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Effect of Fertilizer and Irrigation on Nitrate-Nitrogen and Total Nitrogen in Potato Tubers[1]

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ABSTRACT

This study was conducted to determine the effect of N fertilizer and irrigation management on potato (*Solanum tuberosum* L.) tuber NO_3-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 NO_3-N concentration. The NO_3-N concentration in the tubers on a wet weight basis varied from 36 to 131, 34 to 75, and 25 to 50 ppm in the 3 years of this study. The NO_3-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 NO_3-N due to N fertilizer varied with the season. The addition of manure did not increase the NO_3-N level above those to be expected from similar quantities of inorganic sources of N. Phosphorus fertilizer did not increase the NO_3-N level. The NO_3-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 NO_3-N levels in the tubers will result by increasing N fertilization rates. The levels of NO_3-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 NO_3-N.**

NITRATE concentration is high (>67 ppm NO_3-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 are the toxic principle which may be formed prior to ingestion or during digestion and absorption of food, nitrates may be considered as the index or precursor to the amount of nitrite which may be formed. If foods contain high levels of nitrate, the potential hazard may be increased if conditions during storage or processing are conducive to conversion to nitrite (11). In spite of the appreciable nitrate content of some vegetables such as beets and spinach, no authenticated cases are known for nitrate poisoning of human adults. However, several cases of methemoglobinemia and one death have been reported recently when children, aged 2 to 10 months, were fed spinach purchased as a fresh vegetable and held under questionable storage conditions (1).

In recent years, there has been a steady increase in the use of nitrogen fertilizer to achieve maximum potato production. Also, an increasingly common practice is to add N to the irrigation water throughout the season. The abundance and low cost of N fertilizer has encouraged the use of high fertilization rates in attempts to obtain maximum tuber yields. No reported cases could be found in the literature where high nitrate levels in potato (*Solanum tuberosum* L.) tubers were created by methods of application or rates of N fertilizer. However, Hlavsová, Tucek, and Turek (6) reported nitrate increases in the tubers with increasing N fertilization rates.

This paper reports the effect of irrigation, P, and N fertilizer on the NO_3-N concentration in whole 'Russet Burbank' potato tubers grown in southern Idaho.

MATERIALS AND METHODS

Three experiments were conducted during consecutive years on a Portneuf silt loam soil (Xerollic Calciorthid; 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 (M_1 and M_2). Fertilizer treatments were five N rates (0, 45, 90, 180, and 360 kg N/ha) as NH_4NO_3 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 (M_1). Fertilizer treatments were six N rates (0, 45, 90, 180, 360, and 720 kg N/ha) as urea and ureaform (Dupont's Uramite[3]) with a uniform application of 80 kg P/ha. In a separate study, approximately 38% of the N in ureaform was nitrified in 11 weeks.

Experiment 3 was designed using four replications in randomized block at one moisture level (M_1). 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 (K_2SO_4). 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 hill for the M_1, 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 M_1 treatment (76 cm water per season). For the M_2 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

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[3] Mention of trade names or companies is for the benefit of the reader and does not imply endorsement by the USDA.

compound leaf from the top, generally the fourth, was selected at random throughout each plot from 23 plants. These samples were placed in paper bags, dried at 65C, 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 plant tissue (14).

The potatoes were killed by frost in early October, the tops were removed by the use of a rotary beater, and the potato tubers were harvested 2 weeks later. During grading and specific gravity determinations, a 3 to 4 kg representative sample of U.S. No. 1 potato tubers was taken for NO_3-N and total N analysis. Potato tubers were selected at random. Tubers showing some undesirable characteristic but still qualifying as U.S. No. 1's, were included in the sample taken for N analysis. The potato samples were washed, cut into small sections, dried at 65C, ground to pass through a 40-mesh sieve, subsampled, and analyzed. The 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[4], 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

[4] Part or all of the surface of the tubers was smooth, light colored, and without russeting.

