper soil and climatic conditions in many countries since around 1860 with no reported specific soil damage.

Wheat, maize, cotton, tobacco, sugar beet, vegetables and fruits are just some examples of the most common crops successfully fertilized with Natural Chilean Nitrate. In Japan, the sugar beet crop has been fertilized with Natural Chilean Nitrate for more than 80 years and the application continues today with no sign of negative effect being reported (Mitsubishi, 2001).

The potential accumulation of sodium depends largely on soil texture, the type of mineral clays, and the cation exchange capacity (CEC).

The CEC is strongly affected by the nature and amount of mineral and organic colloids present in the soil. Soils with large amounts of clay and organic matter will have higher exchange capacities than sandy soils low in organic matter.

Examples of CEC values for different soil textures are as follows (Tisdale et al., 1985; Soil Fertility and Fertilizers, fifth edition, p. 89):

| **Soil type CEC** | (meq/100g) |
|---|---|
| Sands (light-colored) | 3 – 5 |
| Sands (dark-colored) | 10 – 20 |
| Loams | 10 – 15 |
| Silt loams | 15 – 25 |
| Clay and clay loams | 20 – 50 |
| Organic soils | 50 – 100 |
| Organic matter | 200 |

In general soil dispersion could occur when exchangeable Na exceeds 10 to 20 % of the CEC. With fine-textured soils, 10% exchangeable $Na^{+}$ can be tolerated, whereas in sandy soils the upper limit is 30% (Tisdale et al., 1985). On tropical soils high in Fe and Al oxides and in some kaolinitic soils, 40% Na saturation is required before dispersion is serious (Tisdale et al., 1985).

A special case are the saline and sodic soils that exist in a few specific regions of the world. Saline soils have an excess of soluble salts. The electrical conductivity (EC) of the saturated extract of saline soils is 4 dS $m^{-1}$ (decisiemens per meter) or higher. Some saline soils are also sodic because they have an excess of sodium. Sodic soils generally have pH higher than 8.5. A saline soils is classified as sodic if the exchangeable sodium percentage (ESP[19]), is 15% or higher. Another criterion to define a sodic soil is that the value of the sodium adsorption ratio (SAR) is 13 or higher (Brady & Weil, 1999).

The chemical determinations EC, ESP and SAR used to define saline and sodic soils are standard analytical procedures and can be obtained in most soil test laboratories (Westerman, 1990). They can be used to decide on the proper use of Natural Chilean Nitrate.

The following model gives an idea about the amount of sodium that has to accumulate before the soil becomes sodic (assuming no leaching):

- sandy soil ESP 15 and 30%, CEC = 3 meq/100g
- clay soil: ESP 10%, CEC = 50 meg/100g
- Soil root zone: 30cm
- Soil bulk density: 1.2kg/l
- Initial Na content: 0% Na and assuming all Na accumulates

1 meq/100g = 36 000 000 meq / ha or 36 000 moles / ha

Figure 41 shows that for a sandy soil from 370 to 750 kg $Na^+$ (499 – 1011 kg $Na_2O$) and for a clay soil more than 4000kg $Na^+$/ha (5392 kg $Na_2O$) can accumulate before there is a hazard of

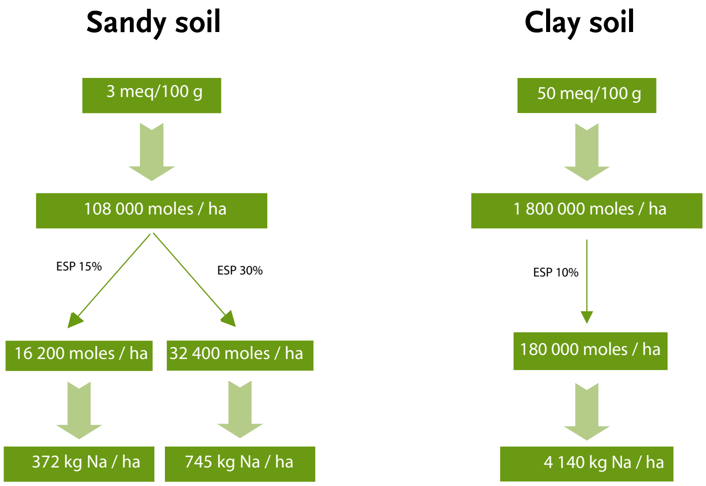

**Figure 41**: Impact from sodium on soil structure: critical content in kg Na/ha depending on different soil CEC and ESP

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[19] ESP: Exchangeable Sodium Percentage i.e. the sodium saturation percentage of the Cation Exchange Capacity (CEC).

dispersion. However sodium, as already mentioned, is extremely mobile and gets easily washed out (it is also much less taken up by the crop in contrast with $NO_3^-$).

This is confirmed by the Limburgerhof trial n° 13 which shows that Na mobility in the soil is very high (much higher than K) and by trial n° 5 already referred to in § 1.2.1.1: compared to the $NO_3^-$ and to K, Na is much more washed out and again does not at all represent a accumulation risk (Jürgens-Gschwind and Jung 1977).

The quantity of sodium added to the soil when applying for example 50 kg complementary N through Natural Chilean Nitrate (26 % $Na^+$) is 81kg (111kg $Na_2O$). Only in sandy soils the sodium could reach the upper limit in 5 years if nothing leaches but, as shown before, this is far from being the case in practice.

Also the addition of 81 kg sodium means that the ESP increases with 3.3 % in a sandy soil and only with 0.2 % in a clay and organic soil, assuming no leaching or plant uptake.

All this shows that Natural Chilean Nitrate, when properly used, **does not represent a dispersion risk.** The situation can be different for ① rain fed farming with limited rainfall in semi-arid and arid environment with no irrigation, ② in areas irrigated with water with a high sodium content and ③ in soils with poor internal drainage, where sodium may tend to accumulate in the soil profile. However this is also the case for all other approved organic mineral fertilizers containing sodium (e.g. Magnesium-kainite, which contains 20% Na).

Note also that sometimes Na impact is associated and confounded with Cl impact i.e. as in NaCl. Natural Chilean Nitrate does not contain Cl.

### *3.1.2.3 Very Long Term Usage of Natural Chilean Nitrate*

A specific comparison of ammonium sulphate and Natural Chilean Nitrate is part of the Broadbalk Experiment conducted at Rothamsted, U.K., since 1844. The comparison spans the years 1885 – 1967, when the two fertilizers were applied at two rates, 48 and 96 kg N $ha^{-1}$, first over continuous wheat (1885-1925) and then during six-year fallow cycles. Other nutrients were supplied to all plots to prevent their deficiencies. A summary of the main results is presented in Table 18. The advantage for Natural Chilean Nitrate was greater during the first 41 years when wheat was grown continuously, specially for the smaller N rate with positive differences of 376 kg grain $ha^{-1}$ (26%) and 916 kg straw $ha^{-1}$ (40%).

Fallowing increased average yield of grain and straw for both treatments, however the superiority of Natural Nitrate remained in the second period. Averaging the result for both N rates over the whole period of 83 years, **Natural Chilean Nitrate** gave 220 kg more grain and 558 kg more straw per ha than **ammonium sulphate**, representing yield increases of 12% and 16% respectively.

Over such a long term, this rise in productivity can only be a proof and a sign **of a healthy soil.** What else could it be a sign of?

### Table 18
### Comparison of Chilean Nitrate and ammonium sulphate for over 80 years in the Rothamsted experimental station, United Kingdom

| Crop rotation | Time period | Fertilizer N Rate | Wheat yield | | Straw yield | |
|---|---|---|---|---|---|---|
| | | | Ammonium sulphate | Chilean nitrate | Ammonium sulphate | Chilean nitrate |
| | | kg N ha$^{-1}$ | kg grain ha$^{-1}$ | kg grain ha$^{-1}$ | kg straw ha$^{-1}$ | kg straw ha$^{-1}$ |
| Continuous wheat | 1885-1925 | 0 | 904 | | 1,268 | |
| | | 48 | 1,456 | 1,832 | 2,309 | 3,225 |
| | | 96 | 2,108 | 2,221 | 3,803 | 4,418 |
| | | Mean N effect | 1,782 | 2,027 | 2,460 | 2,548 |
| Six fallow cycles | 1935-1964 | 0 | 1,606 | | 2,748 | |
| | | 48 | 1,995 | 2,134 | 3,577 | 3,828 |
| | | 96 | 2,472 | 2,711 | 4,706 | 5,083 |
| | | Mean N effect | 2,234 | 2,422 | 4,142 | 4,455 |
| Whole period | 1885-1967 | 0 | 1,142 | | 1,795 | |
| | | 48 | 1,606 | 1,870 | 2,761 | 3,414 |
| | | 96 | 2,184 | 2,359 | 4,142 | 4,606 |
| | | Mean N effect | 1,895 | 2,115 | 3,451 | 4,010 |
| | | Yield difference | | 220 | | 558 |
| | | Yield difference % | | 12 | | 16 |

Source: Garner, H.V. & G.V. Dyke. 1968 The Broadbalk yields. Harpenden, UK, Rothamsted Experimental Station. Report for 1968, Part 2 pp. 34-35

### 3.1.3 *Ecological impact related to controllability and quantity of the nitrogen influx*

According to its specific characteristics, each fertilizer represents a potential hazard for the environment. Some of those hazards like storage and spreading hazards can be contained (controlled) albeit at a cost.

Other hazards are less controllable and represent a potential load for the environment. Those hazards are mostly related to N losses. Table 19 numerically evaluates the potential load of different farm manures, compost and some mineral fertilizers.

Farm manures are an important link in the natural biological on-farm cycles. Nevertheless, according to Table 19, farm manure has a high potential risk score and this due to its lack of N release controllability over time and its low efficiency. The higher the **controllable N availability** of the amendment, the higher the **N efficiency** the lower the N losses and potential hazard score.

#### 3.1.3.1 *Nitrogen availability*

In paragraph 1.2.2 we approached the N mineralization related to synchronization with plant needs.Here we will discuss N mineralization related to ecological impact.

## Table 19:

### Matrix of potential risks for the environment and related costs for different fertilizers (Revue suisse d'agriculture 33 (3) p. 62-63, 2001)

| Type of fertilizer | Potential load for : | | | | Technical criteria and economical investment criteria | | | Total load |
|---|---|---|---|---|---|---|---|---|
| | Water table(1) | Surface waters(2) | Air(3) | Soil(4) | Storing and handling cost | Application cost | Application cost related to environment protection(6) | |
| Slurry | 3 | 3 | 3 | 3 | 3 | 3 | 3 | **21** |
| Manure | 3 | 2 | 2 | 2 | 2 | 2 | 3 | **16** |
| Water treatment sludge | 3 | 3 | 3 | 3 | 1 | 2 | 3 | **18** |
| Compost | 2 | 2 | 2 | 2 | 1 | 2 | 2 | **13** |
| Mineral fert. N(5) | 2 | 1 | 2 | 1 | 1 | 2 | 2 | **11** |
| Mineral fert. P(5) | 1 | 1 | 0 | 2 | 1 | 2 | 1 | **8** |
| Mineral fert. K(5) | 2 | 1 | 0 | 1 | 1 | 2 | 1 | **8** |
| Mineral fert. Mg(5) | 1 | 1 | 0 | 1 | 1 | 2 | 1 | **7** |
| Mineral fert. S(5) | 2 | 1 | 0 | 1 | 1 | 2 | 1 | **8** |
| Chilean nitrate(5, 7) | 2 | 1 | 0 (8) | 1 | 1 | 2 | 2 | **9** |

(1) : Nitrates, chlorine, sulphates, etc
(2) : Phosphates, nitrogen and microbial hazard.
(3) : Ammonium, nitric oxides (NOx).
(4) : Dangerous substances, physical load.
(5) : Manufacturing and transportation load up to the fertilizer application are not taken into consideration.
(6) : Investments (buildings, machines), labor.
(7) : Addition suggested by the authors of this paper.
(8) : No volatilization compared to ammonia.

For all practical purposes the total plant available nitrogen from OM or the $N_{avail}$ is the N that can be mineralized over the first 3 years after application and under optimal conditions. Beyond this period very little N is released from the OM turned into stable humus. This includes the short term availability (same year) and the after-effect or medium term (2 to 3 years later[20]). This $N_{avail}$ can then be compared with a given mineral fertilizer amount, knowing that the availability of the mineral N is 100%. Of this available nitrogen, only a part is valorized by the crop. The other part, determined as non-valorized, are N-losses (volatilization, leaching, run off, etc). The **N-availability** can be defined as follows:

$$\text{N} - \text{AVAILABILITY (\%)} = \frac{N_{tot} - N_{humus}}{N_{tot}} \times 100 = \frac{N_{avail}}{N_{tot}} \times 100$$

$N_{tot}$ = Total N-content of an applied fertilizer after deduction of storage losses
$N_{humus}$ = Part of total N that is fixed in humus
$N_{avail}$ = Quantity of N that becomes available for uptake during first 3 years after application

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[20] Corresponds to the turnover time of the active (labile) fraction of soil organic matter. The stable fraction ((stable) humus) has a turnover time of around 50 years.

Table 20 presents some N-availability values at short (1 year) and medium (3 years) terms for different farm manures.

Available nitrogen can be as low as 5% (green waste compost) and as high as 85% (slurry) with farm yard manure at around 30%.

In another study on compost, the amount of N released was estimated (by difference) to be 26% of compost N added. Initially 7-10% was mineral N and 8% soluble organic N, therefore 8-11% was released from insoluble N in the compost (Hadas et al., 1996).

The difference between total nitrogen ($N_{tot}$) and available nitrogen ($N_{avail}$) of farm manures is stored in the soil under form of humus ($N_{humus}$).

$$N_{tot} = N_{avail} + N_{humus}$$

Furthermore, Walther (2001) observed the values of $N_{min}$[21] in the different layers of the soil. He concluded that, at **medium term**, nitric nitrogen is accumulating, not only in winter but also during the period of vegetation, in the deeper layers of the soil, only partially accessible to the plants. The nitrate infiltration in the depth of the soil is increasing in the following order (as well in winter as in summer): (1) Integrated Production without nitrogen fertilization < (2) Integrated Production with fertilization (organic and mineral) < (3) Biological production.

