Nitrate (NO$_3^-$) versus ammonium (NH$_4^+$)

**Soil nitrogen conversion processes**

The three main sources of nitrogen, used in agriculture are urea, ammonium and nitrate. The biological oxidation of ammonia to nitrate is known as nitrification. This process consists of various steps, as demonstrated in Figure 1, and is mediated by autotrophic, obligately aerobic bacteria. In waterlogged soils the oxidation of NH$_4^+$ is thus restricted. Urea is decomposed by the enzyme urease or chemically hydrolyzed into ammonia and CO$_2$. In the ammonification step, ammonia is converted by ammonium-oxidizing bacteria into ammonium. In a next step, ammonium is converted by nitrifying bacteria into nitrate (nitrification).

The nitrogen conversion rate depends on the conditions, present in the soil for nitrifying bacteria. Nitrification of NH$_4^+$ to NO$_3^-$ preferably occurs under the following conditions:

- In the presence of nitrifying bacteria.
- Soil temperature > 20 °C.
- Soil pH 5,5 - 7,5.
- Sufficiently available soil moisture and oxygen.

Ammonium may accumulate in the soil, when this nitrogen conversion is limited or completely stopped if one or more of the following soil conditions are present (Mengel and Kirkby, 1987):
Nitrate (NO₃⁻) versus ammonium (NH₄⁺)

- Low soil pH conditions substantially depress microbial NH₄⁺ oxidation.
- Lack of oxygen (e.g. waterlogged soils).
- Lack of organic matter (as a source of carbon for bacteria).
- Dry soils.
- Low soil temperature depresses nitrification, due to low soil micro-organism activity.
- Nitrification attains its optimum at 26 °C, whilst the optimum for ammonification is as high as 50 °C. Thus in tropical soils, even under neutral pH conditions, ammonium may accumulate as the result of the low rate of nitrification.

Figure 1. N conversion processes in the soil. (Click on the figure to enlarge, Click here to open and print the figure)

Advantages of nitrate over ammonium-containing fertilisers

Nitrates are the preferred nitrogen source:
Nitrate (NO3-) versus ammonium (NH4+)

- Non-volatile: unlike ammonium, nitrate is non-volatile, so there is no need to incorporate it in the soil when applied by top- or side dressing, which makes it a convenient source for application.
- Mobile in the soil - direct uptake by the plant, highest efficiency.
- Nitrates synergistically promote the uptake of cations, such as K, Ca and Mg, while ammonium competes for the uptake with these cations.
- Nitrates can be readily absorbed by the plant and do not need to undergo any further conversion, as is the case with urea and ammonium, before plant uptake.
- No acidification of the soil if all the nitrogen is applied as nitrate-nitrogen.
- Nitrates limit the uptake of harmful elements, such as chloride, into large quantities.
- The conversion of nitrates to amino acids occurs in the leaf. This process is fuelled by solar energy, which makes it an energy-efficient process. Ammonium has to be converted into organic N compounds in the roots. This process is fuelled by carbohydrates, which are at the expense of other plant life processes, such as plant growth and fruit fill.

The higher nitrogen uptake efficiency with nitrate, compared to ammonium fertilisation, was clearly demonstrated by Legaz et al (1996). They found that the highest efficiency in N absorption (labelled isotope N-15) in citrus trees in function of the type of fertiliser (KNO₃, ammonium sulphate), applied to a sandy and a loamy soil, and measured over a six month period, was obtained with nitrates. Differences in N-uptake were greatest in the sandy soil with 60 % N-uptake efficiency when N applied as potassium nitrate, and only 40 % N-uptake efficiency, when N was applied as ammonium sulphate.

**Optimum nitrate / ammonium ratio in soils**
In soils, Knight et al (2000) found high NO$_3^-$ as opposed to high NH$_4^+$ nutrition to be beneficial in a consideration of potato yield, a number of quality characteristics, and higher financial return for the grower. Their study was conducted in the Sandveld of the Western Cape, South Africa, where low soil pH, and the lack of clay and organic matter in the soils disfavour nitrification. Three differing ratios of ammonium to nitrate, namely 80:20, 50:50, 20:80, for three differing levels of N were compared. Best results in terms of grower return were achieved when 80 % of the required N was applied as NO$_3^-$ and 20 % as NH$_4^+$.

Where NO$_3^-$ : NH$_4^+$ application rate differences have been of issue, similar conclusions have been drawn in a number of other crops regarding increased performance (Italian ryegrass – Cunningham, 1963; citrus - Van der Merwe, 1953; tomato - Kafkafi et al, 1971).

Optimum nitrate / ammonium ratio in hydroponics

In hydroponics, standard quantities of NH$_4^+$ added to nutrient solutions for soilless culture are between 5 and 10 % of the total N supply and seldom will exceed 15 %. For rose it tends to 25 % during the vegetative stage, whilst for melon it tends to 0 % during fruit development, for example. The tuning of the NH$_4^+$ addition merely
occurs during crop growth in relation with the pH development in the root environment. Addition of NH$_4^+$ lowers the pH in the root environment, because of an activation of the cation (NH$_4^+$) uptake and a reduction of the anion (NO$_3^-$) uptake. When NH$_4^+$ is taken up, the plant releases H$^+$ in order to maintain the plant's electrical neutrality, which causes a lower pH in the root environment. Optimum pH levels in the substrate solutions range from 5 to 6 for almost all crops (Sonneveld and Voogt, 2009).

Addition of NH$_4^+$ as a replacement of NO$_3^-$ in substrate systems can reduce the uptake of other cations, like K$^+$, Ca$^{2+}$ and Mg$^{2+}$, which can be explained by cation competition of NH$_4^+$ and these cations. The proportion of these effects depends on different factors like crop, growing conditions and the adjustments made in the ionic balance of the nutrients. Therefore, a careful use of NH$_4^+$ is recommended for crops which are sensitive to Ca deficiency. This is especially true when such crops are grown under climatic conditions that reduce the Ca transport to fruits. Good examples of this are the production of tomato and sweet pepper under dry and hot conditions. Both crops are sensitive to blossom-end rot, caused by Ca deficiency in the fruit, which is stimulated by a hot and dry climate. Under such conditions every reduction in Ca uptake becomes dangerous and thus, the use of NH$_4^+$ too (Sonneveld and Voogt, 2009).
References:


