Acidifying Nitrogen Compounds and Range Fertilization[1]

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Highlight

Soil pH changes on plots fertilized with ammonium-containing compounds indicated possible detrimental effects on range plant communities. The mechanism for the pH change and possible solution for correction of the problem are discussed.

Fertilization offers range managers a tool to manipulate forage production. Herbage yield increases, particularly in wetter sections of the prairie, have been stimulated by nitrogen fertilization (Mader, 1956; Moser, 1964). Crude protein percentages and moisture-use efficiency have increased with added nitrogen (Owensby, 1969). Those results have encouraged ranchers to plan use of nitrogen on native range in eastern Kansas.

Weed control measures must be implemented to maintain desirable species in the stand because shifts in botanical composition frequently occur in True Prairie when nitrogen is applied (Mader, 1956). However, information concerning long-term effects of nitrogen fertilization on soil chemical properties is lacking.

The purpose of this paper is to discuss the mechanism for pH change from acidifying nitrogen fertilizers and to present data on pH changes on nitrogen fertilized native range.

Soil Acidification

Increased soil acidity following nitrogen fertilization may result from 1) so-called "physiologic acidity" and 2) nitrification. Physiologic acidity results when cations and anions are absorbed at different rates from applied fertilizers (Adams and Pearson, 1967). Nitrogen containing cations are taken up at a higher rate than the associated anions (SO_4^{--}, Cl^-, NO_3^-). Leaching moves those anions with the cations (Ca^{++}, Mg^{++}, K^+, Na^+) to a lower part of the soil profile and thereby reduces base saturation of the leached surface zone. The impact of physiologic acidity is not fully realized until residual salts are leached from a particular soil horizon.

Nitrification releases hydrogen ions (H^+) which cause the soil to become acid (Tisdale and Nelson, 1966). The ammonium ion (NH_4^+) is converted to the nitrite ion (NO_2^-) largely by a group of obligate, autotrophic bacteria, *Nitrosomonas*, which mediate this reaction:

$$2\,NH_4^+ + 3\,O_2 \longrightarrow 2\,NO_2^- + H_2O + 4\,H^+$$

Another genus of obligate autotrophic bacteria, *Nitrobacter*, cause oxidation of nitrite to nitrate (NO_3^-),

$$2\,NO_2^- + O_2 \longrightarrow 2\,NO_3^-$$

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The amount of acidity produced by a given fertilizer varies with soil characteristics, plant community, environment, and fertilizer rate. The proportion of applied nitrogen taken up by the plant as ammonia also affects potential acidification.

Bear (1953) presented potential acidity or alkalinity values varying from –148 to +62 in terms of calcium carbonate for 100 pounds of fertilizer material. Potential acidity associated with such nitrogen sources as anhydrous ammonia, urea, ammonium nitrate, ammonium sulfate, and ammonium phosphate is high. Nonacidifying sources such as calcium cyanamide, calcium nitrate, and sodium nitrate are less commonly used in the United States owing to low nitrogen percentages, or, in the case of sodium nitrate, because it is detrimental to soil structure.

Research findings in tame pasture fertilization indicate that nitrogenous acidification is a serious problem. Coastal bermudagrass (*Cynodon dactylon* (L.) Pers.) requires high amounts of nitrogen (500 to 1000 lb./acre) for sustained high production in the southeastern United States (Adams et al., 1967), where soil pH has been seriously reduced. Abruna et al. (1958) and Jackson et al. (1961) have reported stand reductions and decreased dry-matter yields of bermudagrass from highly acid soils. Their studies dealt with high nitrogen rates applied only a few years.

Reductions in pH were severe and availability of other fertilizer elements was increased on smooth brome (*Bromus inermis* Leyss.) plots fertilized 20 years with ammonium nitrate at annual rates up to 200 lb. N/acre (Owensby et al., 1969). Soil pH was reduced by rates of nitrogen above 60 lb./acre. As much as 20 to 30 tons per acre of lime were required to correct increased acidity on plots where high nitrogen rates had been used. Unpublished data from the plots indicate herbage-yield reductions from high acidity soils from 6000 lb./acre to 300 lb./acre in June, 1970.

Reports on soil pH changes in native range are scant. Moser (1964) reported pH decreases over four years from pH 6.35 to 6.10 on Kansas native range fertilized annually with 100 lbs. N/acre as ammonium nitrate. Soil data were taken from the 0 to 6-inch layer in 1963; fertilization occurred from 1951 through 1954; pH changes likely were tempered during the ten intervening years by basic cations deposited at the surface in dead plant material.