In the **long term**, after mineralization and denitrification, a part of this nitrogen returns as $N_2$ to the atmosphere. A small part is transformed in $N_2O$ gas, contributing in the greenhouse effect (Vlassak and Agenbag, 1999).

If the farmyard manures are not used in an optimal way (e.g. unfavorable climate and soil conditions) the quantity of nitrogen becoming available may still be considerably lower.

### *3.1.3.2 Nitrogen efficiency*

Only part of the available N is valorized by the crop. Therefore the **N-efficiency** will always be lower than the N-availability.

In order to assess the ecological impact of N fertilizers one has to evaluate the controllability of the nitrogen release to optimize uptake efficiency. An important part of the available nitrogen can be lixiviated, submitted to run off and/or volatized. These losses have a negative impact on the environment and should be reduced as much as possible by using efficient fertilizer management strategies. Nitrogen dynamics and risks of losses depend largely on the soil, the meteorological conditions local, cultural practices and the crop itself. It can never be completely controlled (Zihlmann et al., 2003; Walther, 2001).

Figure 42 shows the total nitrogen input over 5 years (crop rotation: '91: oats, '92: wheat, '92/93: turnip, '93: barley, '93-'94: white clover, '95 carrots) of seven different treatments in comparison with the nitrogen uptake over the same period. The total uptake is compared to a control field that did not receive any fertilization. This allows studying the **additional** nitrogen

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[21] $N_{min}$ = Mineral nitrogen

## Table 20:

## Ratio of available nitrogen to total N of different farm manures (Revue suisse d'agriculture, 33 (3), 2001 p. 56)

| Type of fertilizer | N-Availability at medium term (= first 3 years) (%)[1] | N-Availability in the year of application (for the crop which follows the application)[2] | |
|---|---|---|---|
| | | Fodder crop | Main crop |
| Cow slurry | 50-70 | 55 | 45 |
| Slurry (poor in feces) | 65-85 | 70 | 60 |
| Heap stored manure | 20-40[3] | 20 | 15 |
| Free stable manure | 25-50[3] | 25 | 20 |
| Horse manure | 10-25[3] | 15 | 10 |
| Sheep manure | 40-60[3] | 40 | 30 |
| Pork slurry | 50-70 | 60 | 50 |
| Solid pork manure | 40-60[3] | -[4] | 35 |
| Hen droppings | 40-60[3] | -[4] | 40 |
| Hen manure (boxes elevated from soil) | 40-60[3] | -[4] | 35 |
| Poultry manure ( chickens, turkeys) | 40-60[3] | -[4] | 35 |
| Water treatment sludge | 40-60[3] | 40[4] | 40 |
| Water treatment sludge (dehydrated) | 30-50[3] | 25[4] | 25 |
| Water treatment sludge (dehydrated + limed) | 25-40[3] | 20[4] | 20 |
| Dried and granulated water treatment sludge | 25-30[3] | 15[4] | 15 |
| Composted manure[6] | 20-45 | - | - |
| Manure compost[7] | 25-50 | - | - |
| Green Waste Compost[5] | 5-10[3] | 5[4] | 5 |
| Sugar beet waste | 70-80 | 70 | 60 |

(1) : On average soil conditions in Switzerland, under optimal application conditions; in case of application of only solid manures the effect is spread over 2 to 3 years. In case of liquid manures this way of calculating makes no sense. If the manures are not applied under optimal conditions (climatically or unfavorable soil conditions) the numbers may be considerably lower.

(2) : During an application under optimal conditions.

(3) : In soils that have a clay content higher than 30%, higher number than the lower range should not be used as the efficiency is lower in that case.

(4) : Is not advised in natural grassland.

(5) : Independent from the place and way of composting, as from the degree of compostation. In other sources values from 10-25% (Power & D, 1984) up to 33% N-availability (Chèneby et al., 1994) are found.

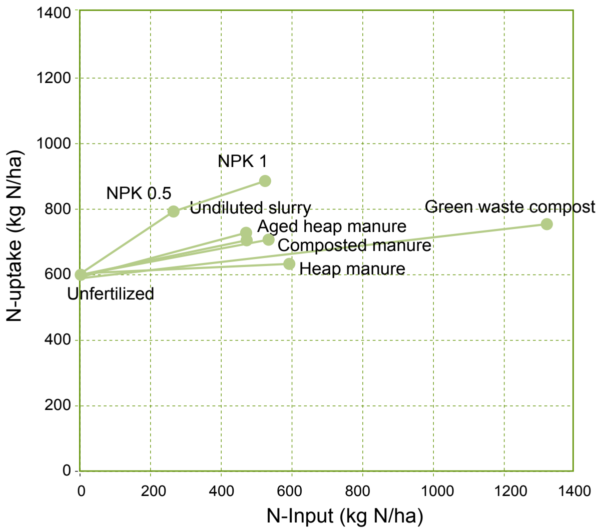
(6) : Manure stored for 3 months. The structure of the raw material is still recognizable. Raw materials : fresh manure or stable manure of different animals.

(7) : Manure stored for 6 months. The structure of the raw material is not recognizable. Raw materials : fresh manure or stable manure of different animals.

uptake from the different fertilizers. The treatment with only half of the standard dosage of the mineral fertilizer (NPK 0.5) gives an uptake of almost 200 kg N for an input of approximately 260 kg N, or an efficiency of over 70%. The standard application (NPK 1) results in the highest uptake, however the efficiency is lower.

Table 21 shows the efficiency of different manures.

Undiluted slurry, aged heap manure and composted manure lay close to each other. They give the best N-uptake of the different organic manures in the trial, but still these results are lower than for the mineral treatments. Slurry, which has higher, directly available ammonium content, suffers more ammonia losses resulting in an unfavorable situation compared to the mineral fertilizer. Green waste compost has the highest nitrogen uptake of all organic manures in the trial, however the N-input is also a lot higher resulting in a very low efficiency. Heap manure provides a higher N-input because of smaller losses during manure preparation. But because of very low N-uptake, a low efficiency is obtained (Berner et al, 1997).



Note:
NPK 0.5: fertilized with half of standard application of mineral fertilizer
NPK 1: fertilized with standard application of mineral fertilizer
(authors translation in English)

**Figure 42**: Sum of N-input and N-uptake (5 years) compared (Berner et al., 1997)

The N efficiency can be defined as follows:

$$\mathrm{N-EFFICIENCY} = \frac{\mathrm{Nuptake_{fert}} - \mathrm{Nuptake_{unfert}}}{\mathrm{Ninput_{fert}}} \times 100 = \frac{\mathrm{Nuptake_{fert}} - \mathrm{Nuptake_{unfert}}}{\mathrm{Ntot_{fert}}} \times 100 = \frac{\mathrm{Nuptake_{fert}} - \mathrm{Nuptake_{unfert}}}{\mathrm{Navail} + \mathrm{Nhumus}} \times 100$$

$\mathrm{Nuptake_{fert}}$ = Total nitrogen uptake by fertilized crop
$\mathrm{Nuptake_{unfert}}$ = Total nitrogen uptake by unfertilized crop
$\mathrm{Ninput_{fert}}$ = Total fertilizer nitrogen input

Table 21 shows that N efficiency of these different fertilizers at above mentioned application rates vary from 75% for the NPK 0.5 treatment **to as low as 6% for the heap manure treatment.**

The other fertilization treatments are in between.

### Table 21:

### Overall nitrogen efficiency from different fertilizers (a) during and after field application and (b) taking also into consideration the production process and storage (Berner et al., 1997)

| Fertilizer | (a) Field application efficiency | (b) Overall efficiency[22] |
|---|---|---|
| | % | |
| Heap manure | 6 | 5 |
| Aged heap manure | 23 | 16 |
| Composted manure | 20 | 14 |
| Green waste compost | 12 | - |
| Undiluted slurry | 27 | - |
| NPK 0.5 | 74 | - |
| NPK 1 | 56 | - |

When the preparation process is also considered, the N-efficiency for aged heap manure and composted manure drops with another 7 and 6 % points respectively. Although ammonia is considered as mineral nitrogen, the ammonia fraction of manures can not be seen as available nitrogen due to its volatility (Revue suisse d'agriculture, 1994).

### *3.1.3.3 Efficiency of nitrate-N versus ammonia-N*

In a field experiment conducted in Belgium by Riga, A. et al. (1988), the fate of split applied nitrogen from sodium nitrate and from ammonium sulphate was evaluated using a $^{15}$N balance sheet and a micro-plot field technique. The specific objective was to evaluate the influence of the time of split application and type of N carrier on the fate of the amount of N applied at each split application. A total dressing of 100 kg N ha$^{-1}$ was split into 35 kg ha$^{-1}$ applied at end of tillering, 45 kg ha$^{-1}$ at heading and 20 kg ha$^{-1}$ at the beginning of flowering. In order to follow the fate of each N split application, $^{15}$N-tagged sodium nitrate ($Na^{15}NO_3$) and $^{15}$N-tagged ammonium sulphate $(^{15}NH_4)_2SO_4$ was used. Percent recovery of fertilizer N by the crop is shown in Table 22.

The greater percentage of N recovered by the harvested whole plant as well as by the components grain and straw corresponded to the sodium nitrate carrier, whereas the ammonium sulphate carrier left the greater percentage of N in the soil. This result shows that available nitrogen in the soil applied as sodium nitrate can be better synchronized with plant uptake than N supplied by ammonium forms.

It can be concluded that the use of Natural Nitrate nitrogen is a valuable complement to the organic sources of nitrogen in the organic farming system. Timely application of split doses of

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[22] Overall efficiency includes, besides field efficiency, preparation and storage efficiency i.e. all losses from preparation, storage and field application.

## Table 22:

**Effect of N fertilizer carrier on the recovery by wheat of $^{15}N$ split applied at different stages of development**

| N carrier | Plant component | N applied (kg ha$^{-1}$) | | |
|---|---|---|---|---|
| | | Tillering end 35 | Heading 45 | Flower inic. 20 |
| | | N recovered (%) | | |
| $NaNO_3$ | Grain | 34.2 | 51.5 | 55.7 |
| | Straw | 20.4 | 16.3 | 14.2 |
| | Whole plant | 54.6 | 67.8 | 69.85 |
| | Soil | 17.9 | 10.4 | 11.6 |
| $(NH_4)_2SO_4$ | Grain | 32.2 | 48.4 | 52.5 |
| | Straw | 19.4 | 15.2 | 13.6 |
| | Whole plant | 51.6 | 63.6 | 66.1 |
| | Soil | 22.5 | 12.7 | 15.2 |

Source : Riga, A., Francois, E., Destain, J.P., Guiot, J. & R. Oger. 1988. Fertilizer nitrogen budget of $Na^{15}NO_3$ and $(^{15}NH_4)_2SO_4$ split-applied to winter

Natural Chilean Nitrate can be synchronized with the crop N uptake, producing the best results in terms of yield, crop quality and protection of the environment.

### *3.1.3.4 Mineralization examples: Some trials from California and the United Kingdom*

- **Mineralization of nitrogen in manures and composts in California**

The study by Cavero et al. (1997) reviewed in § 1.1.1.2 (tomato trial) indicates that one of the reasons for the low N availability to the tomato crop grown under the organic system was the low proportion of N mineralization from turkey manure during the growing season.

Given the importance of organic manures as supplemental sources of N for crops grown under organic systems, Hartz et al. (2000) conducted a two parts research to evaluate the mineralization dynamics of nitrogen (N) and carbon (C) in manures, composted manures and composts from plant residues and municipal yard wastes. One part of the study was a bioassay where fescue (*Festuca arundinacea Shreb*.) grown in pots under controlled conditions was used to measure the N released from the different amendments. The other part of the study consisted in direct laboratory measurements of the N and C mineralized from the amendments incubated under standard laboratory techniques at 25 °C. As stated by the authors, *"the primary objective* *of this study was to determine the N mineralization dynamics of a range of manures and composts representative of those currently used as soil amendments in California vegetable production"* (Hartz et al., 2000).

A summary of selected characteristics of the organic amendments included in the study is described in Table 23.

**Table 23:**
**Range of selected characteristics of the organic amendments (Hartz et al., 2000)**

| Amendements | Numbers of Samples | Total N (%) | P(%) | Organic N (%) | K (%) | C/N Ratio |
|---|---|---|---|---|---|---|
| Manure | | | | | | |
| Poultry, pelletized | 1 | 4.7 | 3.9 | 5.2 | 2.6 | 4.5 |
| Poultry, dehydrated | 1 | 3.3 | 3.0 | 1.1 | 2.0 | 9.0 |
| Poultry, aged | 3 | 3.1 - 2.5 | 2.9 - 2.2 | 2.6 - 1.9 | 3.2 - 2.7 | 9.1 - 11.6 |
| Feedlot, aged | 2 | 2.4 - 2.0 | 2.0 | 1.3 - 1.1 | 1.7 - 1.4 | 12.4 - 12.5 |
| Manure compost | | | | | | |
| Poultry | 7 | 3.8 - 1.3 | 3.6 - 1.3 | 1.4 - 2.9 | 0.5 - 3.0 | 5.7 - 10.2 |
| Feedlot | 6 | 2.2 - 1.9 | 2.2 - 1.8 | 1.2 - 0.6 | 3.2 - 2.0 | 8.8 - 11.4 |
| Dairy | 2 | 1.5 - 1.2 | 1.4 - 1.2 | 1.1 - 0.5 | 1.8 - 1.5 | 10.5 - 14.0 |
| Residue compost | | | | | | |
| Crop residue | 1 | 1.2 | 1.2 | 0.2 | 1.4 | 9.3 |
| Municipal yard waste | 8 | 1.7 - 1.0 | 1.7 - 1.0 | 0.4 - 0.2 | 1.4 - 0.6 | 9.3 - 15.5 |

Total N and organic N concentrations in the amendments range from 4.7 to 1.2% and from 3.9 to 1.2%, respectively. Non composted manures have the highest N levels and the largest differences between the two types of N, probably due to a higher mineral N content. Composting results in a reduction of the difference between total and organic N, this effect **being more apparent as the N content in the amendment decreases**. No difference was observed below a nitrogen concentration of 1.4%. The C/N ratio shows a tendency to increase as the N content of the amendments decreases. The rates of N mineralization from organic amendments measured by the bioassay using festuca (*Festuca arundinacea Shreb*) and by the laboratory incubation test presented a high correlation coefficient R = 0.95. The linear regression equation and the coefficient of determination $R^2$ are in Figure 43.