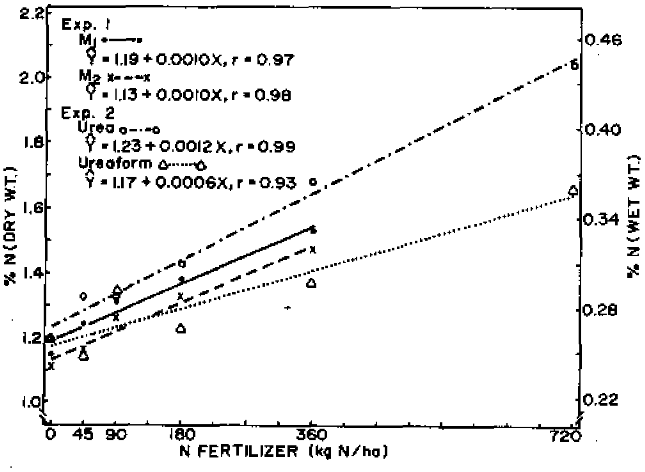

Fig. 1. Effect of N fertilizer on the N percentage in whole potato tubers in Experiments 1 and 2. (Data from Experiment 1 averaged over all P levels. Regression equation is on a dry weight basis.)

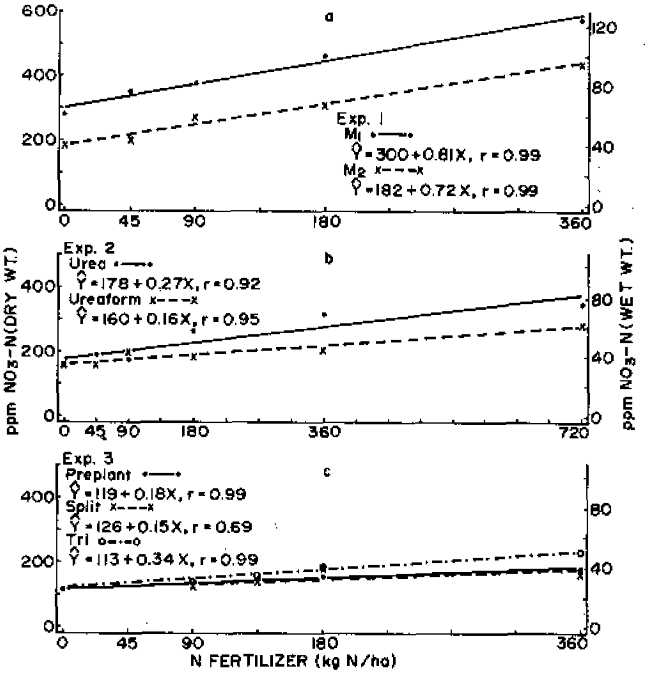

Fig. 2. Effect of N fertilizer on the NO_3-N concentration in whole potato tubers in Experiments 1, 2, and 3. (Data from Experiment 1 averaged over all P levels. Regression equation is on a dry weight basis.)

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.

Nitrate-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.

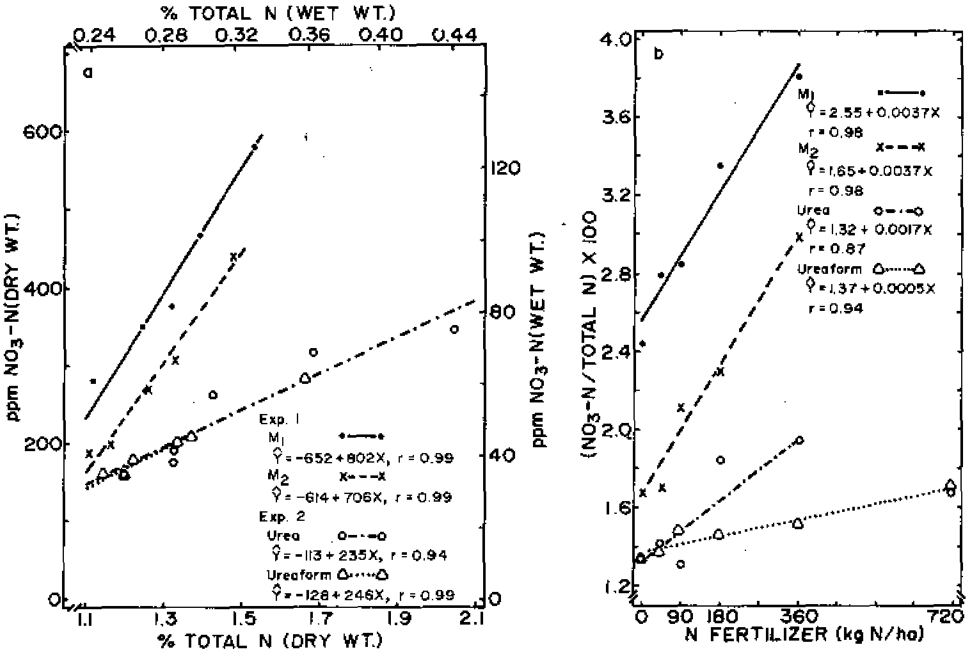

Fig. 3. Effect of total N percentage on the NO_3-N concentration and N fertilizer rates on the NO_3-N/total N ratios in whole potato tubers in Experiments 1 and 2. (Data from Experiment 1 averaged over all P levels. Regression equation is on a dry weight basis.)