Materials and Methods

Soil samples were taken from fertilization trials on native range at Manhattan and Hays, Kansas. Soil acidity was determined by adding 5 ml of distilled water to 5 grams of soil, stirring, and reading after 20 minutes with a pH meter. A description of each study area follows:

Manhattan.—Ammonium nitrate was applied to circular (4.5 ft diameter) plots at rates of 0 and 50 lb. N/acre May 1, 1965, through 1969 on loamy upland bluestem ranges (Smolan silty clay loam, 0 to 1% slope). Vegetation consisted primarily of big bluestem (*Andropogon gerardi* Vitman.), little bluestem (*A. scoparius* Michx.), Indiangrass (*Sorghastrum nutan* (L.) Nash.), Kentucky bluegrass (*Poa pratensis* L.), and numerous annual and perennial forbs. Four soil cores (¾ inch diameter) were taken from each plot to 12 inches deep. Each core was divided to 0 to 6-inch and 6 to 12-inch increments and pH determined. Analysis of variance for four replicates was calculated.

Hays #1. Ammonium nitrate fertilizer was broadcast at rates of 0, 40, 80, and 120 lb. N/acre annually and biennially May 1, 1965, through 1969 in paired, 6 × 12 ft plots on a clay upland range site (Harney silty clay loam, 0 to 1% slope). Vegetation was a mixture of blue grama (*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.), buffalograss (*Buchloe dactyloides* (Nutt.) Engelm.), western wheatgrass (*Agropyron smithii* Rydb.), and associated weedy species, primarily Japanese brome (*Bromus japonicus* Thunb.) and western ragweed (*Ambrosia psilostachya* DC.). One soil core (¾-inch diameter) was taken April 27, 1969, to 12 inches deep from each plot. Each core was divided into 0 to 6-inch and 6 to 12-inch increments. Soil cores from like treatments, depths, and four replicate plots were composited for analysis.

Hays #2. Single applications of ammonium nitrate at 20 to 1000 lb. N/acre were made on 12 × 25 ft plots on clay upland and breaks range sites May 8, 1969. The clay upland range site (Harney silty clay loam, 3 to 4% slope) supported a mixture of buffalograss, blue grama, western wheatgrass, Kentucky bluegrass, Japanese brome, and various forbs. Vegetation on the breaks range site (Brownell gravelly loam, 2 to 3% slope) consisted mainly of tall- and midgrass species, i.e., big bluestem, little bluestem, Indiangrass, sideoats grama (*Bouteloua curtipendula* (Michx.) Torr.), hairy grama (*Bouteloua hirsuta* Lag.), and numerous forbs. Three soil cores (¾ inch diameter) were taken in December, 1969, from each plot to 6 inches deep, composited, and pH determined. Analysis of variance was run on the data from three replications.

Results and Discussion

pH Changes

Soil pH decreased on plots receiving nitrogen at Manhatan and on plots with Harney silty clay loam soil at Hays. At Manhattan a total of 200 lb. N/acre applied at 50 lb./acre/year for four years lowered pH by 0.3 in the 0 to 6-inch soil layer, but had no effect on the 6 to 12-inch soil layer (Table 1).

Cumulative applications of 160 lb. N/acre or more appeared to reduce pH after three years of nitrogen application on Hays #1 plots in the 0 to 6-inch soil layer (Table 2). Application of 200 lb. N/acre or more on Hays #2 plots increased

Table 1. Reaction (pH) of 0 to 6 and 6 to 12-inch soil layers of Smolan silty clay loam soil on plots near Manhattan, Kansas, fertilized May 1 each year 1965 through 1968 at indicated rates (lb./acre) with ammonium nitrate. Soil samples taken in November, 1969.

Nitrogen rate	Depth	
	0–6 inch	6–12 inch
0	6.3[1]	6.0[2]
50	6.0	6.0

[1] $LSD_{.05} = 0.1$.
[2] No significant difference.

soil acidity on the Harney soil, but did not change soil pH on the well-buffered Brownell soil (Table 3).