The high correlation of the laboratory incubation method with the plant bioassay method indicates that the former is an adequate analytical procedure to estimate the quantity of organic N that becomes available to plants from the organic amendments. However, given the strong effect of temperature on microbial activity formerly indicated in this document, lower mineralization rates may be expected at lower temperatures prevailing during cold seasons in many agricultural regions over the world.

Values of total N uptake by fescue and organic N mineralization rates averaged for different

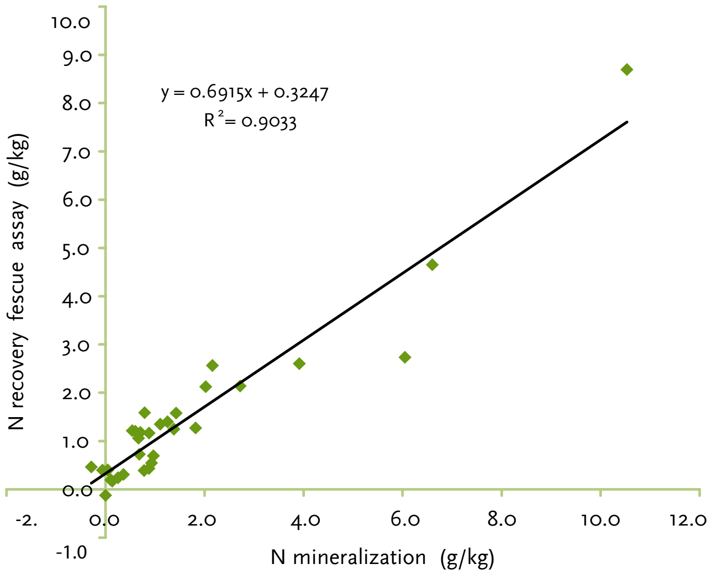

**Figure 43:** Correlation of N recovered by the Fescue (*Festuca arundinacea Shreb.*) bioassay and N mineralized during incubation of 31 organic amendments. Combined results from 1996 and 1997 trials (Hartz, et al., 2000).

types of amendments are in Table 24.

Absolute quantities of mineralized N range from 10.5 to less than 1.0 kg N $mt^{-1}$ of amendment, corresponding to 27.0 to 1.3 % of the organic N present. The non composted animal manures have the highest quantities of organic N and the highest share of that N being mineralized, ranging from 39 to 20 kg N $mt^{-1}$ and 27 to 11.4 %, respectively. The residue composts, either from crops or municipal yard waste, have the lowest organic N content **and** mineralization rates, ranging from 15 to 12 kg $mt^{-1}$ and 1.3 to –0.5%, respectively. The negatieve mineralization figure for crop residue compost means there is N immobilization instead of release. The manure composts represent intermediate figures between the non composted manure and the residue composts. Average figures for total N recovered in the fescue assay follow a similar pattern to those of the N mineralization laboratory test, consistent with the high correlation for the respective individual observations as indicated in Figure 43.

From a practical point of view, the data in Table 24 indicate that, in order to supply a crop with, for example, **50 kg of available N/ha** when the soil temperature, at least during daytime, is around 25 °C, the needed quantity of amendment, due to this compounded effect would range from **5 to 20 Mt/ha** when using non composted manures, from **around 25 to 65 Mt/ha** when using composted manures, and **over 200 Mt/ha** when using composted municipal yard wastes.

## Table 24:

**N recovered by fescue ( *Festuca arundinacea Shreb.* ) from total N and N mineralized from organic N, respectively, in soil amendments, average values (Hartz et al., 2000).**

| Amendments | Number of samples | Total N | Total N recovered by Fescue | | Organic N | | Organic N mineralized | |
|---|---|---|---|---|---|---|---|---|
| | | kg mt$^{-1}$ | kg mt$^{-1}$ | % | kg mt$^{-1}$ | % | kg mt$^{-1}$ | % |
| Manure | | | | | | | | |
| Poultry, pelletized | 1 | 47 | 8.70 | 18.5 | 39 | 83 | 10.53 | 27.0 |
| Poultry, dehydrated | 1 | 33 | 4.70 | 14.2 | 30 | 91 | 6.60 | 22.0 |
| Poultry, aged | 3 | 28 | 2.43 | 8.7 | 26 | 93 | 2.70 | 10.4 |
| Feedlot, aged | 2 | 22 | 1.71 | 7.8 | 20 | 91 | 2.27 | 11.4 |
| Manure compost | | | | | | | | |
| Poultry | 7 | 24 | 1.47 | 6.1 | 23 | 96 | 1.83 | 8.0 |
| Feedlot | 6 | 21 | 1.01 | 4.8 | 20 | 95 | 0.74 | 3.7 |
| Dairy | 2 | 14 | 0.82 | 5.8 | 13 | 93 | 0.74 | 5.7 |
| Residue compost | | | | | | | | |
| Crop residue | 1 | 12 | 0.40 | 3.3 | 12 | 100 | - 0.06 | - 0.5 |
| Municipal yard waste | 8 | 15 | 0.27 | 1.8 | 15 | 100 | 0.19 | 1.3 |

- **Mineralization of organic nitrogen from animal manures in the United Kingdom.**

A study was conducted in the UK to (a) characterize the different manure N fractions, and, (b) determine the mineralization rate of manure organic N through a bioassay using plants in a pot experiment. The information is required to predict both short- and long-term supply of plant available N to avoid accumulation in the soil and eventual losses by leaching and/or denitrification (Chadwick, et al., 2000a and b).

Fifty samples from different types of animal manures were included in the study. The average composition for the types of manures is presented in Table 25.

A pot experiment was conducted to estimate the mineralization rate of the organic N in a sub sample of 17 manures, applied at a target rate of 200 kg total N/ha. Perennial ryegrass (Lolium perenne L.) was sown to the pots and kept for 200 days at 18 °C for 16 hour days and at 12 °C for 8 hour nights. A summary of results is presented in Table 26.

Layer manure and pig slurry have the highest levels of mineralization rate, 55% and 27.6%, respectively, measured as the N uptake of ryegrass grown under controlled conditions. Mineralization rate for other substances ranges from 21.3% for pig FYM to 12.2% for cattle slurry. The mineralization rate was inversely related to the carbon to nitrogen C / N ratio in organic amendments.

According to the above results, except for layer manure and broiler litter, the application of even **a moderate rate of N** to a crop will require the application of **substantial quantities of manure** per hectare. The application of for example 50 kg N /ha will require manure rates ranging from 38 Mt/ha of pig FYM to 138 Mt/ha of cattle slurry.

## Table 25:
## Average values for selected characteristics of manure samples (Chadwick et al., 2000a and b)

| Manure type | Number of samples | Dry matter | Fresh Weight basis | | Dry Weight basis | | | C / N ratio |
|---|---|---|---|---|---|---|---|---|
| | | | Total N | Organic N | Total N | Organic N | | |
| | | % | kg mt$^{-1}$ | Kg mt$^{-1}$ | kg mt$^{-1}$ | Kg mt$^{-1}$ | % | |
| Cattle slurry | 12 | 11.1 | 4.1 | 2.9 | 37 | 26 | 71 | 9.63 |
| Pig slurry | 8 | 5.7 | 4.5 | 1.6 | 80 | 28 | 35 | 4.01 |
| Cattle FYM | 14 | 20.2 | 5.2 | 4.5 | 26 | 22 | 87 | 14.8 |
| Pig FYM | 6 | 22.7 | 8.6 | 6.1 | 38 | 27 | 71 | 9.84 |
| Broiler litter | 6 | 56.3 | 24.9 | 20.2 | 44 | 36 | 81 | 7.64 |
| Layer manure | 4 | 44.0 | 19.8 | 12.4 | 45 | 28 | 63 | 3.67 |

## Table 26:
## Average N content and organic N uptake by ryegrass from organic amendments in a controlled pot experiment (Chadwick et al., 2000a and b)

| Manure type | Number of samples | Dry matter | Total N FW (1) | Organic N | | N uptake org. N applied __ FW | |
|---|---|---|---|---|---|---|---|
| | | | | | FW (1) | | |
| | | % | kg mt$^{-1}$ | % | kg mt$^{-1}$ | % | kg/Mt |
| Cattle slurry | 3 | 11.08 | 4.12 | 70.87 | 2.92 | 12.20 | 0.36 |
| Pig slurry | 3 | 5.71 | 4.54 | 35.24 | 1.60 | 27.60 | 0.44 |
| Cattle FYM | 3 | 20.15 | 5.20 | 86.54 | 4.50 | 14.00 | 0.63 |
| Pig FYM | 4 | 22.66 | 8.58 | 70.86 | 6.08 | 21.30 | 1.30 |
| Broiler litter | 3 | 56.28 | 24.86 | 81.34 | 20.22 | 20.60 | 4.17 |
| Layer manure | 1 | 44.04 | 19.75 | 62.68 | 12.38 | 55.00 | 6.81 |

(1): FW = Fresh Weight

There is general consistency of the results of this study (Chadwick, et al., 2000a and b) and the study done by Hartz et al. (2000). Except for a few substances, mineralization rates are **around 20%** or less of the organic nitrogen in the amendment.

The quantity of carbon added in plant residues is an important factor affecting the soil organic matter level. The close correspondence between cycling of C and N in soil suggests that the retention of organic N from cover crop residues may be closely associated with organic C retention (Kuo et al., 1997).

In short : the higher the C/N ratio, the higher the humification coefficient and therefore the higher the humus building capacity. However this implies also a lower mineralization rate. Therefore for **2 amendments with the same $N_{tot}$, $N_{min}$ and $N_{org}$ content, the one with the highest humus building capacity potential will have the lowest N supply capacity and this more then proportionally. 50 Kg N in the form of Natural Chilean Nitrate could go a long way towards replacing some of this excess tonnage of organic fertilizers (amendments).**

### 3.1.3.5 *Efficiency trial*

**Corn Yield under Organic and other Management Systems in Crop Rotations – Minnesota**

Two- and four-year rotation experiments were conducted at 2 sites in the Southwest Research and Outreach Center near Lamberton, Minnesota (Porter et al., 2003). The objective was to compare four managements systems, i.e., high inputs (HI), low inputs (LI), organic inputs (OI), and zero inputs (ZI) under the two and four year rotation systems. The two-year rotation was a corn-soybean crop sequence. The four-year rotation was a corn-soybean-oat/alfalfa-alfalfa crop sequence. Each crop of each rotation was grown each year, with three replications. The yields of the two-year HI corn-soybean rotation were used as the basis of comparison because this cropping strategy most closely resembles the practices of the majority of farmers in the North Mid-West of the USA. A summary of the results is presented in Table 27.

**Table 27:**
**Corn yield results in rotation experiments in Minnesota**

| Crop rotation | Farming strategy (1) | Average fertilizer rates N kg ha$^{-1}$ | $P_2O_5$ kg ha$^{-1}$ | $K_2O$ kg ha$^{-1}$ | Average corn yield 1993-1999 mt ha$^{-1}$ | % | Yield increase dY mt ha$^{-1}$ (2) | Nitrogen efficiency dY/dN (3) |
|---|---|---|---|---|---|---|---|---|
| Site V1 | | | | | | | | |
| 2 year | HI | 146 | 70 | 44 | 8.96 | 100 | 4.57 | 31.3 |
| 4 year | OI | 318 | 136 | 289 | 8.15 | 91 | 3.76 | 11.8 |
| 4 year | LI | 69 | 69 | 43 | 8.60 | 96 | 4.21 | 61.0 |
| 4 year | ZI | 0 | 0 | 0 | 4.39 | 49 | | |
| Site V2 | | | | | | | | |
| 2 year | H | 143 | 24 | 2 | 8.72 | 100 | 1.05 | 7.3 |
| 4 year | OI | 185 | 90 | 158 | 8.11 | 93 | 0.44 | 2.4 |
| 4 year | LI | 62 | 29 | 17 | 8.72 | 100 | 1.05 | 16.9 |
| 4 year | ZI | 0 | 0 | 0 | 7.67 | 88 | | |

① : HI = high inputs; OI = organic inputs; ZI = zero inputs; LI = low inputs

②: dY = yield difference over the ZI yield.

③: dY/dN = Yield increase per unit of fertilizer N (kg kg$^{-1}$)

Source: Porter, P.M., Huggins, D.R., Perillo, C.A., Quiring, S.R., & R.K. Crookston. 2003. Organic and other management strategies with two- and four-year crop in Minnesota. Madison, Wisconsin, Agronomy Journal 95:233-244

In site V1, corn yield for the 2-yr high input (LI) strategy averaged 8.96 mt ha$^{-1}$ over the 7 year period 1993-1999. Compared with the 2-yr HI strategy, the 4-yr organic (OI) strategy yielded 91%, the 4-yr LI strategy yielded 96% and the 4-yr zero input (ZI) strategy yielded 49%. Low P soil levels may contribute to explain the low average corn yield in the ZI strategy.

