COMPARISON OF SOME NITROGEN SOURCES FOR POTATOES

by

R. Kunkel, N.M. Holstad and B.L. McNeal

Nitrogen is involved in all life processes. The element is most notably found in protein and amino acids, where it is associated with protoplasm, enzymes and photosynthesis. There are four nitrogen atoms in each chlorophyll molecule. Therefore, a nitrogen deficiency results in a yellowing of the leaves.

Nitrogen stimulates above-ground and below-ground vegetative growth. Because of the increased size of nitrogen-stimulated root systems, nitrogen-fertilized plants are able to increase the uptake of most other elements. Nitrogen is mobile within the plant, and moves from older parts to areas where new growth is taking place. For this reason, nitrogen deficiency appears first in the older leaves and progresses towards the younger, upper leaves. Such deficiency is expressed as a stunting of growth and a yellowing of leaves, which may eventually be followed by a dropping of the nitrogen-deficient leaves. However, diseases, water stress and deficiencies of other nutrients may also cause potato plants to shed their lower leaves.

We have studied sources and rates of nitrogen in a number of experiments in the Columbia Basin of Washington over the past twenty years. Our cumulative results should serve as guidelines for those wishing to grow potatoes in this highly productive area.

Nitrogen fertilizers: Nitrogen comes in many forms, each having its particular advantages and disadvantages. Some of the more common sources of nitrogen are listed in Table 1. The sources differ in their percentages of nitrogen and in their degrees of acidity or basicity. The more acid or alkaline ones produce the greatest effects in the soil. Those fertilizer materials having the highest proportions of ammonium nitrogen (e.g. ammonium sulfate) or producing the highest proportions of ammonium nitrogen as they react with the soil (e.g. anhydrous ammonia and urea) are the most acidifying, because two hydrogen ions are produced for every ammonium ion that is converted to nitrate by soil microbes. Anhydrous ammonia and urea would be even more acidifying if their initial reaction with the soil to form ammonium ions did not produce base (hydrozide ions) and temporarily increase the soil pH until after nitrification of ammonium begins.

Table 1. Nitrogen Content and Relative Acidity of Selected Nitrogen Fertilizers[1]

Material	Percent Nitrogen	Residual Effect	Net Acidity[2]
Ammonium Nitrate	32	Moderately acid	1200
Ammonium Phosphates	11-21	Mod. to highly acid	1300-2260
Ammonium Sulfate	20-21	Highly acid	2200
Anhydrous Ammonia	82	Highly acid	2960
Aqua Ammonia	20	Slightly aicd	1080
Calcium Nitrate	15.5	Neutral to Mod. Alkaline	----
Nitric Phosphates	12-20	Moderately acid	400
Urea	42-45	Moderately acid	1500

[1]Data from Using Commercial Fertilizers, pg. 48.

[2]Pounds of limestone required to neutralize one ton of fertilizer material.

The acids produced by acidic fertilizers react with the limestone in the calcareous soils common to the Columbia Basin. Once the reserve of limestone in the soil has been used up, however, the soils will become increasingly more acid as more fertilizer is applied. Limestone may be needed periodically to keep the soil from becoming detrimentally acidic. Excessively acidic conditions reduce microbial activity, cause deficiencies of some nutrient elements and toxicities from certain metals.

Growers in some potato-producing areas control potato scab by adjusting the pH to between pH 5.5 and 5.0 by adding either acid fertilizers or limestone. Intentional acidification is highly impractical in calcareous soils, because of the tremendous amounts of sulfur required to lower soil pH to 5.5 or 5.0 in such highly-buffered systems. Attempts to control scab by application of sulfur or acid-forming fertilizers to calcareous soils have not generally proved succesful.

Salt Indices and Solubilities: In addition to acidifying effects, nitrogen compounds are capable of inducing artificial drought because of their high soluble salt effects. This is particularly important if they are used in large quantities and placed close to the seed-piece. Some of the common nitrogen fertilizers and their salt indices are listed in Table 2.

Table 2. Nitrogen Content and Salt Indices of Some Common Nitrogen Fertilizers[1]

Material	Percent Nitrogen	Salt Index[2] per ton of material	Salt Index[2] per unit (20 lbs) of nitrogen
Ammonium mitrate	35	104.7	2.990
Ammonium sulfate	21.2	69.0	3.253
Anhydrous ammonia	82	47.1	0.572
Calcium nitrate	15.2	65.0	4.194
Natural organic	5.0	3.5	0.702
Natural organic	13.0	3.5	0.270
Nitrogen solutions 406	40.6	78.3	1.930
Urea	46.5	75.4	1.618

[1] Data from Farm Chemical Handbook, pg. B 61.

[2] Basis of sodium nitrate (soda nitre) = 100

The higher the salt index, the greater the tendency for seeds and developing plants to suffer from water stress. If the total salt content of the soil becomes too high, plants may not obtain adequate water even if the soil appears quite moist. The salt effect on plants resulting from placing too much soluble fertilizer too near the seed-piece can be overcome by thorough irrigation or by split applications of the total seasonal fertilizer needs.

The relative solubilities of nitrogen fertilizers can have effects both on the salt index and on the tendency of nitrogen to leach beyond the potato root zone. The formulas and relative solubilities of some common nitrogen fertilizers are given in Table 3. Nitrogen occurs in the ammonium, nitrate and urea forms, as shown in the table. The chemical reactions in the soil also differ. Ultimately, however, the nitrogen is converted to soluble ammonium (NH_4^+) or nitrate (NO_3^-) ions.

Table 3. Formulas and Relative Solubilities of Some Common Nitrogen Fertilizers[1]

Material	Formula	Parts per 100 parts of water[2]
Ammonium nitrate	NH_4NO_3	118
Ammonium sulfate	$(NH_4)_2SO_4$	71
Anhydrous ammonia	NH_3	90
Diammonium phosphate	$(NH_4)_2HPO_4$	25
Monoammonium phosphate	$NH_4H_2PO_4$	43
Potassium nitrate	KNO_3	13
Urea	$CO(NH_2)_2$	67

[1]Data from Farm Chemical Handbook, pg. B 64.

[2]Solubility in distilled water at 32°F.

Reactions: Typical reactions of the four most common nitrogen fertilizers are presented below:

1.) Ammonium Nitrate: Ammonium nitrate dissolves in water to produce ammonium and nitrate ions. The ammonium ion carries a positive charge, and is adsorbed on the surfaces of negatively-charged soil colloids. As long as it remains in this form it will not leach from the soil, and can move to appreciable depths only in very sandy soils. The nitrate ion carries a negative charge, which is repelled by the negative charge on the colloids. It is readily leached from soils by water, especially sandy soils. The loss of nitrate nitrogen by leaching can be expensive. In addition, if large quantities get into the drinking water it can interfere with oxygen metabolism in infants, and produce the "blue baby" syndrome.

With time, the adsorbed ammonium is converted by soil microbes to the leachable, hazardous nitrate ion. The hydrogen produced during this process can acidify the soil (lower the soil pH). Conversion of the NH_4^+ ion to the nitrate ion is an important soil process because the nitrate form moves most readily to plant roots and is absorbed readily by most plants.

2.) Ammonium Sulfate: Ammonium sulfate dissolves in water to form ammonium and sulfate ions. The reactions of ammonium have been described above. The fact that all the nitrogen is in the ammonium form accounts for the greater acidifying tendency of ammonium sulfate than of ammonium nitrate. The sulfate ion (which leaches almost as readily as the nitrate ion) can provide some of the sulfur needs of the crop. Ammonium sulfate contains 24% sulfur, which is greater than its nitrogen content. Relatively small amounts of sulfur are required by potatoes, most of which can be supplied by river water and by sulfur applications to control mildew. Hence, it is an economically unsound practice to use only fertilizer materials containing sulfate. Supplemental data, based on petiole analyses, strongly suggest that it may be possible to reduce potato yields when the sulfur level of the plant becomes too high.

3.) Urea: Urea is highly soluble in water and rapidly hydrolyzes (reacts with water) in the presence of the soil enzyme urease, according to the reaction

$$CO(NH_2)_2 + 2\ H_2O \rightleftharpoons 2NH_4^+ + CO_3^{2-}.$$

The carbonate ion produced further reacts with water, according to the reaction

$$CO_3^{2-} + H_20 \rightleftharpoons HCO_3^- + OH^-.$$

The formation of the hydroxyl ion (OH^-) causes an alkaline reaction, which temporarily raises the pH of the soil in the immediate vicinity of the urea fertilizer particle. The ultimate effect on pH of fertilization with urea, however, is to lower the soil pH, because the hydroxyl ion is neutralized by one of the hydrogen ions produced during microbial conversion of ammonium to nitrate as discussed before. This leaves one hydrogen ion from the nitrification process for each ammonium ion converted, and hence a net acidification, and reduction in soil pH.