Nitrogen acidification was limited to the upper six inches of the soil horizon at both Hays and Manhattan; however, Adams and Pearson (1967) pointed out that increased soil acidity due to nitrogen fertilization is not limited to the surface horizon. Abruna et al. (1958) found soil pH lowered two feet deep in a clay loam profile under napier-grass (*Pennisetum purpureum* Schumach). Acidity in lower horizons results from nitrogen compounds leaching before nitrification or from hydrogen or aluminum ions leaching into lower soil horizons.

Nitrogen acidification may be more severe with nitrogen application amounts above consumptive potential of plants. Abruna et al. (1958) found that more acidity developed from each pound of nitrogen applied above recommended rates. Heavy applications for use over several years apparently would be more likely to cause reductions in pH than annual applications of amounts near consumptive use.

Table 3. Reaction (pH) of 0 to 6-inch soil layer of plots near Hays, Kansas, fertilized May 8, 1969, at indicated rates (lb./acre) with ammonium nitrate. Soil samples were taken in December, 1969.

Nitrogen rate	Soil series	
	Harney	Brownell
0	6.5[1]	7.6[2]
20	6.5	7.6
40	6.5	7.6
60	6.6	7.6
80	6.5	7.6
100	6.4	7.6
200	6.3	7.6
400	6.3	7.6
600	6.2	7.6
800	6.0	7.6
1000	6.1	7.5

[1] $LSD_{.05} = 0.2$.
[2] No significant differences.

Other Nitrogen Sources

Alternative nitrogen sources appear to be needed, particularly for sites that do not inherently contain high amounts of calcium carbonate in the upper soil profile. Among the alternative sources are calcium cyanamide, calcium nitrate, and sodium nitrate, but using them would introduce alkalinity. Lack of availability and high cost per pound of nitrogen also limit use of these alternate sources. A possible solution might be to use a fertilizer rotation system that balances acidity and alkalinity that different nitrogen sources create.

Table 2. Reaction (pH) of 0 to 6 and 6 to 12-inch soil layers of Harney soil series on plots near Hays, Kansas, fertilized May 1 from 1965 through 1968 at indicated rates (lb./acre) with ammonium nitrate. Soil samples taken April 27, 1969.

Nitrogen rate	Annual application		Biennial application	
	0–6 inch	6–12 inch	0–6 inch	6–12 inch
0	6.9	6.8	6.8	6.8
40	6.8	6.8	6.8	6.7
80	6.7	6.8	6.7	6.8
120	6.6	6.8	6.6	6.8

Animal wastes from extensive feedlot operations might offer a new source of nitrogen, but high salt concentrations and ammonium (acidifying) nitrogen limits their usefulness. Feedlot wastes also could introduce detrimental weed seeds.

Liming

Liming also is a possibility for pH correction, but it does not move in the profile of fine-textured soils. Peterson (1970) at Columbus, Kansas, reported little movement of lime out of the plow layer during 15 to 20 years. Adams and Pearson (1969) showed lime movement in sandy soils into lower horizons. Because range soils typically are not tillable, extra caution is needed to avoid creating a situation that cannot be rectified.

Effect of pH on Range Communities

Porter (1969), reviewing nitrogen use in grassland ecosystems, predicted increased use of nitrogen fertilizers in the Great Plains. The present paper was prompted by his omission of recommendations for research on soil chemical property changes. Increased use of acidifying nitrogen fertilizers could greatly alter plant communities.

An extensive review by Kline (1969) of the effects of soil reactions on plant responses and chemical properties of soil indicates that hydrogen ion concentration has little direct effect on plant growth, but that plant communities may be altered by changes in soil pH. However, Spurway (1941) listed pH preferences of plants indicating definite ranges of adaptation.

Availability of other nutrients may also affect plant growth and plant community development. Only slight changes in soil reaction may make a particular element more or less available for plant growth. At certain soil pH levels some elements are toxic. Aluminum and manganese have been implicated as toxic at pH 5.0 or less (Kline, 1969).

Soil microorganism activity also may be affected by soil pH. High acidity may hinder decomposition of organic matter (Alexander, 1961). A buildup of undecomposed plant material reduces nutrient cycling and can thus lead to drastic botanical changes. Not all effects of soil pH on soil microorganisms are so drastic, but slight changes in soil reaction may impair microbe effectiveness in decomposition.

Range is a multi-species complex in which a slight alteration of one abiotic factor of the ecosystem may change community dynamics to the extent that species composition changes. Soil reaction changes due to acidifying fertilizers could drastically alter delicate balances now existing.

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