Effect of Soil and Foliar Application of Molybdenum on the Glycoalkaloid and Nitrate Concentration of Potatoes

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The effect of two methods of molybdenum (Mo) application, banding and foliar spray, on total glycoalkaloid (TGA) and nitrate nitrogen (NO_3-N) concentration of Katahdin tubers was studied and compared during each of 2 consecutive years. Sodium molybdate (Na_2MoO_4) was the source of Mo used. The levels of Na_2MoO_4 application were 0.0, 2.8 (1.25), 5.6 (2.5), and 8.4 (3.75) kg/ha (ppm soil). Banding of Na_2MoO_4 was carried out during the time of planting, while foliar spray was applied 13 weeks following planting when the nitrate reductase activity was at its peak level. Both TGA and NO_3-N were significantly ($p < 0.01$) reduced by all levels of Mo application and by both methods of application. Nitrate reductase activity of the leaves was significantly ($p < 0.05$ for banding and $p < 0.01$ for foliar application) increased by Mo application. Tuber Mo concentration was significantly ($p < 0.01$) increased at all levels of application but did not reach levels that would be toxic for human consumption. Foliar spray resulted in significantly greater decreases in TGA and NO_3-N and increases in nitrate reductase activity and molybdenum concentration than banding.

INTRODUCTION

Molybdenum (Mo) is the only transition element of group VI in the periodic table that is essential for normal growth, metabolism, and reproduction of higher plants. The requirement of Mo in higher plants is lower than that for any other nutrient. The most available form of Mo to plants is the molybdate oxyanion MoO_4^{2-}. Molybdenum is the metallic component of the enzymes nitrate reductase, nitrogenase, xanthine oxidase/dehydrogenase, aldehyde oxidase, and sulfite oxidase. In plants, the presence of only nitrate reductase and nitrogenase has been conclusively proven. Molybdenum is indispensable for nitrate reduction (Beevers and Hageman, 1980) and nitrogen fixation (Mulder, 1948). Since these are key enzymes in plant metabolism, it is imperative that adequate Mo be available to ensure normal plant growth. Uptake of Mo is dependent on soil pH, organic matter, and Mo concentration of the soil. The Mo concentration of soils in the United States is highly variable; soils in the east have Mo concentrations as low as 0.08 ppm, while some western soils have Mo levels as high as 30 ppm (Kubota, 1977).

Glycoalkaloids. Glycoalkaloids are the naturally occurring toxicants of the potato, the predominant glycoalkaloids being α-solanine and α-chaconine. These toxicants are known to possess anticholinesterase activity (Patil et al., 1972), and consumption of potato tubers high in the glycoalkaloids has resulted in severe illness and sometimes death (McMillan and Thompson, 1979). Sinden et al. (1976) reported that the presence of high levels of these compounds also imparts a bitter flavor to the potato tubers.

Nitrates. Nitrates are also naturally occurring toxicants of the potato tuber and are precursors of nitrites, which oxidize ferrous hemoglobin to ferric hemoglobin, subsequently inhibiting oxygen transportation through the body and resulting in methemoglobinemia, a condition characterized by decreased capacity of the blood to transport oxygen (Phillips, 1971). Infants are highly susceptible to this disorder. Nitrates can react with secondary or tertiary amines to form carcinogenic and mutagenic *N*-nitroso compounds (Walters et al., 1979). White (1975) states that about 14% of the per capita ingestion of nitrates in the United States is contributed by potatoes.

Previous studies in our laboratory showed that application of Mo by banding to the soil resulted in a significant decrease in nitrate and glycoalkaloid concentration of potato tubers (Munshi and Mondy, 1988). Since mineral elements can be supplied to the plant either by foliar spray or by banding, this experiment compares the effect of two forms of application of Mo on the tuber concentration of nitrate nitrogen and glycoalkaloids.