In site V2, corn yield for the 2-yr high input (HI) strategy averaged 8.72 mt ha$^{-1}$ over the 7 year period 1993-1999. Compared with the 2-yr HI strategy, the 4-yr organic (OI) strategy yielded 93%, the 4-yr LI strategy yielded the same and the 4-yr zero input (ZI) strategy yielded 88%. All yield responses over the ZI strategy in site V2 are rather low and the higher level of soil P, as compared to soil P level in site V1, may be a factor explaining the high yield for the 4-yr ZI strategy in site V2. The high average yield level for the ZI strategy may also explain the low efficiency for the added fertilizer nitrogen in site V2. However, **nitrogen efficiency in the OI strategy is the lowest in both sites** (and will probably lead **to P and K accumulation** in the soil as their average input is 2.3 respectively 7 times larger).

### *3.1.4 Encouragement and enhancement of biological cycles within the farming system, involving micro-organisms, soil flora and fauna, plants and animals*

The influence of the cultivation system on the quantity, the diversity and the activity of the soil micro-organisms, fauna and flora are of major importance for the long term protection of soil quality.

#### *3.1.4.1 Microbial biomass*

Extensive studies (from 1979 to 2002) on 24 lots (DOC-trials) by Dubois et al. (2002) showed that in 30% of cases the quality of the soil improved in microbial values, about 50% showed no difference and for about 20% there was a decrease when using organic practices compared to conventional (low input) system.

Few specific long term trials as the DOC trial have been carried out to try to determine the influence of different **farming** systems on the quality and quantity of soil microbial biomass.

Even than such studies can hardly be used to try to extrapolate the specific influence of different **fertilizing** systems and this for the reason already mentioned in section 1 i.e. because of “confounding variables” such as:

- **Pesticides** (e.g. fungicides) use is different among different systems and can be assumed to influence microbial biomass (fungi/bacteria).
- **Type of fertilization** Even if manures are applied at the same doses (e.g. expressed in OM weight/ha) it is not always clear at which point in the mineralization (composting) process the doses are referred to.

  In the DOC trials, according to Fliessbach et al. (2000a), similar (but not equal) **amounts of OM** are used in the 3 systems[23], although in another publication (Dubois et al., 2003) concerning the **same** DOC trial, the same yearly **amount of fresh manure** before composting is this time indicated to have been used i.e. 1.4 “LAE”/ha equivalent.

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[23] Bio-dynamic: 0.92t OM/ha; bio-organic: 1.27t OM/ha; conventional 1.03t OM/ha for low intensity and respectively 1.84/2.33/2.06t OM/ha for high intensity

However starting from fresh manure, composted FYM loses 45% and rotted FYM 25% of OM (Berner et al., 1997), which is a substantial **difference** (see also § 3.1.3.2).

- **Levels of fertilization** (expressed in plant nutrient doses) are different between the systems: bio-dynamic systems received 80kg N/ha/y as composted FYM (with corresponding PK and other nutrient (in organic form)) from the beginning of the trial in 1978 till the end.

  The mineral conventional system in contrast received **no fertilizer during the first 8 years** and from 1986 onwards 90kg/ha mineral N (and other mineral nutrients conforming official norms).
- **The fertilization schedule** in the organic systems involved small and more frequent manure applications then in the conventional system where the total amount of manure was split to be applied to red beets and potatoes only i.e. 2x in a 7 year rotation (Fliessbach et al., 2000b).

Further **soil microbial biomass** C ($C_{mic}$) and N ($N_{mic}$) differences between conventional (con.FYM) and bio-organic (bio.org) are much smaller (12.5% average) **than differences between the 2 organic systems** (bio.dyn and bio.org) themselves (37% average or 3 x more). This is also the case for the pH **but not for yields**; yields were similarly low for both organic systems.

Results from the Broadbalk Continuous ( >140 years) Wheat Experiment have showed that soils that received mineral fertilizer contain more microbial biomass than soils from the corresponding plot that have not received mineral N (Shen et al., 1989). There is however only a small difference in the microbial biomass N between the different rates of N-fertilizer (48, 96, 144 or 192 kg/ha) applied over this time. When microbial biomass N contents were monitored over a 4 year period, no consistent changes were observed.

Studies at the same site carried out by Glendining et al. (1996), confirmed that different rates of mineral N-fertilizer (48, 96,144 and 192 kg N/ha since 1852) had no effect on the soil microbial biomass N or C contents though there was some positive correlation with the specific mineralization rate of the biomass contents (defined as N- mineralized per unit of biomass). Although the size of the microbial population appears unchanged, its activity was greater in soils receiving long-continued applications of N mineral fertilizer.

- **Organic matter and pH**

In the DOC trial **total N** showed a positive trend in the organic systems but differences were not statistically significant (neither in low nor high intensity mode). Also the **C/N ratio** was “hardly affected by the different systems”, according to Fliessbach et al. (2000a).

As in numerous other studies a rather narrow relationship between the different microbiological parameters of the soil has been found to exist. Furthermore those parameters represent a narrow relationship with the **pH** and the $\mathbf{C_{org}}$ soil content. According to Oberholzer et al. “With the help of a multiple regression, 85% of the microbial biomass variability can be explained by the dependence of those 2 parameters (...). The increased acidification in the conventional (low input) system explains very certainly a major part of the relatively poor microbiological referential values of this system during the DOC trial (in practice such a decrease of pH is not noted in general in the conventional (low input) system)" (Oberholzer et al., 2003).

On the other hand the **pH** seems to be the one and sole parameter that is clearly and consistently influenced by the different systems in most trials, including the DOC trial.

Also in a 53-year fertilizer trial at the university of Munich, Germany, on a sandy silt loam of pH 5.9, it was found that the Biological activity of the soils (based on the activity of 5 enzymes and $O_2$-consumption) depended mainly on the pH( Bosch et al., 1983). Further in a decomposition trial of composted white pine it was found that sodium nitrate promoted the development of spore-forming bacteria, aerobic cellulose-decomposing bacteria and fungi (Gorbanov et al., 1981).

Indeed most mineral N fertilizers, but not all, have a tendency to lower the pH over time.

For all these reasons microbial biomass will be further discussed more conventionally in the light of those 2 parameters:

① organic matter content
② pH

### *3.1.4.1.1 Organic matter content*

With reference to the 40 year (1963-2003) trial bij Vuillioud et al., mentioned in § 3.1.2.1 where three different farming practices (mineral fertilizer only, mineral fertilizer + crop residues and mineral fertilizer + farm yard manure) are compared: soil organic matter content was not significantly influenced by the three fertilization systems.

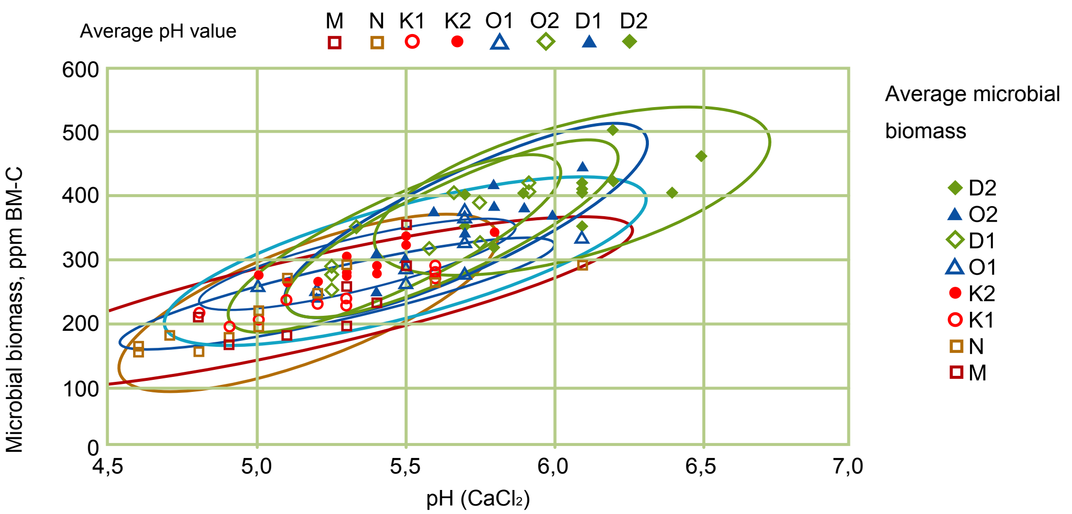
Furthermore the Limburgerhof trial 8 (23 years) (Jürgens-Gschwind and Jung, 1977) shows that a **higher humus level** is obtained when mineral fertilizer is **added** to manure: 1.70% against 1.94% humus.

The above long term trial results suggest that complementary use of Natural Chilean Nitrate would not have a direct impact on microbial biomass as OM content would not be affected negatively. Moreover, only vegetative waste can increase organic soil matter. Fertilizer produced with animal waste, as bone meal, feather meal, etc., does not increase organic soil matter, except indirectly through higher yields and consequently a larger amount of crop residues that stay on the field. The same can be said of Natural Chilean Nitrate.

### 3.1.4.1.2 *pH*

- **Fertilization systems and impact on soil pH.**

**Figure 44:** shows the importance of the second parameter,the pH, in the DOC trial.



O = Organo-biologic
D = Biodynamic
K = Conventional (mineral + organic fert.)
M = Conventional (mineral fert. only)
N = no fertilizer
1 and 2 = low and high fertilizer intensity

Figure 44: Relation between pH and microbial biomass expressed as BM-C (Oberhozer and Mäder, 2003)

The influence of pH was also shown in a study by McAndrew & Malhi (1992). The long-term N fertilization effects on a solonetzic soil with high rates of N application (152 and 300 kg N/ha) showed decreased microbial biomass C and N and decreased amounts of mineralisable C and N. The explanation for the reduced microbial biomass activity in this study was the **increase in soil acidity** caused by the N fertilizer.

Soil pH may also impact soil microbial size and activity indirectly through its effect on earthworm populations, as will be explained later.

- **Impact of Natural Chilean Nitrate on pH**

In most trials the mineral N fertilizers tested are acidifying (ammonium nitrate, ammonium sulphate, urea, etc).

In Natural Chilean Nitrate, the alkaline effect of the sodium is added to the non-acidifying effect of the nitrate (Bernie, 1991). Therefore it helps to increase or at least maintain the pH of various types of soils and in that way contributes to an increased microbial life.

In a 53 year fertilizer rial (sandy silt loam) of pH 5.9 the effects of farmyard manure, calcium cyanamide, ammonium sulphate, the latter + lime, sodium nitrate and calcium nitrate were compared. Ammonium sulphate decreased the pH of the topsoil to 4.9, acidification reaching a depth of 50 cm. Calcium cyanamide prevented a drop in pH. The other treatments [manure, sodium nitrate and calcium nitrate] gave pH values of between 5.8 and 6.0. The biological activity of the soils depended mainly on the pH (Bosch et al., 1983).

Unlike ammonia and its derivatives, including urea, sodium nitrate will not promote cation losses in the soil and lead to unsuspected soil acidity (IFDC & UNIDO, 1998. Fertilizer Manual, p. 239).

The acidifying effect of a given mineral fertilizer can be obtained through the Sluijsman formula:

($CaO$ * 1.0) + ($MgO$ * 1.4) + ($K_2O$ * 0.6) + ($Na_2O$ * 0.9) - ($P_2O_5$ * 0.4) - ($SO_3$ * 0.7) - ($Cl$ * 0.8) - ($N$ * 1.0) = kg CaO equivalent/100 kg fertilizer added to or substractedsubtracted from soil.

Table 28 shows the acidifying effect of some common mineral fertilizers. **Natural Chilean Nitrate is the most alkalizing mineral N fertilizer.**

### Table 28:
### Acidifying effect of fertilizers based on Sluijsman formula

| Fertilizer | Formula | Effect |
|---|---|---|
| 100 kg lime | $CaCO_3$ | = 50 kg CaO added |
| 100 kg Natural Chilean Nitrate | $NaNO_3$ | = 15.5 kg CaO added |
| 100 kg calcium nitrate | $Ca(NO_3)_2$ | = 11 kg CaO added |
| 100 kg potassium sulphate | $K_2SO_4$ | = 0.9 kg CaO loss |
| 100 kg ammonium nitrate | $NH_4NO_3$ | = 35 kg CaO loss |
| 100 kg urea | $NH_2(CONH_2)$ | = 46 kg CaO loss |
| 100 kg ammonium sulphate | $NH_3SO_4$ | = 62 kg CaO loss |

Limburgerhof trial 12 (Jürgens-Gschwind and Jung, 1977) confirms this indirectly:

In acid soils (pH 4-5) the additional yields from the plots with FYM are 3x higher than those from the alkaline plots (pH 7).

Explanation given: “the better yield effect from FYM on acid soils is attributed to its neutralizing side effect. Conversely acidifying ammonium nitrate on acid soils is less translated in additional yield than on alkaline soils”.

Natural Chilean Nitrate as an alkalizing N fertilizer, used in conjunction with organic fertilizer,should therefore stimulate microbial biomass.

Other parameters as temperature, moisture status, soil texture and structure and redox potential have an influence on microbial activity, but their discussion is beyond the scope of this document since they are not relevant in the context of evaluating the use of Natural Chilean Nitrate.

### *3.1.4.1 Fauna*

The protozoa and nematodes **(microfauna)** generally feed on fungi and bacteria, so that their contribution to nutrient cycling is by their feeding on and assimilation of microbial tissue [biomass], and excretion of mineral nutrients. [As previously said microbial biomass seems not to be negatively influenced by (complementary) use of Natural Chilean Nitrate.] The specific contribution of **mesofauna** to nutrient cycling is poorly understood. To complicate matters, micro-arthropods can be bacterivorous, fungivourous, predatory (feeding on other fauna) or omnivorous, thus making a complete understanding of their interactions difficult (Sheperd et al., 2002).

The third category of fauna is the **macrofauna**, which is again, a diverse group of organisms, whose roles include:

- the break-up and burial of organic detritus, thus increasing its availability to soil microbes and facilitating the transfer of nutrients deeper into the soil profile;
- the physical rearrangement of soil particles, thus changing pore size distribution (with effects on infiltration, gaseous exchange, etc.).

