FACT OR FICTION: ANHYDROUS AMMONIA APPLICATION SHOULD NOT EXCEED 10 LB N PER UNIT SOIL CEC

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There are two aspects to this supposed rule of thumb. One, what is the maximum rate of anhydrous ammonia that a soil can "hold" at application? Two, should this be used as a N rate recommendation?

Just what is soil CEC?

CEC is the abbreviation for cation exchange capacity. Cations are positively charged ions, examples being K^+, Ca^{++}, Mg^{++}, NH_4^+. Since the soil has a net negative charge, cations are attracted to the negatively charged soil sites (called exchange sites) by electrostatic attraction (like a magnet). The CEC is determined by clay and organic matter – the source of negative charges in soil. CEC is an important soil property related to supply of certain plant essential nutrients, those taken up in a cation form (like K^+, Ca^{++}, Mg^{++}, NH_4^+), and liming soils for pH correction. CEC is reported in a unit of charge equivalent; for routine soil test reports as meq/100 g soil (meq is the abbreviation for milliequivalent, a charge equivalent concentration rather than weight basis). The CEC for low organic matter, low clay content, and coarse textured sandy soils will be less than 5 meq/100 g, while high organic matter, high clay content, and fine textured soils will greater than 20 meq/100 g.

What happens when ammonia is injected into soil?

Anhydrous ammonia (NH_3) reacts rapidly with soil water (immediately since ammonia is highly soluble in water), ammonium (NH_4^+) is formed, and can be held on the soil CEC. Remember that the word "anhydrous" is important, that is, there is no water in a tank of anhydrous ammonia. Therefore, when injected into the soil an initial reaction will be ammonia dissolution in water. This is why ammonia injury to skin can be severe, the reaction with water in cells, and why having plenty of clean water immediately available in case of an accident is vital to help limit injury.

$$NH_3 + H_2O = NH_4^+ + OH^-$$

This reaction with water (consumes H^+ ions) results in an initial alkaline pH in the ammonia retention zone (pH can temporarily rise above 9 at the point of highest concentration). It is free ammonia and not ammonium that moves and can be lost from soil if it reaches the surface. As pH increases above 7.3, the equilibrium between ammonium and ammonia results in increased free ammonia (the fraction as ammonia would be much less than 1% at pH below 7, 1% at pH 7.3, 10% at pH 8.3, and 50% at pH 9.3). The pH in the retention zone will remain high until nitrification results in a lowering of pH (produces H^+ ions).

$$2NH_4^+ + 3O_2 \Rightarrow 2NO_2^- + 2H_2O + 4H^+$$
$$2NO_2^- + O_2 \Rightarrow 2\ NO_3^-$$

When anhydrous ammonia is injected into soil, several physical and chemical reactions take place: dissolution in water, reaction with soil organic matter and clay, and attraction of the resulting ammonium ions with the cation exchange complex. These reactions all tend to limit the movement and potential loss of ammonia. The ammonia retention zone has the highest concentration of ammonium near the point of injection (depending on rate can be greater than 2,000 ppm N), with a tapering of the concentration toward the outer edges. The greatest ammonium concentration is within the first inch or two of the injection point, and with many soils the overall retention zone is less than approximately four inches in radius (six inches in sandy soils). The size of this zone, and shape, vary greatly depending upon the rate of application and knife spacing, soil texture, and soil conditions at injection (moisture status and soil structure).

Ammonia moves farther at injection in coarse-textured soils and soils low in moisture. Also, if the injection knife causes sidewall smearing, then ammonia may preferentially move back up the knife slot. A similar movement occurs if the soil breaks into clods at application and there are large air voids left in the soil. Both of these conditions can result in greater ammonia concentration toward the soil surface, and greater potential losses at or after application (the same if the injection point is near the soil surface).

Bottom line, when ammonia is injected into soil, the initial reaction at the point of release is violent. The ammonia reacts and binds with soil constituents such as organic matter and clays. It dissolves in water to form NH_4^+. These reactions help retain ammonia at the injection point, not simply soil CEC. Using an acre furrow slice of soil (6 2/3 inch depth), the meq per lb applied N, as NH_4^+ equivalent, is only 0.0035. With the high affinity for water, soil moisture is important for limiting the movement of ammonia, but does not ultimately determine retention in soil. After conversion to ammonium, which is a positively charged ion, it is held on the soil exchange complex and does not move with water. Only after conversion to nitrate (NO_3^-), via the nitrification process, can it be lost from soil by leaching or denitrification.

Ammonia application rates?

The rate of anhydrous ammonia that can be held in soil is not a direct relationship with CEC. Soil properties affect the size of the injection zone, but ultimately several other factors are more important, such as moisture content, depth of injection, and soil coverage, especially with dry soil or coarse textured soil. Wing sealers immediately above the outlet port on the knife can help close the knife track and reduce vertical movement of ammonia. Within agronomic rates of application, there is no real limit or maximum application rate (rates well above agronomic need can typically be injected). Anhydrous ammonia has been successfully injected into sandy soils at rates over 200 lb N/acre. In research conducted with alternate row injection (example 60 inch spacing in 30 inch row corn), more than 200 lb N/acre has been successfully applied – which is an equivalent of more than 400 lb N/acre per injection knife. It's injection depth and multiple soil conditions that determine potential volatile loss, not simply CEC.

Nitrogen rate determination?

Across much of the Corn Belt the current approach to N rate recommendations for corn is the Maximum Return To N (MRTN). This approach uses yield response to N application from many response trials and economics (corn and N prices) to determine application rates. Information on the MRTN approach can be found in the Extension publication *Regional Nitrogen Rate Guidelines for Corn* (www.extension.iastate.edu/Publications/2015.pdf) and is used in the online Corn Nitrogen Rate Calculator (http://extension.agron.iastate.edu/soilfertility/nrate.aspx).

Research has shown that soil properties such as clay and organic matter (components of CEC), or corn yield, are not directly related to economic optimal N rates. In fact, in many areas soils with low CEC and coarse texture (sandy) have higher N fertilization requirements that soils with higher CEC (for example, southern Illinois soils compared to central and northern Illinois; in Wisconsin, sands compared to medium and low yield potential fine textured soils). Therefore, if one simply used a "rule of thumb" such as 10 lb N per unit CEC (or some other multiplication factor) many fields would not be properly fertilized.