MATERIALS AND METHODS

Katahdin potatoes grown at Cornell University, Ithaca, NY, were used in this study. The mean Mo concentration of the soil was found to be 0.08 ppm. The soil type was Howard gravelly loam. Nitrogen–phosphorus–potassium (N–P–K, 14–14–14) fertilizer was banded to the soil of all treatments at the rate of 108 kg/ha at the time of planting of seed potatoes. The mean pH of the soil was 6.90, which is sufficient to ensure proper mobilization of the molybdate ion. Sodium molybdate (Na_2MoO_4, obtained from Sigma Chemical Co., Inc.) was the source of Mo used in this study. Two methods of application of Na_2MoO_4, banding and foliar spray, were used at the following rates: 0.0, 2.8 (1.25), 5.6 (2.5), and 8.4 (3.75) kg/ha (ppm soil). Each treatment was applied to three, randomly assigned, plots. The banding of Na_2MoO_4 was performed simultaneously with the planting of the seed potatoes. Foliar spray was applied 13 weeks following planting when the nitrate reductase activity of the leaves was at its peak. The tubers were harvested 20 weeks following planting and kept at room temperature for a week to allow the periderm to suberize. Tubers were then washed and stored at 5 °C and 95% relative humidity in the dark until analyzed. This study was carried out for each of 2 consecutive years.

Tubers of size C (medium, 3.5–4.0-in. diameter) were cut longitudinally from bud to stem end to obtain equal sampling at both ends. The slices were separated into cortex (including the peel) and pith sections along the vascular ring and analyzed separately since they differ greatly in their metabolic activity. Both the cortex and pith regions were analyzed for NO_3-N, TGA,

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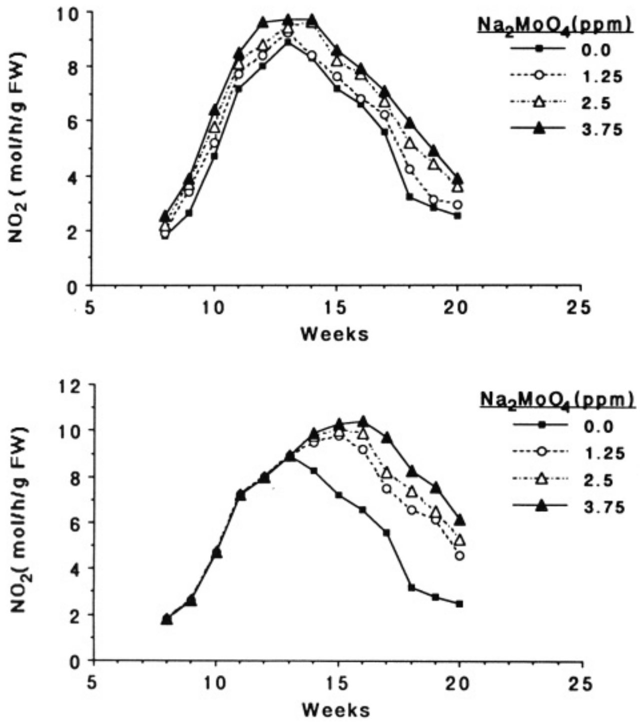

Figure 1. Effect of banding (top) and foliar applications (bottom) of Na_2MoO_4 on leaf nitrate reductase activity. Mean percent error of the data points is 2.5. Error bars have not been incorporated to prevent confusion. For foliar treatment, the curve up to 13 weeks consists of 0.0 Mo application, since no Mo had been sprayed up to this point.

and Mo. Each determination consisted of two subsamples. Each constituent was analyzed in triplicate.

Nitrate Reductase Assay. The in vivo nitrate reductase method of Davies and Ross (1985) was used. Leaf punches weighing about 100 mg were vacuum infiltrated with 0.2 M potassium nitrate (obtained from Fisher Scientific) and sodium phosphate (obtained from Fisher Scientific) buffer (pH 7.5) followed by incubation at 35 °C in the dark. Enzymatic production of nitrite was determined by addition of 1% (w/v) of sulfanilamide in 3 M HCl and 0.2% (v/v) of *N*-(1-naphthyl)-ethylenediamine hydrochloride (obtained from Sigma) in distilled water. Triton X-100 (obtained from Sigma) (0.1% v/v) was used as the nonionic detergent. Absorbance was read at 550 nm. Potassium nitrite (obtained from Fisher Scientific) was used to prepare the calibration curve.