Earthworms play a unique role in building soil structure, by helping the aggregation of soil particles and the formation of a crumb structure. By processing soil and organic residues through their gut, clay and organic matter are intimately mixed and coated with organic stabilizing gums and lime secreted from a special gland within their digestive tract. The result, the worm cast, consist of the type and size of water-stable soil aggregate needed to provide adequate water holding capacity, aeration and nutrient reserves for plant growth (Lampkin, 2002). Earthworms cannot tolerate soil acidity, the use of ammonium sulphate, certain herbicides and fungicides, rotary cultivators and the failure to retain sufficient organic residues in the soil (Hansen and Engelstad, 1999).

According to the Soil fertility review of ADAS[24], HDRA (Henry Doubleday Research Association, IGER (Institute of Grassland and Environmental Research) and UWB (University of Wales Bangor), there is no straightforward relationship between soil management and earthworm populations because there tends to be an interaction between several factors ["confounding variables"] (Sheperd et al, 2000).

For example, even if there have been some reports of fertilizers reducing earthworm populations, Edwards & Lofty (1982) found larger populations with mineral N fertilizers: this was attributed to greater production of crop residues and roots, with the additional organic matter

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[24] ADAS: Established as the State Advisory Service in 1946 and subsequently becoming the National Agricultural Advisory Service of the then Ministry of Agriculture, Fisheries and Food. ADAS became an Executive Agency of MAFF in 1992 and a private company in 1997.

encouraging worms. Edwards & Lofty (1982) suggest that reports of adverse effects of fertilizer may be associated with acidification, rather than the fertilizer per se, since **earthworm population decreases with increasing acidity** . Another example of the complexity of factors is that white clover, which is commonly grown as a cover crop, has been found to inhibit worm activity (Lampkin, 2002) but, overall, organic agriculture tends to favor earthworms because of other specific beneficial management practices: more organic matter additions, different leys systems, less use of pesticides, etc.

There is indeed still a great deal to be learned about the interactions between type and quantity of fertilizer use, crop grown, cultivation practice and earthworm activity. Research by Edwards and Lofty (1982) at Rothamsted, and other research papers quoted by Lampkin, N., (2002), found that straw removal and certain cultivation techniques could have an adverse effect on earthworms and other soil organisms. They also found that the species of earthworms were more numerous in plots treated with organic fertilizers than in untreated plots. There was a strong positive correlation between the rate of mineral N applied and populations of earthworms, probably because of the increased production of roots and residues, although organic fertilizers increased earthworm population much more than mineral N sources. However, plots **receiving both organic and mineral N had the largest population of earthworms.**

A study carried out by Hansen and Engelstad (1999) showed the negative influence on earth worm population of tractor traffic, **soil acidity and low organic material soil content.**

All this suggests that the application of a non-acidifying nitrogen fertilizer as Natural Chilean Nitrate, in combination with standard organic farming practices, should rather have a **positive effect on earthworm population** and other macrofauna.

### *3.1.4.3 Flora*

- **Rothamsted Park Grass Experiment, United Kingdom**

The Rothamsted Park Grass Experiment, started in 1856, consist of a hay meadow divided into adjacent plots receiving different fertilizer treatments. Botanical analysis of samples of the hay has been undertaken at irregular intervals since 1862. These samples were grouped and classified according to the British National Vegetation Classification using the computer program MATCH. The control plots matched to community MG5[25] for almost all individual years. Plots receiving mineral fertilizers, but no nitrogen, were more variable than the controls but still gave MG5 or MG3[26] as the main community each year. **The plot receiving the lowest level of sodium nitrate fertilizer (40 kg N/ha) and the plot receiving FYM every fourth year also remained as MG5 or MG3.** The other plots receiving nitrogen**, especially in the form of ammonium sulphate**, were much more variable with individual years giving best matches to communities from either mesotrophic grassland, sand dunes, mires, upland, or woodland. Generally the plots moved to a MG7D[27] or MG1E[28] community between 1900 and 1949. In the most recent surveys some of the plots matched to the scrub community W23 (Dodd et al, 1994).

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[25] MG5: *Cynosurus cristatus-Centaurea nigra* grassland, but can be more diverse

[26] MG3: *Anthoxanthum odoratum-Geranium sylvaticum* grassland.

[27] MG7D: *Lolium perenne leys* & related grasslands

[28] MG1E: *Arrhenatherum elatius* grassland

The Lolium species declined and disappeared between 1877 and 1903, not only on acidified plots, but also on plots fertilized with non-acidifying sodium nitrate. Thurston et al. (1976) explain this by the fact that the genotype of Lolium present at Park Grass developed under grazing and was therefore not well adapted to a hay regime, used during the experiments.

The plot receiving the lowest level of solely nitrogen fertilizer (40 kg N / ha) as ammonium sulphate showed some degree of acidification in the early years and by 1923 it had a pH of 4.8 compared to 5.7 in 1856; by 1984 the pH had declined further to pH 3.7 indicating considerable acidification (Johnston et al., 1986). This plot achieved the extremes of botanical composition and was completely dominated by either *Festuca rubra, Agrostis capillares* or *Anthoxanthum odoratum*. As indicated above, **the long-term use of 40kg N/ha as sodium nitrate had no effect on the botanical composition and relatively small changes in soil pH were shown to have large effects on botanical composition.**

- **RAC and ADCF trials, Switzerland**

In a collaboration between RAC (Station Fédérale de Recherches en Production Végétale de Changins and ADCF (Association pour le Développement de la Culture Fourragère), two trials were started in 1993 on two permanent meadows ("La Brévine" and "Vuissens") in the Swiss Jura. During 6 years, the effects of various organic fertilizers (cattle slurry and farm yard manure) were compared with those of mineral fertilizers, including ammonium nitrate.

The conclusions were:

- The botanical composition was little influenced by the fertilization treatment;
- At one site legume population increased with mineral fertilizers (ammonium nitrate and PK's) and decreased with organic fertilizer treatment.
  At the other site the opposite effect took place but to a lesser degree.

### *3.1.5 Summary : maintaining long term fertility*

- It has been shown that the complementary use of Natural Chilean Nitrate does not negatively affect the **soil structure** neither through nitrate nor through sodium. It may positively affect soil structure due to increased OM generated by increased yields.
  The situation may be different for: ① rain fed farming with limited rainfall in semi arid and arid envi ronment with no irrigation, ② in areas irrigated with water with a high sodium content and ③ in soils with poor internal drainage, where sodium may tend to accumulate in the soil profile.
- Every farmer, conventional or organic, has the responsibility of reducing N losses as much as possible by adapting his cultivation plan and cultivation practices. Sometimes it is not pos-

sible to ensure enough nitrogen uptake using only organic manures. This does not mean that organic manures should be substituted, on the contrary. They assure a good humus content and soil structure and can often provide a part of the crop nitrogen needs. Therefore they are indispensable, even in conventional agriculture and of course they represent an important link in the N-cycle albeit not a perfect one.

Any fertilizer that increases controllability (i.e. **N-availability and N-efficiency**) in harmony with current organic practices will reduce the impact on the environment. As was amply demonstrated in this section and section 1, Natural Chilean Nitrate fulfils this requirement.

- Two amendments with the same $N_{tot}$, $N_{min}$ and $N_{org}$ content, the one with the highest humus building capacity potential will have the lowest N supply capacity and this more then proportionally. 50 Kg N in the form of Natural Chilean Nitrate could go a long way towards replacing some of this excess tonnage of organic fertilizers applied as N-fertilizer in stead of amendment.
- It is very difficult to conclude that a single fertilizer (mineral or organic) has (only) positive or (only) negative or neutral influences on biological cycles and this because of their complexity and the interaction of several factors.

  An important factor is the size and activity of the **microbial biomass** in the soil. Pesticide use, crop rotations, fertilization levels (manure and mineral), fertilization frequency, cropping frequency, green manuring, etc. can all influence microbial activity. There are however strong indications that the use of Natural Chilean Nitrate, at least on a complementary basis, will positively affect microbial biomass due to its neutralizing effect and increased organic residues.

  The same can be said about **micro-, meso-, and macrofauna.**

- Finally, it was demonstrated that Natural Chilean Nitrate, as a non-acidifying N source, would not have an effect on the **botanical composition** (of meadows and prairies).

## 3.2 Minimizing all forms of pollution

### *3.2.26 Nitrates*

The ecological consequences of the use of nitrogen have largely been discussed in section 1 (§ 1.2.1) and section 3 (§ 3.1.3).

When Natural Chilean Nitrate is applied it is possible to exert a high level of control over the quantity and timing of the resulting level of available nitrate in the soil. Experiments using labeled nitrogen $^{15}N$ demonstrated that split applications of Natural Chilean Nitrate can be synchronized with the rate of nitrogen uptake of the crop thus minimizing the available nitrate left in the [soil] profile after harvest that may be subject to leaching and be harmful to the environment (Riga et al., 1988).

Nitrate leaching will occur only when it is not used properly, that is, when (a) the rate of application is greater than what is necessary according to the type of crop and soil conditions, and, (b) the application schedule and / or availability of the nitrogen is out of synchronization with the rate and timing of nitrogen uptake by the crop.

Natural Chilean Nitrate should not be disposed of as it can be stored for longer periods to be used in subsequent seasons. No alteration of its characteristics will take place as long as common mineral fertilizer storage prescriptions are met.

### *3.2.2 Perchlorates*

Perchlorate is an inorganic anion that is both man-made and naturally occurring. Perchlorate is manufactured to be used, among other uses, as an oxidizing agent and primary component in solid propellant for rockets, missiles, fireworks, and automobile air bag inflators. Years of manufacturing, testing, and improper disposal by these industries have resulted in widespread perchlorate presence in the Colorado River and ground water in California and some other states in the USA. No other documented perchlorate contamination sites have been found elsewhere in the world.

Residual traces of perchlorate are found in fertilizers produced from caliche ore. Those quantities are so small that Natural Chilean Nitrate is not considered in any way as a contributing perchlorate contaminant, by both the EPA[29] (EPA, 2002) and TFI[30] (TFI, 2002).

### *3.2.3 Heavy metals*

The presence of certain heavy metals in fertilizer products has prompted public concern about the safety of fertilizers. Although heavy metals occur naturally in all agricultural soils – and some (such as copper and zinc) are vital plant nutrients – there have been numerous calls to impose more stringent regulations on the fertilizer industry.

- **Cadmium (Cd )**

Much of this attention on heavy metals focuses on phosphate fertilizers, which may carry varying amounts of toxic lead (Pb), cadmium (Cd), as well as Zn and Cu. Arsenic (As), chromium (Cr), mercury (Hg), uranium (U), and vanadium (V) may also be present (Table 29). Pb and Cd pose the greatest environmental and health hazards, but Cd causes the most concern, as a result of its persistence in the environment and its relatively rapid uptake and accumulation in food chain crops.

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[29] EPA: United States Environmental Protection Agency

[30] TFI: The Fertilizer Institute

## Table 29:
## Cadmium and other toxic element levels in different rock phosphates (Lijmbach and Thornton, 2000)

| Country | Deposit | P2O5 (%) | Cd (ppm) | | | As | Cr | Hg | U | V |
|---|---|---|---|---|---|---|---|---|---|---|
| | | (wt %) | mg/kg ore | **mg/kg P2O5**(1) | mg/kg P(2) | (ppm) | (ppm) | (ppb) | (ppm) | (ppm) |
| Israel | | 32 | 25 | **78.1** | 179.2 | 5 | 227 | 130 | 150 | 200 |
| Jordan | | 32 | 5 | **15.6** | 35.8 | 8 | 92 | 48 | 78 | 70 |
| Morocco | Bu Craa | 35.1 | 37.5 | **106.8** | 245.1 | | | | 75 | |
| | Kouribga | 32.6 | 15.1 | **46.3** | 106.3 | 13.4 | 200 | 855 | 88 | 106 |
| | Youssoufia | 31.2 | 29.2 | **93.6** | 214.7 | 9.2 | 255 | 120 | 97 | 200 |
| Togo | | 36.7 | 58.4 | **159.1** | 365.0 | 10 | 101 | 365 | 94 | 60 |
| USA | Florida | 31.9 | 9.1 | **28.5** | 65.4 | 11.3 | 60 | 199 | 141 | 108 |
| | Idaho | 31.7 | 92.3 | **291.2** | 667.9 | 23.7 | 290 | 107 | 107 | 769 |
| | N. Carolina | 29.9 | 38.2 | **127.8** | 293.1 | 11.2 | 158 | 233 | 65 | 26 |
| South-Africa | | 39.5 | 2 | **5.1** | 11.6 | 11 | | | 9 | 17 |
| Tunisia | | 29.3 | 39.5 | **134.8** | 309.3 | 4.5 | 144 | | 44 | 27 |
| Senegal | | 35.9 | 86.7 | **241.5** | 554.0 | 17.4 | 140 | 270 | 67 | 523 |
| Australia | | 28.9 | 4 | **13.8** | 31.8 | 14 | 35 | 75 | 84 | 63 |
| Syria | | 31.9 | 3 | **9.4** | 21.6 | 4 | 105 | 28 | 75 | 140 |
| Russia (3) | Kola | NA | NA | **2** | 4.58 | NA | NA | NA | NA | NA |
| China | | 31 | 2.5 | **8.1** | 18.5 | 26 | 33 | 4990 | 22.8 | 80 |

(1) Authors calculations: mg/kg $P_2O_5$ = mg/kg ore divided by % $P_2O_5$ x 100
(2) Authors calculations: mg/kg P = mg/kg $P_2O_5$ x 2.294
(3) CMC-Engrais Comité Marché Commun de l'Industrie des Engrais Azotes et Phophates, Brussels, 1986. Note de synthèse sur des engrais phopshatés et le cadmium. GB-JAl.

The legal limits set for Cd in phosphates can differ between countries. In Switzerland, for example, the legal limit is 50 mg /Kg P i.e. 21 mg/Kg $P_2O_5$ which translates in about 6,5 mg/kg ore. The average cadmium content of all types of rock phosphates in Table 29 is 90 mg Cd per kg $P_2O_5$. According to Mortvedt and Beaton (1995), rock phosphates commercialized in the EU contain on average 45 mg Cd/Kg ore or 150 mg Cd per Kg $P_2O_5$ and therefore on average, they are out of the legal limits in almost all countries (Figure 45). Most organic organizations set limits for the Cd level at 90 mg Cd Kg/$P_2O_5$, which is higher then the EU directive of 60 mg/kg $P_2O_5$ (EU, 2003).

Rock phosphates used for direct application are the sole source of mineral P authorised in organic agriculture. These rock phosphates must have a minimum reactivity to be useful as a fertilizer. Legally binding minimum reactivity levels have been established in many countries. In the EU and in Switzerland the minimum reactivity is 55% solubility in 2% formic acid (Commission of the European Communities, 2001 and Ordonnance du DFE du 28/02/2001 sur la mise en circulation des engrais, Swiss Law SR 916.171.1).

There are 2 main types of phosphate ores; sedimentary (about 80% of world production) and igneous (about 20%) (IFDC & UNIDO,1998).

- Sedimentary apatites (francolites) have some reactivity and when finely grinded can generally be used (but only in acid soils) for direct application i.e. they mostly have the minimum formic acid solubility of 55%. Unfortunately Cd content is high in sedimentary apatite (Figure 45) and mostly above national maximum legal levels.

- Igneous apatites are found in Russia, Scandinavia, South Africa, Brasil and Jordan. Cd levels in igneous apatites are low and within legal limits. Unfortunately even when finely grinded, these hard crystalline rocks cannot be used legally for direct application even in acid soils (Gros, 1979, page 161).

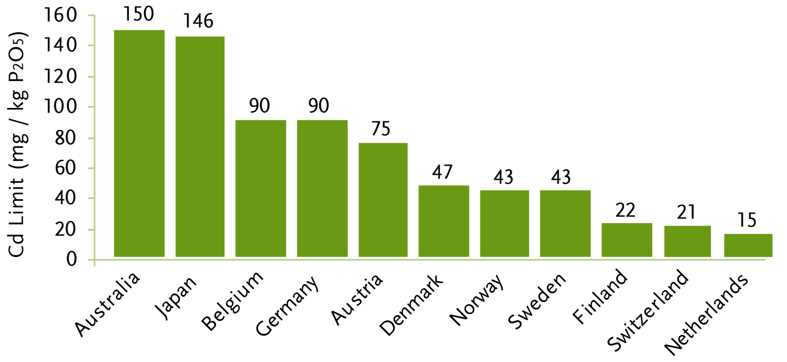

**Figure 45:** Regulated or proposed legal maximum limits of cadmium (Cd) in fertilizers (Fertilizer International, 1999 based on the Potash and Phosphate Institute)

Several techniques are being studied to lower the heavy metal levels. The use of ion exchange, solvent extraction and liquid membrane extraction are promising but not yet used on an industrial scale appearently because of cost considerations.

Also it is not certain that these processes would respect the principles of organic agriculture.

- **Chromium (Cr)**

Basic slag contains up to 25,000 mg Cr/kg P, far more than the legal Swiss limit of 2,000 mg Cr/kg P (Schärer, 1987).

- **Heavy metals in Natural Chilean Nitrate**

Heavy metal content in Natural Chilean Nitrate is extremely low and should be of no concern.

**Table 30:**

**Heavy metals (ppm) in Natural Chilean Nitrate, (SQM analysis if not indicated otherwise) and other organic approved fertilizers**

| | Natural Chilean nitrate | Rock phosphate(1) | Basic slag(2) | Manures(3) (4) | | |
|---|---|---|---|---|---|---|
| | | | | Beef | Pig | Broiler/Turkey litter |
| Cd | < 0.01 | 2 – 92 | < 1 | 0.14 | 0.68 | 0.38 |
| Cr | 0.6 | 257 | 1857 | 1.5 | 1.87 | 7.53 |
| Pb | 0.84 | NA(6) | 600 | 11.3 | 12.8 | 23.7 |
| HM (5) | 5 | NA | NA | NA | NA | NA |

(1) Lijmbach and Thornton, 2000
(2) Acepsa, 1983. Analyses, Conseils et Production SA. Laboratoire de chimie et microbiologie Technologie et production alimentaires, Switzerland.
(3) MAFF. (1994). Fertilizer Recommendations for Agricultural and Horticultural Crops, Reference Book 209. HMSO, London. In: Chambers, B.J., et al. Heavy metal loadings from animal manures to agricultural land en England and Wales.
(4) Menzi and Kessler, 1999
(5) HM = total heavy metal (including Cd and Pb) content expressed as Pb
(6) NA : Not available

### *3.2.4 Summary : minimizing all forms of pollution*

Natural Chilean Nitrate is one of the least contaminant natural sources of fertilizer nitrogen and mineral fertilizers in general. Traces of natural perchlorate are found in fertilizers produced from caliche ore. Those quantities are so small that Natural Chilean Nitrate is not considered in any way as a contributing perchlorate contaminant. Heavy metal content is of no concern either.

On the other hand, under par doses of organic fertilizer will translate, as shown, into unsatisfactory yield and consequently the need of a higher acreage as a compensation.

This will in turn to higher eventual contamination per unit weight of produce.

### 3.3 Conclusion and Score Evaluation

- **Soil Structure and Aggregate Stability**

There is no indication that (complementary) use of Natural Chilean Nitrate would have a negative effect on soil structure and aggregate stability except for ① rain fed farming with limited rainfall in semi arid and arid environment with no irrigation, ② in areas irrigated with water with a high sodium content and ③ in soils with poor internal drainage, where sodium may tend to accumulate in the soil profile.

However the rise in yield caused by a better synchronization of N availability with plant needs implies a larger OM input through more abundent crop residues, which should have a positive influence on SOM and consequently on soil structure.

- **Nitrogen Influx and Controllability**

Any fertilizer that increases controllability (i.e. a controlled N-availability and N-efficiency) in harmony with current organic practices will reduce the impact on the environment. In this context, Natural Chilean Nitrate again will be a very valuable complement.

- **N Supply Capacity**

Two amendments with the same $N_{tot}$, $N_{min}$ and $N_{org}$ content, the one with the highest humus building capacity potential will have the lowest N supply capacity and this more then proportionally. 50 Kg N in the form of Natural Chilean Nitrate could go a long way towards replacing some of this excess tonnage of organic fertilizers (amendments).

- **Ecological Impact related to soil structure and aggregate stability**

It has been shown over and over again throughout this paper that the concentration of nitrate and sodium, when Natural Chilean Nitrate is applied judiciously, will remain well within the range of their natural presence in most soils and under most climates.

- **Influence on Biological Cycles**

Few specific long term trials have been carried out in order to determine the influence of different **farming** systems on the microbial biomass in particular and on biological cycles in general. Even then, such studies can hardly be used to try to extrapolate the specific influence of different **fertilizing** systems or fertilizers and this because of “confounding variables”.

What has been demonstrated is that judicious use of Natural Chilean Nitrate should not negatively affect organic matter content and the pH, on the contrary.

As is our understanding, in the DOC trial only those 2 parameters have been shown to affect the microbial biomass.

The same argument and reasoning applies for the biological cycles involving the other organism.

- **Contaminant Risk**

Natural Chilean Nitrate is one of the least contaminant among the natural sources of fertilizer nitrogen.

When Natural Chilean Nitrate is applied, it is possible to exert a high level of control over the quantity and timing of the resulting level of available nitrate in the soil. Experiments using labeled nitrogen $^{15}N$ demonstrated that split applications of Natural Chilean Nitrate can be synchronized with the rate of nitrogen uptake thus minimizing the available nitrate left in the soil profile after harvest that may be subject to leaching and be harmful to the environment.

Residual traces of perchlorate are found in fertilizers produced from caliche ore. Those quantities are so small that Natural Chilean Nitrate is not considered in any way as a contributing perchlorate contaminant.

Heavy metal content is negligible and even lower than in average manures. This is in contrast to some already approved mineral fertilizers that may exceed some legally imposed limits in some countries.

- **Overall score**

| | Soil Structure and Aggregate Stability | Nitrogen influx and controllability | Impact on biological cycles | Contaminant hazard | Solubility |
|---|---|---|---|---|---|
| Natural Chilean Nitrate | 1-2 | 3 | 2-3 | 3 | n/a |

Scale: 0 (poor) →3 (good)
n/a: not applicable

**Solubility** of fertilizer in general and N fertilizer in particular seems to be considered a negative feature in organic agriculture.

However the **intended use** of Natural Chilean Nitrate in organic agriculture should be to improve N efficiency and decrease N losses during some critical growing stages and by the same token improve crop quality and yield.

At these particular growing stages this can **only** be achieved if that N source is plant available and thus present in the soil solution.

Therefore solubility is **essential** in this context and, to avoid any misunderstanding, the solubility score has not been filled in.

## 4.1 Potential Positive Effects of Usage of Natural Chilean Nitrates

### *4.1.1 Nitrate*

As demonstrated in Section 1, by providing available nitrogen during critical growing stages, Natural Chilean Nitrate improves the quality of certain crops through for example increased protein and essential micro-elements content.

### *4.1.2 Iodine*

The negative effects of iodine deficiency on reproduction in livestock have already been recognized in the early sixties by Calderbank (1963). His findings were confirmed by Hemken (1970) and Underwood (1971). Nowadays, the negative effects on livestock of iodine deficiency are fully recognized. Therefore there's a need for a sufficient supply of iodine to (forage) crops. Especially for animals dependent entirely on grazing for their food supply, a small extra input of iodine can be sufficient to ensure a satisfactory intake of supplementary iodine (Underwood, 1971).

The World Health Organization (WHO) considers **iodine, vitamin A and iron** as very important in global public health terms; their lack represents a major threat to the health and development of populations the world over, particularly to preschool children and pregnant women in low-income countries (www.who.int). Also the western world does not seem to be spared (Artsen Krant, 2003). The solution for this problem lies according to the WHO in iodizing salt. A first step could already be made by making sure that the food consumed contain higher iodine content which would be more in line with the organic agriculture holistic view. Also this would be particularly helpful for persons on a low salt diet. Natural Chilean Nitrate contains a significant amount of iodine (125 ppm, SQM data).

### 4.1.3 *Na-effect in pastures*

Herbivorous animals generally, but ruminants in particular, can exist in a state of metabolic mineral imbalance. This is because a diet derived from plants contains little sodium but a great deal of potassium. The Na/K ratio often widens over the grazing, especially when excess potassium salts are included in fertilizers (Bell, 1995). According to Chiy and Phillips (1995a), the occurrence of **sodium deficiency** is most likely in:

Lactating livestock which are more prone to Na deficiency because of the high Na loss in milk.

Rapidly growing livestock with a high level of retention of Na in fluids and tissues.

Grazing animals under tropical and semi-arid conditions where pasture Na contents are low and transpiration losses are large.

Animals grazing pasture enriched with potassium trough unbalanced manure on sandy soils or on soils naturally rich in K. Since some forages grow satisfactorily at very low Na levels and plants normally exhibit luxury uptake of K, livestock may consume forages that are low in Na but containing K levels which are in excess of animal needs.

Tests showed that when sodium deficiency develops, food consumption and water intake are reduced. The initial sign of Na deficiency is the development of a depraved appetite or pica which manifests itself in an intense craving for salt and can cause the Na-deficient animal to avidly lick wood, soil or the sweat and urine of other animals (Bell, 1995).

In a prolonged deficiency, loss of appetite is accompanied by the development of a haggard appearance, lusterless eyes and a dry and harsh coat. A classic example of Na deficiency symptoms in a herd of 45 lactating Holstein-Friesian cattle was reported by Whitlock et al., (1975). The cows showed polyuria associated with a 40% decrease in herd milk production.

The effects are similar in sheep and goats. The efficient conservation mechanisms of these animals make them less-prone to Na deficiency and only in cases of severe deficiency are the signs of Na deficiency manifested (Chiy & Phillips, 1995a).

Mild and transient Na disorders have a greater effect on animal production than acute deficiencies because they occur over wider areas, affect a large number of animals and are easily confused with the effects of energy and/or protein deficiencies and various types of parasitism (Underwood, 1981).

There are several methods for preventing sodium deficiency, as there are sodium supplements in food, salt blocks and salt licks, addition of salt to water. These direct methods have the disadvantage of an often inaccurate allocation to individual animals. Next to these direct methods, one can also provide Na indirectly by using fertilizer containing Na. Natrophiles such as perennial ryegrass (*Lolium perenne*) will readily accumulate relatively large amounts of Na in their roots and will usually exhibit a growth response to Na fertilizer (Chiy & Phillips, 1995b). The Na can substitute for K and be translocated to the shoot in sufficient quantities to contribute significantly to maintenance of cell turgor (Mengel, 1982). In contrast, natrophobic forages such as Zea mays preferentially accumulate Na in the root system or lower aerial tissues, with the result that only small quantities of Na pass up to the leaves (Chiy & Phillips, 1995b).

Natural sodium nitrate could be used as a source of **Na on pastures** in regions where Na-deficiency in animal husbandry is noticed. A single application of 400 kg Natural Chilean Nitrate (26% Na) can maintain herbage Na levels above the critical value of 1.5 g Na / kg DM necessary to meet the requirements of dairy cows (Lehr et al., 1963).

However this could only be helpful for grassland since for yearly crops, leaching of Na would be too important.

## 4.2 Potential negative effects

### *4.2.1 Nitrate*

- **Ground water nitrate levels**

Negative impact of soil nitrates on aquatic life, human or animal health and water may result when nitrates are leached to the subsoil and contaminate the groundwater. However, as indicated in former chapters, nitrate leaching occurs only when it is not used properly, that is, when the rate of application and availability is larger than the needs under existing soil conditions, and, availability of nitrogen in the soil is out of synchronization with the rate and timing of nitrogen uptake by the crop (Havlin, Beaton, Tisdale & Nelson, 1999; McGill & Myers, 1987; Zihlmann et al., 2003; Walther, 2001). The nitrate leaching can come from various sources, and is mainly caused by fertilizer management practices (Vlassak & Agenbag, 1999; Ryser et al., 1998; Kirchmann & Bergström, 2001)

As explained elsewhere (section 1) in this document, Natural Chilean Nitrate, when used as intended, is one of the **least contaminant** among the natural sources of fertilizer nitrogen.

- **Crop Nitrate levels**

Even though recent studies have not been able to confirm the formally found link between nitrate consumption in e.g. cancer, it is generally accepted that nitrate levels in crops should be kept low.

Nitrates accumulate in plants due to several factors (amount of sunshine, temperature, pluviometry, irrigation and N fertilization rate).

The N fertilization and sunshine rate are the determining factors of nitrate accumulation in vegetables which on their turn contribute for 80% of the nitrates in human nutrition. Analysis of available data show that vegetables produced organically in general contain less nitrate. (AFSSA, 2003; p. 126). This needs to be confirmed by new research taking into account the [recent] evolution in [conventional] agriculture practices, particularly for N fertilization and should also be examined taking into account the conclusions about the current reevaluations concerning nitrate toxicity (AFFSA, 2003; p. 127).

Besides N-fertilization, light, plant species, variety and plant organs, further factors determine the nitrate content (Figure 46). Those are yield, diseases, ripeness, soil, temperature, moisture, conditions of harvesting, storage and processing. The nitrate content in the vacuole sap is also altered by the supply of different nutritional ions and the formation conditions of other osmotics in the plant (Scharpf, 1991).

Practices such as integrated (low input) production, soil plant system simulation models, split N-application, soil (N-min) and crop N-testing have all greatly contributed in minimizing nitrate accumulation in vegetables.

**The judicious use of both organic N and Natural Chilean Nitrate, managed as part of a "system approach" will favor the optimal outcome.**

**Figure 46:** Factors of the nitrate content in plants to be considered in the system approach (Scharpf, 1991)

### *4.2.2 Perchlorates*

Natural Chilean Nitrate is used in agriculture since over 100 years and has not, contrary to other organic (N) fertilizers, been a source of harmful chemical or microbial contamination. Residual traces of natural perchlorate can be found in fertilizers produced from caliche ore.

Following the perchlorates industrial pollution problem in the USA at the end of nineties (see § 3.2.2) US EPA (2002a) and TFI (2002) studies have refuted the fact that Natural Chilean Nitrate could be a contributing factor in perchlorate contaminated surface and ground water.

## 4.3 Conclusion and Score Evaluation

Both iodine and sodium have a positive influence on livestock. Some plants (Natrophiles) can respond positively to complementary sodium. Iodine is an essential element for humans.

Good nitrate husbandry can lead to better quality of the crops, e.g. higher protein content in grains.

Natural Chilean Nitrate is one of the least contaminant among the natural sources of fertilizer nitrogen, provided that the quantity being applied corresponds to the real needs of the soil/plant system, and, , the timing of application is synchronized with the proper rhythm of nitrogen uptake by the plant along its growing cycle.

- **Overall score**

| | Potential positive effects (if properly used) | Potential negative effects (if improperly used) |
|---|---|---|
| Natural Chilean Nitrate | 2 | 2 |

Scale: 0 (poor) →3 (good)

# Section 5:
# Socio-economic factors and values (ethics)

## 5.1 Socio economic reflections

As shown in previous chapters, complementary use of Natural Chilean Nitrate will allow the organic farmer to produce better yields at higher quality and a greater variety of produce. At the same time the environmental score card of organic agriculture will be improved.

This and the access to a more economic source of N will give the farmer a competitive advantage in the market place and an even better image towards the consumer.

Local production will have a much better chance to succeed even in less favorable growing conditions.

The economic advantages can also be approached from a different angle asking the following kind of questions:

Knowing that 1kg N produces around 20 kg wheat (assuming average yields) (Finck, 1979; p. 231) what is preferable in the point of view of socio economic and environmental criteria?

- Either importing from overseas the organic wheat or importing 30% of this quantity in equivalent Natural Chilean Nitrate (20kg wheat for 1kg N or 3-4kg Natural Chilean Nitrate) both from overseas and both by vessel?
- Flying in by plane early vegetables (in crates and the crates in an air shipping container) instead of a much smaller quantity of Natural Chilean Nitrate in bulk by vessel?

Even when not considering **environmental and sustainability criteria ("food-miles")**, the mere **economic arguments** above call for the local fertilizer option.

Nevertheless in Switzerland for example over 95% of organic cereals are imported from overseas (Swiss import export statistics, Direction générale des douanes, Bern, 2002). It would be worth it to produce those cereals locally (Cahiers de la FAL 45, 2003; p. 26).

This will only be feasible if the quality will be up to baking standards and this as demonstrated in sections 1 and 3 is only possible with adequate N-fertilizer.

A similar reasoning could be used for early vegetables and other crops.

Furthermore, for vegetables in particular, the ultimate beneficiary will be the consumer since they will have a steady supply of fresh organic farm product during a longer period of time and even year-round in some regions.

## 5.2 Values (ethics) of organic farming related to the usage of Natural Chilean Nitrate

The organic farming movement originated as a response to the systemic problems that modern society and modern agriculture are faced with, and it is based on a holistic perception of nature, where humans and human society are perceived as an integrated part of nature. From the beginning, sustainable agriculture was conceived as closely connected to health as part of a continuum through soil, plant, animal and man. The values and principles of organic farming stem from this way of thinking.

The special values have been formulated as three basic interrelated "principles of acting" (Alroe and Kristensen, 2001):

**The cyclical principle**, stating that physical co-operation with nature should be performed by way of using, improving or establishing cyclical processes.

**The precautionary principle**, which states that decisions on new practices and technologies should reflect the limitations of knowledge as well as the established knowledge, and that actions should be taken to prevent future problems.

**And the nearness principle**, which states that good social relations between producers and consumers should be secured through direct, experiential interaction and transparent, informative communication.

With respect to the more widely used environmental principles for development, organic farming has a special conception of ① **sustainability** (which has been termed 'functional integrity') and ② **of risk** and ③ **decision making** (characterized as the precautionary principle). Given that there are special values and principles of acting in organic farming, how well are these expressed in practice for Natural Chilean Nitrate?

### *5.2.1 The Cyclical Principle*

It is generally agreed that the prohibition of artificial (synthetic) fertilizer, and the development in manure practices are found to be in line with the cyclical principle.

In order to act according to the cyclical principle farmers are being encouraged to plant cover crops in winter, avoid poor cropping practices, and plant "buffer" vegetation between fields and water courses to trap nitrogen run-off. Legumes, "free" natural fertilizers are introduced into crop rotations. Ploughing of residues back into the soil also assist in maintaining soil structure and fertility. However still there are opportunities for almost all organic farmers to improve the efficiency of nutrient cycling on the farm and increase short-term productivity and long-term sustainability.

Due to a lack of synchronization and synlocation of the mineralization with some critical growing stages, the N-supply can be insufficient and an N-gap often exists.

During the critical stages Natural Chilean Nitrate can compensate for this inherent and natural net loss in the N-cycle in a similar way as prescribed in the organic principles for S fertilization (S-cycle net loss compensation). Consequently, with the judicious dosage and correct timing, **Natural Chilean Nitrate will assist the natural systems and cycles.**

### *5.2.2 The Precautionary Principle*

*"An investigation of the development of organic farming and the use of different practices and technologies shows that, for instance, there is a good correspondence between the actual development and the precautionary principle in plant production i.e. machine technology with foreseeable consequences is largely accepted, while chemical and biological technologies with less foreseeable consequences are avoided."*

The consequences of using Natural Chilean Nitrate are foreseeable. Long–term trials with Natural Chilean Nitrate showed no negative and/or unforeseeable effects on soil fertility, soil aggregate stability, pH, salinity, biological life, pollution etc. Also related to ecological impact - controllability and quantity of the nitrogen influx - the consequences are foreseeable and positive.

Plant nutrition systems, using Natural Chilean Nitrate as complementary nitrogen source, could prove important in effective management of plant nutrients as an element of broader organic agricultural development. They can be designed to balance the nutrients available, resulting in greater N efficiency , and minimize "leakage" of minerals into the wider environment.

### *5.2.3 The Nearness Principle*

*"The development in trade, distribution, and marketing seems to be at odds with the nearness principle, and it puts large demands on the mechanisms of control and certification as means of maintaining consumer confidence in the organic qualities. And what about the organic producers?"*

Using Natural Chilean Nitrate in organic systems could help to meet specific farming needs, yield and quality targets, the physical resource base, and the farmer's socio-economic background. Organic farmers could achieve higher financial returns and at the same time bring him or her nearer to the consumer ("image of proximity").

### *5.2.4 Alternative view on specific values and ethical principles*

All what is written above has been expressed on a different but masterly manner by Colin Tudge in his recent famous book:

"**So Shall We Reap**" (How everyone who is liable to be born in the next ten thousand years could eat very well indeed ; and why, in practice, our immediate descendants are likely to be in serious trouble).

Following some specific values and ethical principles of organic farming related to the usage of Natural Chilean Nitrate set against and preceding some corresponding excerpts of this book.

(Note : For clarity we have replaced the word "artificial (s)" by "mineral")

### *5.2.4.1 The Nature of the Problem and the Meaning of Agriculture (excerpts from Chapter 1)*

- Section 1 and 3 demonstrated that the **tempered use** of Natural Chilean Nitrate conforms to the demands of **biologic reality** and therefore is an essential tool in **enlightened** organic agriculture inspired by **good husbandry.**

*"We can reasonably suggest that agriculture that does play to the strengths of the animals, plants and landscape, and is structured to interrupt or pre-empt possible chains of infection, is **good husbandry.** Farming that deploys good husbandry, and which can therefore feed everybody well, and in principle can do so for ever, might reasonably be called **"enlightened"**. It seems enlightened, after all, to want to feed people well; (and wicked or at least perverse to farm in ways that detract from this goal)" (page 87).*

*"Farming practice that truly conforms to the **demands of biology,** and is **tempered** at least to some extent by morality and aesthetics, can reasonably be called **'good husbandry'**. An agricultural strategy based on good husbandry, deeply rooted in biological reality and shaped by morality and aesthetics, can be called enlightened" (page 99).*

- For certain countries and regions the use of complementary nitrate, as shown, stimulates **local biologically robust production** and therefore contributes greatly **to self-reliance in basic food** with a high general **standard of nutrition.**

*"A system of farming that was truly designed to feed people and to go on doing so for the indefinite future, would be founded primarily on mixed farms and **local production.** In general, each country would contrive to be self-reliant in food. **Self-reliant** does not mean self-sufficient" (page 88).*

***"Self-reliance** does mean, however, that each country would produce its **own basic foods,** and be able to get by in a crisis" (page 88).*

*"(...) if all the world's countries opted for systems of agriculture that were aimed at national **self-reliance,** with trade restricted mostly to non-essential delectable, and achieved this primarily via the mixed farm, then world food production as a whole would be **biologically robust,** and the **general standard of nutrition** and gastronomy **could and should be very high** indeed – as high as it is possible to be" (page 89).*

- As shown, Natural Chilean Nitrate **bridges** a gap and the nitrogen cycle. Promoting the use of Natural Chilean Nitrate will certainly help the Organic Movement toward providing what the [whole] world needs.

*"The **organic movement** has ramifications that run far beyond food, deep into the philosophy of science, morality, aesthetics and religion; and partly for those very reasons, it has all too often been dismissed by the orthodox and the strait-laced, as "muck' n mystery". But it deserves to be taken **very seriously.** Enlightened agriculture, expressly designed to serve all humanity for all time (and our fellow creatures), should surely incorporate and build upon many of the techniques and the broad ideas of the organic movement. Yet organic farming as it now stands does not quite provide what **the world needs.** [Kant test about ethical principles, pages 335 and 349].*

- The **judicious use** of nitrate has been advocated in this paper.

The specific "nature" of Natural Chilean Nitrate should, as shown, should be the **stepping stone** for it to become specifically recommended in organic circles.

*"Some great twentieth-century agricultural scientists, such as Sir George **Stapledon** and the Nobel laureate Sir John **Boyd Orr,** in many ways inspired the organic farming movement and yet did not formally sign up to it. In particular, **Stapledon and Orr** (and others) advocated **judicious use** of mineral fertilizers, expressly banned in organic circles" (page 338).*

*Like vegetarianism, [organic agriculture] can be seen more as a demonstration of what can be achieved outside the simplistic industrial approach; and also as a **stepping stone to truly enlightened agriculture.** This may sound a little lofty, even arrogant. But that's the way it is" (page 336).*

- Having **many people work on the land** is only possible when given the tools necessary to produce optimum yields at best quality. Natural Chilean Nitrate is one of those and therefore a very **positive proposition**.

*"Even more to the point, though, is the grand strategy and ethos of **organic farming.** Organic farming tends to be defined for legal purposes in negative terms (the list of technologies that may not be used). But this is **unfortunate.** Its **real message lies in positive propositions** that are very much in tune with the **requirements of enlightened agriculture,** as outlined in earlier chapters and summarized in Chapter II. Above all, organic farmers emphasize the principles of good husbandry. They believe (rightly) that good husbandry is intricate, and therefore requires a lot of people; and also perceive that **when many people work on the land,** some of the most enviable human communities result" (page 338).*

- Judicious use of Natural Chilean Nitrate certainly contributes, as demonstrated, to better ecology.

*"Organic farmers perceive that farming as a whole cannot be <u>sustained</u> in the long term unless it marches to the drum of* ***ecology****(...)" (page 339).*

- The tempered use of nitrate makes sense; its use in the form of Natural Chilean Nitrate makes it **sensible.**

*"(...)"****Sense and Sensibility".*** *That's what we need" (page 100).*

- Allowing or prohibiting Natural Chilean Nitrate should not be a **matter of dogma** but a matter of **sense and sensibility.**

*"Of course we would farm along enlightened lines,* ***with sense and sensibility"*** *(page 100).*
*" (...)matter of* ***dogma****(...)" (page 101).*

- The balanced use of Natural Chilean Nitrate at certain critical stages of plant growth will compensate for the natural lack of predictability and flexibility.

*"(...): the nutrient that crops require in greatest amounts (apart from carbon, oxygen and hydrogen which come from air and water) is soluble nitrogen, and of this there are four great sources [nitrogen* ***fixation, farmyard manure,*** *mineral nitrogen in the* ***soil, mineral fertilizer]"*** *(page 197).*

*"All in all, we need a* ***sensible balance*** *between the four. It has often been* ***suggested*** *that mineral fertilizers are too cheap for the world's good and are applied excessively, so that they run off and pollute waterways (or oxidize and pollute the atmosphere). So, beyond doubt, they have often done. But in Britain at least, studies at* ***Rothamsted*** *have shown that grassland ploughed for arable in the Second World War accounted for most of the nitrogen pollution that was manifest after the war. Grass is itself rich in nitrogen, mainly in the form of protein, and when it is ploughed in it dies,* ***and that nitrogen is released into the soil.*** *If the land is then left bare for any length of time, the nitrogen begins to run away into the groundwater.* ***Farmyard manure*** *carelessly applied can be* ***at least as damaging.*** *Mineral fertilizers come in convenient forms and with care can be applied in* ***exactly the right amounts exactly when and where they are needed,*** *and so in* ***principle can be least polluting of all, since they are taken up by the crops almost as soon as they are applied.*** *Yet it is clearly pernicious to use mineral fertilizers to the exclusion of all else simply because they are cheap and because they seem to represent modernity, and idle to deny the advantages of natural bacterial nitrogen fixation and of farmyard manure. All in all, then, the world needs to aim* ***for balance.*** *Sometimes this is achieved, sometimes not" (page 198).*

***"Nature*** *is wonderfully flexible, but – unlike human imagination and human conceit – it is* ***not infinitely flexible.*** *It has its own rules. It marches to the drum of* ***biology, and geology, and climate;*** *and* ***none of these*** *is exhaustively comprehensible, or precisely* ***predictable.*** *If the system of farming* *that any one society devises matches the requirements of biology and the physical environment, then that system of farming, and the society that creates it,* ***will survive"*** *(page 102).*

- Before the advent of synthetic fertilizers, mastodont machinery and synthetic pesticides and consequently the start of the vicious circle of ever increasing productivity at any cost, the entire world agriculture was basically organic (what else could it have been); at that time Natural Chilean Nitrate was used. Indeed this nitrogenous rock was used as "organic" fertilizer before its time.

*"Before Haber and Bosch, [synthetic (artificial) fixation of nitrogen] fertility had mostly been a matter for the farmers themselves, with* ***a little help*** *from(...)* ***nitrogenous rock*** *[Chilean Nitrate] (...)" (page 197).*

- In fact organic agriculture rules and regulations could have dogmatically forbidden the use of tractors powered by fossil fuels instead of horse traction contributing to the N-cycle (the Amish and Mennonite farmers still use horses instead of tractors and are doing apparently well). Organic agriculture rules and regulations however have been flexible enough to allow this on an optional basis.

  In contrast the real, proven and non-avoidable N-gap, as showed, has somehow to be filled It as just **plain good husbandry** and there is no other option here.

  It should be done with the fertilizer that best satisfies all other organic fertilizer criteria.

*"But the role of machines (like that of science, I suggest) should be* ***to assist good husbandry :*** *not to replace it with some unvarying and simplified routine. In the modern farm the tractors and the combines grow bigger and bigger. They also grow more expensive. The more that's invested, the bigger the yields have to be, to justify the costs" (page 92).*

- In short:

*"All in all, then, organic farming has a huge amount to offer. In strategy and ambition, and notably in its emphasis* ***on good husbandry,*** *it provides much of the model for the enlightened agriculture that the world needs" (page 351).*

*"Organic farmers are on the whole deeply committed to the general ideas of* ***enlightment,*** *(...) Hence, if we* ***support*** *organic farmers, then we know we are supporting enlightenment. But still it is* ***not sensible*** *to close the door to technologies that could further the grand cause simply as a matter of dogma of for legalistic convenience. Furthermore, as many farmers already demonstrate, it is possible to pursue excellence in husbandry (...) without being committedly "organic" (page 351).*

### 5.2.4.2 *Biology, Morality, Aesthetics: The meaning of Enlightened Agriculture (excerpts from Chapter 2)*

- Local production instead of imported is a guarantee for freshness by **shortening the supply chain.**

  The local organic production should therefore be given all its chances within the organic agriculture frame work.

  Combining sustainability with productivity, the use of Natural Chilean Nitrate will, enhance **local production, employment and self-reliance** as well.

*"In short, the social need to **employ people,** and the need to combine **productivity** with **sustainability,** go hand in hand" (pages 354-355).*

*"These, then, are the physical and logistical requirements: good, plentiful food for everybody for ever; a fair deal for producers; labour intensiveness – a maximal number of good jobs, giving rise to working rural communities; benign husbandry; (...)" (page 355).*

*"When we put the two kinds of requirements together – the physical and **logistical** requirements, and the underlying values – a number of themes emerge that between them define the shape of enlightened agriculture. These include: the broad structure of enlightened farming in any one country – including the idea of the 'mosaic', animal welfare and a **short supply chain** – and at the global level the importance of **national self-reliance** (incorporating the ideas of autonomy and cultural diversity)" (page 356).*

## 5.3 Conclusion and Score Evaluation

We are convinced that Natural Chilean Nitrate, as an essential but most natural plant food, has proved to be a valuable contribution to the success of organic agriculture in that it will allow organic agriculture to improve in a significant way its productivity, sustainability, its potential to produce fresh food of best quality and to fulfill the logistical requirements to offer a fair deal for consumers and promote local labor intensiveness by shortening the supply chain and promoting national self reliance.

The judicious use of Natural Chilean Nitrate respects and supports the cyclical precautionary and nearness principles dear to the organic agriculture community. It supports expressions of value and ethics such as: "self-reliance", "biologically robust", "high general standard of nutrition", "enlightened agriculture", "ecology, sensible balance", "excellence in husbandry", "productivity together with sustainability", "maintaining rural communities", "shorter supply chain", "common sense", "biological reality", etc.

- **Overall score**

| | Ethics | Socio-economic aspects |
|---|---|---|
| Natural Chilean Nitrate | 2 - 3 | 3 |

Scale: 0 (poor) →3 (good)

# SECTION 6:
# Matrix Evaluation of substances against criteria

This matrix was set up to be presented to the CODEX ALIMENTARIUS Committee on Food Labelling. It contains the technical justification supporting the request from the Delegation from Chile to include the Natural Chilean Nitrate in the list of accepted sources of nitrogen for organic crops. The argumentation for the matrix can also be found in the related document also presented to the CODEX ALIMENTARIUS Committee on Food Labelling.

The structure of this matrix follows the same structure of concepts set up by CODEX in order to incorporate new substances into the list of approved Substances for Use in Soil Fertilizing and Conditioning (APPENDIX V, ALINORM 03/22A p. 44). The content follows the concepts in Section 5 "requirements for inclusion of substances in Annex 2 and criteria for the development of lists of substances by country", that are grouped into two subsections, 5.1 General Criteria, and, 5.1 (a) Used for fertilization, soil conditioning purposes.

Substance to be used for fertilization, soil conditioning purposes.

Scoring: ++ very positive;
+ positive; oo not to evaluate;
- rather negative;
- - very negative

Proposed substance: Natural Chilean Nitrate as source of nitrogen for crops

## Section 5.1
## General Principles

| Criteria | Evaluation Against Criteria | Score | Proposed by |
|---|---|---|---|
| Consistent with principles of organic farming. | Natural Sodium Nitrate (NSN ) is a natural substance extracted from Caliche ore present in the inert surface of the Atacama Desert. It is extracted by mechanical and hydraulic processes, but not subjected to chemical processes. NSN is a complementary source of N to the organic N sources, it promotes biodiversity and increases the biological activity by delivering available N when the organic sources can barely provide any. NSN helps to preserve soil fertility by facilitating the decomposition and humus formation from organic substances with relative high carbon content (high C / N ratio). It does not harm the environment when properly used. | ++ | |
| Necessary for intended use | NSN supplies nitrogen in a form that is directly absorbed by plant roots with no need of biological transformations. Its nitrogen is readily available during all growing seasons, in particular when climatic conditions prevent the transformation of organic nitrogen needed to release available N. The sodium provided by NSN helps to prevent soil acidification resulting from decomposition of organic substances and it is a nutrient for halophytic crops (sugar beets, rape (canola), asparagus, forage crops), NSN also supplies small but significant quantities of Potassium, Magnesium, Sulfur and microelements Copper, Boron, Manganese and Iodine. | +/++ | |
| Manufacture, use and disposal does not result in, or contribute to harmful effects on the environment | The Atacama Desert is an extremely dry region with less than 2 mm rainfall per year, no surface soil, no trace of living organisms and no soil forming process. NSN is extracted by water solutions but no liquid effluents leave the plants. Water is lost only by solar evaporation used to concentrate solutions. Solar radiation is a main source of energy and the quantity captured cover 57% of the total energy used in the extraction process. Use of NSN for more than 80 years under experimental conditions (UK) and in farming (Japan) and for more than a 100 years elsewhere has shown not a trace of negative effects on the environment. NSN does not loose its proprieties over time and should not be disposed of but properly stored for subsequent crops. | + | |
| It has the lowest negative impact on human or animal health and quality of life | All forms of organic N are transformed in the soil to the ammonium and nitrate forms. These are practically the only forms of N that are absorbed by plants. Hence, the nitrate N present in Natural Sodium Nitrate is of the same nature as that resulting from organic transformations. No harm may be expected to soils, crops and biological soil life when used according to soil and crop needs. Sodium is also a natural constituent in the soil profile, and sodium rates applied with NSN are well within the natural range of Sodium in normal soils. Being an alkaline element it contributes to maintain the pH at a favorable level, not affecting the biological life. Content of Cadmium, Arsenic, Chrome and Lead in NSN is less than one mg kg-1. This levels are among the lowest in natural fertilizers. | + | |

| | | | |
|---|---|---|---|
| Approved alternatives are not available in sufficient quantity or quality. | NSN is the only natural non-organic substance that provides N in the nitrate form, that is available to crops<br>with no need of biological transformations that depend on temperature and other soil conditions. | + | |

Scoring: ++ very positive; + positive; oo not to evaluate; - rather negative; - - very negative

## Section 5.1 (a)
## Use for fertilization, soil conditioning.

| Criteria | Evaluation Against Criteria | Score | Proposed by |
|---|---|---|---|
| Essential for obtaining or maintaining fertility of the soil or fulfill specific nutrition requirement of crops, soilconditioning and rotation purposes which cannot be satisfied by the practices included in Annex 1, or other products included in Table 2 of Annex 2. | Nitrogen is an essential element for soil fertility and crop production. All organic N needs to be transformed into ammonium and nitrate forms to be absorbed by plant roots.<br>The transformation is driven by soil microorganisms and depends on soil temperature, pH, moisture and other proprieties. Research has shown that the quantity of N provided exclusively by organic sources is less than the N required to produce acceptable yield and quality of crops. This is because (a) insufficient level of total N in organic sources, and, (b) lack of synchronization between the rate of transformation of N from organic sources and the rate of uptake of N by plant roots along the growing season. This often results in leaching of the N from the organic sources.<br>NCN supplies N that can be immediately absorbed by plants, allowing to control the quantity of N to be applied and the timing of the application, thus synchronizing the N supply with the specific plant nutrition requirements. | + | |

| | | | |
|---|---|---|---|
| Ingredient is of plant, animal, microbial or mineral origin; may undergo the following processes: physical<br>(mechanical, thermal), enzymatic or microbial (composting, fermentation); only when the above processes have been exhausted,<br>chemical processes may be considered and only for the extraction of carriers and binders. | NSN is extracted by leaching the ground Caliche ore with weak salt solution at 40-45 °C. After leaching the ore the solution is cooled to 12 °C to precipitate NSN. After precipitating the NSN, the weak solution is further concentrated in ponds at the solar evaporation system before entering a second salt precipitation cycle. Chemical N fertilizers use an average of 40 Giga Joule (G J) per ton of N. The process toe extract NSN uses a total of 44 GJ, being close to the average of the industry. The solar energy captured by the system is equal to 25 G J per ton of N (6.25 ton of NSN). This is equal tot 57% of the total energy consumption, and represents a large saving of non-renewable energy.<br>The wet NSN is dried to be used as a source of N for crops. | ++ | |
| Their use does not have a harmful impact on the balance of the soil ecosystem or on the soil physical characteristics, or water and air quality. | Use of Natural Chilean Nitrate for around 100 years in experimental conditions (UK) and in farming in Japan, and even more in USA and other countries has not shown any negative effect on the environment. Also nitrate N from NCN does not volatilize as it is the case with ammonia nitrogen. | +/++ | |
| Use may be restricted to specific conditions, specific regions or specific commodities. | Use of Natural Sodium Nitrate is not recommended in saline or sodic soils. This can be determined by simple soil analysis. Its use is also not recommended in soils with poor internal drainage and in dry land farming with low rainfall and no access to irrigation water.<br>In the USA the use of NSN is restricted to 20% of the crop nitrogen requirements. | + | |

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