Nitrogen transformations in the soil

Nitrogen undergoes transformations in the soil, depending on the chemical composition of the nitrogen applied. While nitrate is taken up directly by plants, ammonium and urea need to be first transformed into nitrate. Transformation losses are lowest with nitrate and highest with urea.

1. **Application of fertilizers**, containing mineral nitrogen as urea, ammonium, nitrate or a mix. Organic fertilizers and manure contain mostly complex organic nitrogen compounds and ammonium.
2. **Uptake of nitrate** is rapid due to the high particle mobility. Most plants therefore prefer nitrate over ammonium.
3. **Uptake of ammonium** is slower than nitrate. Ammonium is bound to clay particles in the soil and roots have to reach it. Most of the ammonium is therefore nitrified before it is taken-up by plants.
4. **Nitrification** by soil bacteria converts ammonium into nitrate in between a few days and a few weeks. Nitrous oxide and nitric oxide are lost to the atmosphere during the process.
5. **Denitrification** is favoured by lack of oxygen (water logging). Soil bacteria convert nitrate and nitrite into gaseous nitrous oxide, nitric oxide and nitrogen. These are lost to the atmosphere.
6. **Immobilization** transforms mineral nitrogen into soil organic matter. Activity of soil microbes is mainly stimulated by ammonium. Immobilized nitrogen it is not immediately available for plant uptake, but needs to be mineralized first.
   Mineralization of soil organic matter (and manure) releases ammonium into the soil.
7. **Hydrolysis of Urea** by soil enzymes converts urea into ammonium and CO_2 gas. Depending on temperature, hydrolysis takes a day to a week. The soil pH around the urea granules strongly increases during the process, favouring ammonia volatilization.
8. **Ammonia volatilization** occurs when ammonium is converted to ammonia and lost to the atmosphere. A high soil pH level favours conversion of ammonium to ammonia. If conversion takes place at the soil surface, losses are highest. These two conditions are met when urea is spread and not immediately incorporated.
9. **Leaching** of nitrate occurs mainly in winter when rainfall washes residual and mineralized nitrates below the root zone. Accurate fertilization prevents leaching during the growth period.

CO_2	carbon dioxide (gas)
$CO(NH_2)_2$	urea
NH_3	ammonia (gas)
NH_4^+	ammonium
NO_3^-	nitrate
NO_2^-	nitrite
NO	nitric oxide (gas)
N_2O	Nitrous oxide (gas)
N_2	nitrogen (gas)