The NO_3-N 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 NO_3-N 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 NO_3-N 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 NO_3-N 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 NO_3-N percentages in relation to the total N from one season to the next but is probably due to climatic effects.

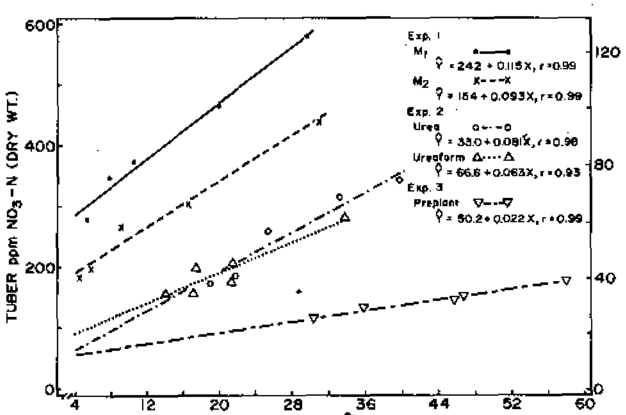

Fig. 4. Relationship between the leaf and whole potato tuber NO_3-N concentrations in Experiments 1, 2, and 3. (Leaves taken on 7/28 in Experiment 1, 7/27 in Experiment 2, and 7/31 in Experiment 3. Data from Experiment 1 averaged over all P levels. Regression equation is on a dry weight basis.)

The NO_3-N concentration in the potato tubers for each moisture treatment, form of fertilizer, and year of study was directly proportional to the NO_3-N level in the leaves in late July or near full bloom (Fig. 4). This indicated that any management practice that would increase the NO_3-N 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 NO_3-N 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 NO_3-N 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 NO_3-N level necessary to create various nitrate concentrations in the tubers.

Greater concentrations of NO_3-N 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 NO_3-N 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 NO_3-N may be reduced.

Table 1. Effect of skin removal on the NO_3-N concentration in tubers.

Tuber part	% of whole tuber	NO_3-N Concentration	
		Dry wt	Wet wt
	Dry wt	ppm	
Peeled tuber	94.8	307	66
Skin	5.2	1,208	177
Whole tuber	100.0	354	75

Table 2. Nitrate-N concentration of vegetables reported in 1907, 1964, and 1970.

Vegetable	NO_3-N Concentration, wet wt				
	1907*		1964†		1970‡
	Range	Avg	Range	Avg	Avg
	ppm				
Potato	9 to 24	17	8 to 32	23	42
Onion	4 to 189	51	4 to 70	39	14
Sweetpotato	6 to 29	15	6 to 12	10	0
Beet	209 to 1,808	583	151 to 373	270	600
Carrot	9 to 20	15	4 to 44	23	32
Radish	119 to 665	411	282 to 391	337	402
Lettuce	89 to 795	375	110 to 202	150	170
Spinach	70 to 854	431	54 to 167	118	524
Bean	10 to 149	99	33 to 69	52	35

* From Richardson (12). † From Jackson, Steel, and Boswell (7). ‡ From Maynard and Barker (8).

DISCUSSION

The NO_3-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 NO_3-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 NO_3-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 NO_3-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 NO_3-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 NO_3-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 NO_3-N concentrations in the tubers in these experiments. Greater concentrations of NO_3-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 NO_3-N in the tuber from 10 to 12%. Also, boiling and draining of the cooking water from the tubers should reduce the NO_3-N level approximately 80% (11). However, in baking and in commercial processing the NO_3-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 7.2C) 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 NO_3-N) may become a health hazard if the NO_3-N or NO_2-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 growth patterns caused by year-to-year differences in climate directly affect the initial concentration and increase in NO_3-N resulting from N fertilization. The highest nitrate levels obtained are still well below those in many commonly used vegetable products. However, NO_3-N concentrations obtained by excess N fertilizer applications may contribute to the overall health hazard of high NO_3-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.

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