4.) Anhydrous Ammonia: In addition to the above solid forms of nitrogen, gaseous anhydrous ammonia is also commonly used by injecting it into the soil or metering it into irrigation water for rill-irrigated fields (but not for sprinkler application). When ammonia dissolves in water the following reaction occurs

$$NH_3 + H_2O \rightarrow NH_4^+ + OH^-.$$

Subsequent behavior follows the ammonium reactions of the ammonium ion (NH_4^+) and the acid-base reactions of urea. Because of the hydroxyl ion produced, the initial effect of anhydrous ammonia is to raise the pH (lower the acidity) in the immediate area of application. As with urea, the ultimate effect is a lowering of soil pH as acidity is generated during the nitrification process. Because of the high nitrogen content of anhydrous ammonia, it has the greatest soil acidification tendency per pound of nitrogen of any of the common nitrogen fertilizer sources, Table 1.

Ultimately, all forms of nitrogen, including organic forms, end up as inorganic ammonium or nitrate ions before being absorbed by plants. Most ammoniacal nitrogen is nitrified to nitrate, which is the most common form taken up by plants. Hence, it is not surprising that studies where potatoes are fertilized with different sources of nitrogen often fail to produce significantly different results. Secondary effects on the solubility of other essential elements, or the supplying of additional elements directly, may in some cases provide sufficient justification for paying extra for a particular source of nitrogen. Such secondary benefits are not apparent from the cumulative results of our long-term studies with various nitrogen fertilizer sources for potatoes in the Columbia Basin.

Table 4. Cumulative results of studies over five years with ammonium nitrate, ammonium sulfate, and urea nitrogen fertilizers.

	SOURCES OF NITROGEN		
	NH_4NO_3	$(NH_4)_2SO_4$	Urea
Total yield (cwt/a)	540	553	530
Percent No. 1's	67	68	68
Specific gravity	1.082	1.082	1.082
Blackspot index	67	67	68
Chip color	26	26	26
Percent petiole nitrate	3.28	3.53	3.47
Percent total N	2.73	2.88	2.83
" " P	.33	.34	.33
" " K	7.30	7.50	7.41
" " Ca	1.52	1.37	1.41
" " Mg	.77	.73	.76

Crop Responses: In studies made over a long period in the Columbia Basin area, we found no overall differences in yield, tuber quality, or nutrient uptake among ammonium nitrate, ammonium sulfate, or urea nitrogen fertilizer sources, Table 4. The data in the table are averages of experiments wherein the rates of fertilizer nitrogen varied from nil to 500 lbs/a.

Amounts of nitrogen needed: The amount of nitrogen needed to grow a crop of potatoes is closely related to the size of crop produced. This in turn is closely correlated to the length of growing season. We have recently noted a relationship between the amount of nitrogen in the plant and the amount of nitrogen in the tubers.

On each of four harvest dates, plants and tubers in ten consecutive potato hills were harvested from each of eight replications. This was done for plants fertilized with 200 lbs/a of nitrogen and for plants fertilized with 500 lbs/a of nitrogen. Both the tubers and the vines from which they came were preserved for chemical analysis.

Three conclusions seem justified from the data, Figure 1:

1) The amount of nitrogen in the tubers is roughly equal to the amount of nitrogen translocated out of the vines. Therefore,

2) the roots did not absorb nitrogen rapidly enough to meet the needs of the tubers and to maintain the nitrogen level of the vines.

3) If adequate nitrogen isn't present in the vines by mid-season, it probably won't get to the tubers.

The total yield of tubers for this fertilizer application rate was 617 cwt/acre. When the amounts of nitrogen in the vines and the tubers were added together, it became obvious that virtually all fertilizer nitrogen was recovered, with some additional nitrogen coming from the soil as well. This was particularly evident when it was recognized that the nitrogen in the roots was not even considered, and that rarely was more than 50 to 75% of the fertilizer nitrogen applied actually recovered by the plant, Table 5. The quantity of nitrogen available to the plant from the soil, however, is not readily determined when using standard soil sampling procedure.

Figure 1. Changes in the amount of nitrogen in the tubers and vines when fertilized with 200 pounds of nitrogen and planted April 1.