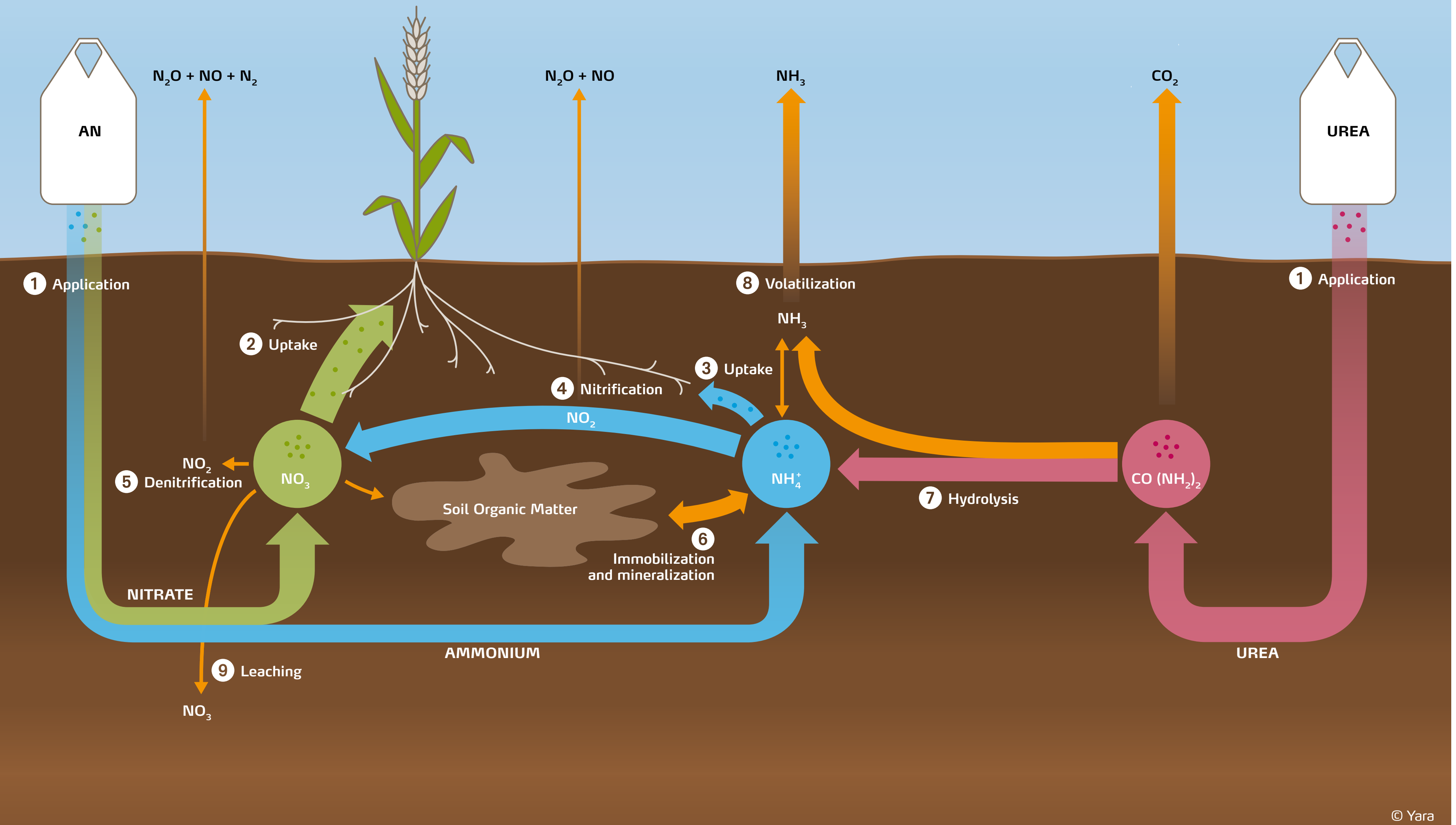

FIGURE 3: Transformation of urea, ammonium and nitrate in the soil. Urea suffers the highest transformation losses, nitrate the lowest. UAN, a 50/50% mix of ammonium nitrate and urea, undergoes the same transformations and losses as its components.

Nitrogen from nitrate

Nitrate (NO_3^-) is easily absorbed by plants at high rates. Unlike urea or ammonium, it is immediately available as a nutrient. Nitrate is highly mobile in the soil and reaches the plant roots quickly. Applying nitrogen as ammonium nitrate or calcium ammonium nitrate therefore provides an instant nutrient supply.

The negative charge of nitrate carries along positively charged nutrients such as magnesium, calcium and potassium.

It is important to note that essentially all the nitrogen in the soil, whether it was applied as urea, ammonium or nitrate, ends up as nitrate before plants take it up. If nitrate is applied directly, losses from the transformation of urea to ammonium and from ammonium to nitrate are avoided.

Nitrogen from ammonium

Ammonium (NH_4^+) is directly absorbed by plants at low rates. The positively charged ion fixes to soil minerals and is less mobile than nitrate (NO_3^-). Plant roots therefore need to grow towards the ammonium. Most of the ammonium is transformed into nitrate by soil microbes. This nitrification process depends on temperature and takes between one and several weeks. Another part of the ammonium is immobilized by soil microbes and released only over longer periods of time, thus building up soil organic matter.

Nitrogen from urea

Plant roots do not directly absorb the ureic form of nitrogen in significant quantities. Urea needs to be first hydrolysed to ammonium by soil enzymes, which takes between a day and a week, depending on temperature. Moisture is required for hydrolysis.

The ammonium generated by hydrolysis does not, however, behave exactly as the ammonium from ammonium nitrate. Hydrolysis of urea results in a short-term alkalinization in the immediate vicinity of the urea grain applied. It shifts the natural balance between NH_4^+ and NH_3 to the latter form, resulting in volatilization losses. These losses are the main reason for the lower N-efficiency observed with urea. This is also the reason why urea, whenever possible, should be incorporated into the soil immediately upon application.

In the long term, urea, as well as other sources of nitrogen, has an acidifying effect on the soil.

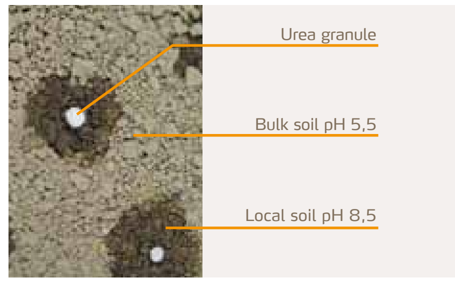

FIGURE 4: Hydrolysis of urea leads to local alkalinazation, resulting in NH_3 rather than NH_4^+ formation and susequent volatilization.