Determination of Nitrate Nitrogen (NO_3-N). The NO_3-N concentration of potato tubers was determined according to the phenoldisulfonic acid method of Ulrich et al. (1959). Potassium nitrate was used as the standard.

Determination of Total Glycoalkaloids (TGA). The TGA concentration of potato tubers was determined according to the modified nonaqueous titration method of Bushway et al. (1980). Tomatine (obtained from Sigma) was used as the standard.

Statistical Analysis. A randomized block design was employed, and statistical significance of data was determined by two-way analysis of variance (ANOVA) as recommended by Steel and Torrie (1980). Data from both years were pooled since there were no statistically significant interactions between them.

RESULTS AND DISCUSSION

Nitrate Reductase Activity. The nitrate reductase activity was significantly ($p < 0.05$ for banding and $p < 0.01$ for foliar application) increased by both banding and foliar spraying of Na_2MoO_4 (Figure 1). This increase was achieved at all levels of Mo application, with the highest levels resulting in greatest increases in enzyme activity. Nitrate reductase activity peaked at 13–14 weeks following planting for those plants to which Na_2MoO_4 was banded as a soil application. For those treated with foliar spray, nitrate reductase activity peaked between 15 and 16 weeks. Foliar application resulted in significantly ($p < 0.05$) greater increases in enzyme activity than banding. Since Mo is the metallic cofactor of nitrate reductase, the increase in enzyme activity could be due to the increased uptake of Mo.

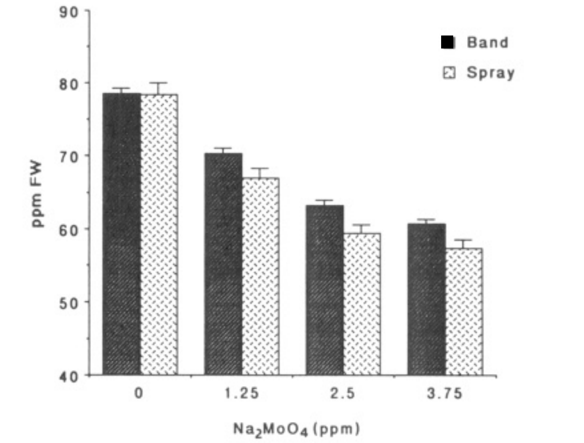

Figure 2. Nitrate nitrogen (NO_3-N) concentration of Katahdin potato tubers as affected by banding and foliar applications of Na_2MoO_4.

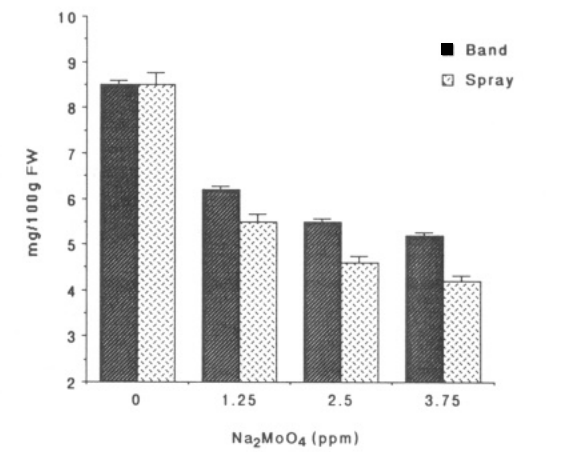

Figure 3. Effect of banding and foliar applications of Na_2MoO_4 on the total glycoalkaloid (TGA) concentration of Katahdin potato tubers.