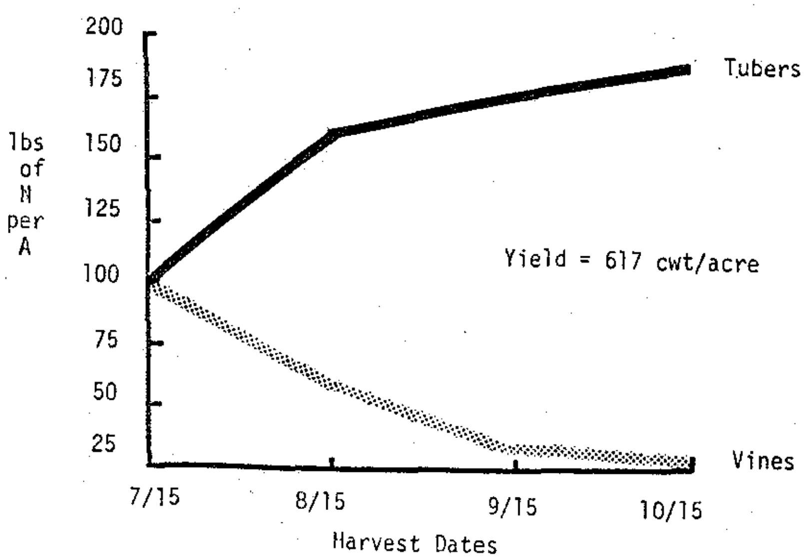

Table 5. Amount of Nitrogen in the Tubers and Vines When Fertilized With 200 lbs Nitrogen Per Acre, Planted April 1.

Sampled	Tubers	Vines	Total N
7/15	102	100	202
8/15	162	58	220
9/15	177	32	209
10/15	186	25	211

In the same experiment, the amount of nitrogen in the tubers and vines was also determined when 500 lbs/a of N were applied, Figure 2. The top yield of tubers in this case was 732 cwt/a. The level of nitrogen in the vines was maintained a month longer than at the 200 lbs/a fertilizer rate of nitrogen. After a month of very rapid tuber enlargement, as indicated by the amount of nitrogen in the tubers, the level of nitrogen in the vines decreased continuously as it had in the case of the lower fertilizer rate. Again, the data suggest that if the amounts of nitrogen in the vines are not sufficient to meet tuber nitrogen demands it cannot be sufficiently supplied by the roots. The pounds of nitrogen in the total plant, except for the roots, are easily determined from data such as these, Table 6.

Table 6. Amount of Nitrogen in the Tubers and Vines When Fertilized With 500 lbs Nitrogen Per Acre, Planted April 1.

Sampled	Tubers	Vines	Total N
7/15	81	164	245
8/15	177	178	355
9/15	207	94	301
10/15	219	49	268

When the 500 lbs/acre rate of N was used, producing a yield of 732 cwt/a, considerable nitrogen remained in the soil at harvest time. Some of this was .

When the 500 lbs/acre rate of N was used, producing a yield of 732 cwt/a, considerable nitrogen remained in the soil at harvest time. Some of this was in organic form in the roots. Leaves which had abscised could not be gathered for testing because of soil contamination. An additional amount remained in the soil, probably in leachable form. A deep-rooted cover crop would tie up any soluble nitrogen and store it for future use.

Loss of nitrogen from the soil is often of major concern, both economically and environmentally. Ultimately, the nitrogen is converted microbially to nitrate ions, which move with the wetting front when water is applied. The conversion of ammonium nitrogen to nitrate can be delayed, to various degrees, by (1) soil fumigants that retard the growth of soil microbes: (2) coating the surfaces of the nitrogen fertilizer particles with compounds of limited solubility, such as sulfur or formaldehyde; or (3) through the use of nitrification inhibitors such as "N-Serve". We have had, and continue to have, several of these materials under study. However, their discussion is beyond the scope of the present report.

Nitrogen uses: Plants can absorb nitrogen as urea ($CO(NH_2)_2$), ammonium (NH_4^+) and nitrate (NO_5). The urea is the least toxic of the three forms. Plants can absorb urea and nitrate directly through the leaves. The urea form is the only ammoniacal form of nitrogen that can be washed into the soil, but, once in the soil, it is rapidly converted to the non-leachable ammonium ion.

The use of high initial application rates of nitrogen, under conditions where nitrogen is not heavily leached, may actually decrease yields of tubers (due to salt effects) if water is inadequate or the growing season too short.

The use of anhydrous ammonia too close to the seed piece or when applied too near the time of planting may cause seed piece decay and reduced yields. Rates of nitrogen as high as 350 lbs. of N/a, from anhydrous ammonia, have not caused seed piece decay when applied about six inches deep in the soil and about six inches to each side of the seed piece.

Figure 2. Change in the amount of nitrogen in the tubers and vines when fertilized with 500 pounds per acre of nitrogen and planted April 1.