Effect of Fertilizer and Irrigation on Nitrate-Nitrogen and Total Nitrogen in Potato Tubers

J. N. Carter and S. M. Bosma

ABSTRACT

This study was conducted to determine the effect of N fertilizer and irrigation management on potato (Solanum tuberosum L.) tuber NO₃-N levels and the relationship to the potential health hazard created by high nitrate levels in food products. *Russet Burbank* potatoes grown using different N fertilizer rates, methods of application, and irrigation levels were analyzed for NO₃-N concentration. The NO₃-N concentration in the tubers on a wet weight basis varied from 56 to 131, 34 to 75, and 23 to 50 ppm in the 3 years of this study. The NO₃-N concentration for each year of study was found to be directly related to the level of applied N fertilizer. The initial concentration and increase in NO₃-N due to N fertilizer varied with the season. The addition of manure did not increase the NO₃-N level above those to be expected from similar quantities of inorganic sources of N. Phosphorus fertilizer did not increase the NO₃-N level. The NO₃-N concentration in the tubers where more water was applied at each irrigation was less than on the lower level of applied water at each N rate. These data indicate that greater NO₃-N levels in the tubers will result by increasing N fertilization rates. The levels of NO₃-N obtained in this study were not expected to contribute substantially to the methemoglobinemia health hazard.

Additional index words: Nitrate health hazard, Nitrogen fertilization, Leaf NO₃-N.

Nitrate concentration is high (>67 ppm NO₃-N) in certain vegetable products such as beets (Beta vulgaris L.), spinach (Spinacia oleracea L.), and lettuce (Lactuca sativa L.) (3, 7, 8, 10, 12, 15, 16). There is considerable concern that use of these high nitrate containing vegetables could cause methemoglobinemia, especially in infants. Although nitrites and one death have been reported recently when adults. However, several cases of methemoglobinemia, especially in infants. Although nitrites and one death have been reported recently when adults. However, several cases of methemoglobinemia, especially in infants. Although nitrites and one death have been reported recently when adults.

MATERIALS AND METHODS

Three experiments were conducted during consecutive years on a Portneuf silt loam soil (Solluc Calcic Haplustoll; coarse-silty, mixed, mesic) near Twin Falls, Idaho to evaluate the effects of N and irrigation management on production and quality of the tubers. This soil has a cemented hardpan commencing at the 40 to 45 cm depth that does not materially affect water movement but restricts root growth. The areas used in these experiments had not received fertilizer the year previous to these investigations and were considered deficient in both N and P but amply supplied with other nutrients.

Experiment 1 was designed using four replications in a randomized block having split plots at two moisture levels (M₁ and M₃). Fertilizer treatments were five N rates (0, 45, 90, 180, and 360 kg N/ha) as NH₄NO₃ and five P rates (0, 20, 40, 80, and 160 kg P/ha) as concentrated superphosphate in all combinations. An additional treatment of 180 kg N, 80 kg P, and 9,700 kg/ha of dry manure (200 kg N/ha) was also included.

Experiment 2 was designed using four replications in a randomized block at one moisture level (M₂). Fertilizer treatments were six N rates (0, 45, 90, 180, 360, and 720 kg N/ha) as urea and ureaform (Dupont's Uramite®) with a uniform application of 80 kg P/ha. In a separate study, approximately 56% of the N in ureaform was nitrified in 11 weeks.

Experiment 3 was designed using four replications in randomized block at one moisture level (M₃). Fertilizer treatments were five N rates (0, 90, 135, 180, and 360 kg N/ha) as urea in one, two, and three applications with a uniform application of 80 kg P/ha and 112 kg K/ha (K₂SO₄). The urea N treatments were applied all preplant; 1/2 preplant and 1/2 on July 11; and 1/3 preplant, 1/3 on July 11, and 1/3 on August 8. The N applied during the season was broadcast followed by the application of 4 cm of water applied by sprinklers to move the N into the root zone.

The preplant fertilizer application in all experiments was broadcast and worked into the upper 8-cm soil layer. Following preplant fertilizer application in early May, the potato seed pieces were planted 23 to 28 cm apart in 91-cm rows.

The time and amount of irrigation were determined by the use of tensiometers placed throughout the experimental area. Irrigations were applied when the mean soil moisture stress reached 0.5 to 0.6 atm at a depth of 20-cm below the top of the hilled up for the M₃ or when the soil moisture level was approximately 60% of the total available soil moisture capacity in the active root zone of the soil. Irrigation water was applied to alternate furrows at each irrigation for the M₃ treatment (76 cm water per season). For the M₃ treatment (124 cm water per season), every furrow received water at each irrigation. The irrigation date and duration were the same for the two moisture levels.

Leaf samples (leaflets and petiole) were taken on all fertility and moisture treatments at one sampling date. The first mature
compound leaf from the top, generally the fourth, was selected at random throughout each plot from 25 plants. These samples were placed in paper bags, dried at 65°C, and ground to pass a 40-mesh sieve. NO$_3$-N concentration was determined by the phenoldisulfonic acid method using a water extract of the ground whole tubers (14). The use of the nitrate electrode by methods of Milham et al. (9) produced variable results which indicated incomplete recovery when compared with the phenoldisulfonic acid method. Total N was determined by the Kjeldahl method modified to include nitrate.

**RESULTS**

Potato yields were increased by N and P application in Experiment 1 and by N application in Experiment 2. Maximum production of U.S. No. 1's occurred when ammonium nitrate or urea was applied at the 180 kg N/ha rate on soil fertilized with 80 kg P/ha. When the slowly available form of N was used (ureaform), maximum production was at 360 kg N/ha. In Experiment 3, the residual soil N was high enough to give maximum production. As a consequence, there was no yield increase due to preplant or seasonal application of N fertilizer. The potatoes grown at high levels of readily available N applied preplant showed a greater percentage of tubers that were immature, had poor netting, and had pointed ends. These effects were more noticeable in Experiment 1 than in Experiments 2 or 3 and were less prominent where the N was applied in split applications, as slowly available material, or at the high level of irrigation ($M_2$).

Total N in the potato tubers was directly related to the rate of N fertilizer application (Fig. 1). The increase in total N with increasing rates of fertilization was approximately the same for the ammonium nitrate and urea. Total N was reduced by the greater application of irrigation water and the use of a slowly available form of N at any given rate of N fertilizer. This reduced N content of the tubers was expected because of the movement of soil N below the root zone by the greater water applications and less N being available from the slowly available form. Total N level of the tubers was not affected by the P level in the soil.

Nitrato-N concentration in the whole potato tubers increased with the addition of N fertilizer (Fig. 2). The NO$_3$-N concentration depended upon the level of added N fertilizer, moisture level, and the year of the study. The highest level of NO$_3$-N in the potato tubers occurred, in all cases, at the highest level of applied N. The NO$_3$-N concentration in the potato varied from 36 to 131 ppm in Experiment 1, from 34 to 75 ppm in Experiment 2, and from 25 to 50 ppm in Experiment 3 on a wet weight basis. The mechanism is unknown for NO$_3$-N concentration varying from one season to the next. The concentration of NO$_3$-N was reduced at the higher irrigation water level and by the application of N fertilizer in the slowly available form. The application of N fertilizer in smaller increments during the season did not cause any significant variation in the NO$_3$-N concentration in the potato. Adding high levels of manure in addition to adequate levels of N for maximum production did not increase the NO$_3$-N level in the potatoes ($M_1 = 108$ ppm, $M_2 = 79$ ppm) above those expected from addition of similar quantities of inorganic N fertilizers ($M_1 = 125$ ppm, $M_2 = 91$ ppm). The P fertilizer level did not cause a variation in NO$_3$-N.
The $\text{NO}_3^-$ concentration for each irrigation treatment and year of study was directly proportional to the total N in the tubers (Fig. 3a). However, the proportion of $\text{NO}_3^-$ to total N increased with increasing N rates and increased linearly to 360 kg N/ha when ammonium nitrate and urea were the N sources and to 720 kg N/ha when ureaform was used (Fig. 3b). The proportion of $\text{NO}_3^-$ to total N decreased slightly at 720 kg urea N when compared to the 360 kg level, indicating that a plateau may have been reached. The proportion of $\text{NO}_3^-$ to total N decreased with larger applications of water and was lower in Experiment 2 than in Experiment 1 even at higher N rates. The reason is unknown for the variation in $\text{NO}_3^-$ percentages in relation to the total N from one season to the next but is probably due to climatic effects.

The $\text{NO}_3^-$ concentration in the potato tubers for each moisture treatment, form of fertilizer, and year of study was directly proportional to the $\text{NO}_3^-$ level in the leaves in late July or near full bloom (Fig. 4). This indicated that any management practice that would increase the $\text{NO}_3^-$ level in the leaves throughout the season with a corresponding increase in N uptake would increase the nitrate level in the potato tubers. Adding N fertilizer during the season with a corresponding increased $\text{NO}_3^-$ level in the leaves for a short period following N application did not increase the nitrate level in the tubers above levels where similar quantities of N fertilizer was applied preplant. The overall $\text{NO}_3^-$ in the plant throughout the season has the predominant effect rather than high levels at any one time. Also, seasonal differences play a predominate role in the tissue $\text{NO}_3^-$ level necessary to create various nitrate concentrations in the tubers.

Greater concentrations of $\text{NO}_3^-$ are located in or just below the skin of the tubers (Table 1). Removing the peel, which is about 5% of the whole tuber, reduced $\text{NO}_3^-$ level approximately 12%. However, in commercial processing using the wet or dry peel process, the percentage of the tubers removed as skins and reduction in $\text{NO}_3^-$ may be reduced.

**Table 1. Effect of skin removal on the $\text{NO}_3^-$ concentration in tubers.**

<table>
<thead>
<tr>
<th>Tubers part</th>
<th>% of whole tuber</th>
<th>$\text{NO}_3^-$ Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry wt</td>
<td>ppm</td>
</tr>
<tr>
<td>Peeled tuber</td>
<td>94.8</td>
<td>327</td>
</tr>
<tr>
<td>Skin</td>
<td>5.2</td>
<td>1.208</td>
</tr>
<tr>
<td>Whole tuber</td>
<td>100.0</td>
<td>334</td>
</tr>
</tbody>
</table>
**DISCUSSION**

The NO₃-N level in tubers was generally higher than previously found by others (6, 7, 12, 15) even at the lower N fertilizer rates (Table 2). This difference is probably due to the variety of potato used or tuber preparation rather than to the level of N available to the potato plant. These NO₃-N levels, although higher than those found by others, seem within tolerable limits when compared to other vegetables such as spinach, beets, and lettuce (Table 2). This is especially true when compared to the NO₃-N concentration obtained at adequate, but not excess levels of N fertilization.

Although good quantitative information is not available on the health hazard of nitrate concentration in vegetable products, an estimated level for spinach processed as baby food is 67 ppm NO₃-N on a wet weight basis (13). This was considered to be a very safe tolerance level and indications are that the actual safe level may be considerably higher (2). If this same NO₃-N level applies to the potato, then the 67 ppm value was only exceeded in Experiment 1 at optimum N fertilizer rates. However, when excess N was applied for maximum production, this level of NO₃-N in the tubers was exceeded in 2 out of the 3 years of this study.

Whole potatoes, including the skins, were used for determining the NO₃-N concentrations in the tubers in these experiments. Greater concentrations of NO₃-N are located just below or in the skin of the tubers. The removal of this skin, either by peeling or by the commercial wet or dry peel process, should reduce the NO₃-N in the tuber from 10 to 12%. Also, boiling and draining of the cooking water from the tubers should reduce the NO₃-N level approximately 80% (11). However, in baking and in commercial processing the NO₃-N concentration in the tubers is not reduced by water extraction but may be reduced in other cooking processes.

Potato tubers may be stored for periods up to a year before being processed or sold as a fresh-packed potato (4, 5). They are normally stored at a reduced temperature (4.4 to 7.2°C) which is not conducive to bacterial action or the reduction of nitrate-N to nitrite-N. There are periods when the potato temperature in the commercial piles, during transportation to markets or in the home, could rise to levels where bacterial action and conversion to the nitrite form may occur. Under these conditions, high nitrate potatoes (>67 ppm NO₃-N) may become a health hazard if the NO₃-N or NO₂-N is retained during processing. More research is needed to determine the significance of this potential problem.

In conclusion, these data indicate that moderately high nitrate levels can be obtained in the tubers by excess application of N fertilizer. Variable response to growth patterns caused by year-to-year differences in climate directly affect the initial concentration and increase in NO₃-N resulting from N fertilization. The highest nitrate levels obtained are still well below those in many commonly used vegetable products. However, NO₃-N concentrations obtained by excess N fertilizer applications may contribute to the overall health hazard of high NO₃-N level in many vegetable products. Consequently, the nitrate levels should be kept as low as possible while near maximum yields are maintained. This can be accomplished by applying recommended amounts of N fertilizer that are based on soil and tissue analyses.

**LITERATURE CITED**