Nitrate Nitrogen (NO_3-N). The NO_3-N concentration of the tubers was significantly ($p < 0.01$) reduced by both banding and foliar application of Na_2MoO_4 (Figure 2). Sodium molybdate levels greater than 2.5 ppm soil did not result in further significant decreases in the NO_3-N concentration of the tubers. Decreases in tuber NO_3-N concentration were significantly ($p < 0.05$) greater for foliar treatment than banding. The NO_3-N concentration of the cortex region was decreased by 9% and that of the pith by 6% due to banding of Na_2MoO_4. Foliar applications of Na_2MoO_4 decreased the tuber NO_3-N by 10% in the cortex region and 8% in the pith region. The decrease in tuber NO_3-N concentration could be a result of increased reduction of NO_3^- due to elevated nitrate reductase activity. Previous work showed that banding of Na_2MoO_4 to potato plants during the time of planting significantly decreased the NO_3-N levels in the tuber (Munshi and Mondy, 1988).

Total Glycoalkaloid (TGA) Concentration. The TGA concentration of tubers was significantly ($p < 0.01$) reduced by both foliar application and banding of Na_2MoO_4 (Figure 3). Foliar applications resulted in significantly ($p < 0.05$) greater decreases than banding. Banding of Na_2MoO_4 decreased the tuber TGA content by 8% in

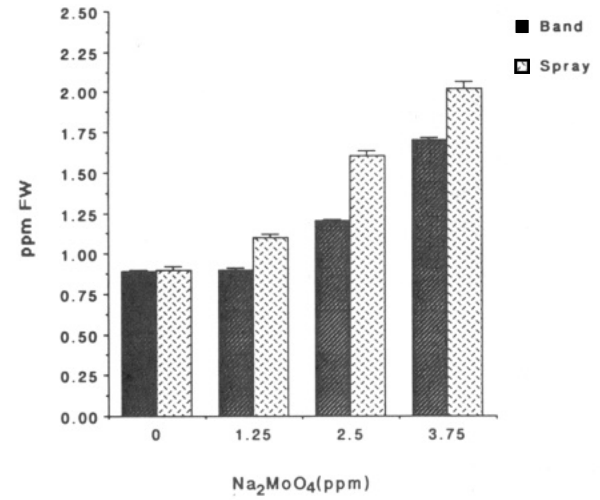

Figure 4. Molybdenum (Mo) concentration of Katahdin potato tubers as affected by banding and foliar applications of Na_2MoO_4.

the cortex region and 5% in the pith region, while foliar application resulted in decreases of 9% in the cortex region and 7% in the pith region. Previous work in our laboratory showed that the TGA concentration of potato tubers was significantly decreased by banding of Na_2MoO_4 (Munshi and Mondy, 1988). The mechanism behind the reduction in TGA is not fully understood.

Molybdenum. The molybdenum concentration of both the cortex and pith regions of the tuber was significantly increased by both banding and spraying of Na_2MoO_4 (Figure 4). Foliar application resulted in significantly ($p < 0.01$) greater concentration of Mo in the tubers than banding. The Mo concentration of tubers given the highest level of Na_2MoO_4 through foliar application was 2.02 ppm FW. A meal consisting of 250 g of potato would provide 0.5 mg of Mo, which is several times lower than the toxic intake of 10–15 mg/day but adequate to supply the recommended dietary allowance of 75–250 μg/day (National Research Council, 1989).

Conclusions. Banding and foliar applications of molybdenum, using sodium molybdate as the source of molybdenum, significantly decreased tuber concentrations of the toxicants glycoalkaloids and nitrates. Nitrate reductase activity of leaves and molybdenum concentration of the tuber increased significantly with increasing levels of molybdenum application. Foliar application resulted in greater decreases in the toxicants and increases in leaf nitrate reductase activity and tuber molybdenum concentration than banding. On the basis of the results of this experiment and those reported previously, it is evident that application of molybdenum significantly improves the overall quality of the potato, in terms of both increasing the nutritive value (by increasing vitamin C and protein concentration) and decreasing the levels of the toxic compounds, glycoalkaloids and nitrates. We recommend that in areas where the soil concentration of molybdenum is low, potato plants be supplemented with minute quantities of this element. Further, on the basis of observations of this experiment, foliar spray of molybdenum results in a more efficient use of the element than banding and, hence, this mode of application would be recommended over banding to the soil.

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