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Effect of Magnesium Fertilization on the Quality of Potatoes. Yield, Discoloration, Phenols, and Lipids

Lisa B. Klein, Subhash Chandra, and Nell I. Mondy*

The effect of magnesium fertilization on yield, discoloration, phenols, and lipid content of potatoes was examined during a 2-year study. Magnesium sulfate was applied at rates of 0, 20, 40, and 100 lb/acre. Maximum yield was obtained at 20 lb/acre. Tubers receiving 40 lb/acre $MgSO_4$ discolored significantly less ($p < 0.05$), were significantly lower ($p < 0.05$) in total phenolic content, and were significantly higher ($p < 0.01$) in crude lipid and phospholipid content than the controls.

Potatoes are more sensitive to magnesium deficiency than many other crops (Bolton, 1977), yet such deficiences may be corrected through the use of magnesium sulfate in fertilizers (Houghland and Strong, 1941; Houghland, 1964). In acid peat and sandy soils magnesium deficiency is the principal cause of poor growth (Mulder, 1950). Response to magnesium is particularly apparent on acid and sandy loams which also contain less than 76 lb of exchangeable magnesium/acre and have a pH below 5.5 (Doll and Thurlow, 1965). Sawyer and Dallyn (1966) found that plots of potatoes fertilized with over 40 lb/acre magnesium sulfate (oxide equivalent) tended to depress yield and that 40–60 lb/acre was adequate in building up and maintaining the lower soil levels found on Long Island. Laughlin (1966) observed that soil or spray applications of magnesium sulfate had no significant effect on yield, yet magnesium sulfate was applied to the soil at high rates of 0, 250, and 500 lb/acre. In addition, soil analyses prior to fertilization suggested already high fertility levels ranging from 119 to 350 lb/acre available magnesium. Adams et al. (1978a) observed that yields of tomatoes grown in peat demonstrated an overall increase in yield of 8.6% with added magnesium but neither the quality nor the composition was affected. Adams et al. (1978b) also found, however, that lettuce grown in peat did not respond to added magnesium. These authors suggest that such results are consistent with earlier trials which demonstrate that lettuce is not severely affected by magnesium deficiency, whereas tomato crops are highly susceptible.

Crop fertilization may also affect the quality and chemical composition of the product. Magnesium is essential for the translocation of sugars in potato plants (Lewin and Lewin, 1956). Magnesium sulfate fertilization increases anaerobic respiration, decreases O_2 consumption, increases CO_2 evolution, and increases chlorophyll formation by tubers in the light (Vermes et al., 1974). Magnesium does not appear to affect tuber discoloration consistently, however. Length of time prior to analysis may result in an increase, decrease, of insignificant effect on black spot production in potatoes (Jacob, 1959). Mueller (1976) observed that magnesium-fertilized tubers discolored more than control tubers 1 month following harvest yet discoloration was significantly less than that for controls after 10 months of storage. Supplementation of magnesium with potassium decreased discoloration, whereas magnesium fertilization on its own increased discoloration (Massey, 1952).

Since crop fertilization may affect the chemical composition and quality of the product and thus the ultimate nutritive value and economic return, it is important that the outcome of such agricultural practices be as clearly delineated as possible. This study was therefore undertaken in order to establish the effect of magnesium fertilization on yield, discoloration, and phenolic and lipid contents of Katahdin potatoes grown during 2 successive years.

MATERIALS AND METHODS

Katahdin potatoes grown at the Cornell Vegetable Research Farm in Riverhead, Long Island, during the 1978 (year 1) and 1979 (year 2) growing seasons were used in the studies. Soil type was Riverhead fine sandy loam. Magnesium in the form of magnesium sulfate was banded at planting at rates of 0, 20, 40, and 100 lb/acre. Different plots were used each of the 2 years in order to avoid a cummulative effect. Available magnesium levels on these plots averaged 70 lb/acre. Soil organic matter averaged 2.9%, and soil pH was ~6.1 during both years. The randomized block design contained two replicated plots per treatment, and all plots were irrigated in the same manner during both seasons.

Tubers were harvested 24 weeks after planting and stored at 5 °C for 5 months prior to analysis. Uniform tubers of medium size were sliced longitudinally from bud

Division of Nutritional Sciences and Institute of Food Science, Cornell University, Ithaca, New York 14853.

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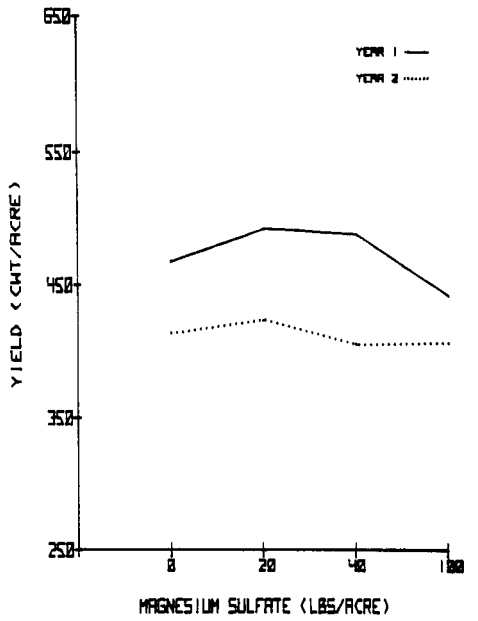

Figure 1. Effect of magnesium fertilization on the yield of Katahdin potatoes.

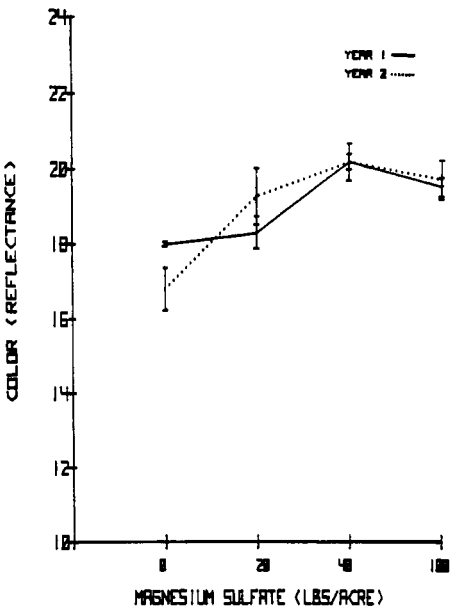

Figure 2. Effect of magnesium fertilization on the discoloration of cortex tissue from Katahdin potatoes. Reflectance value (Rd) decreases as blackening increases.

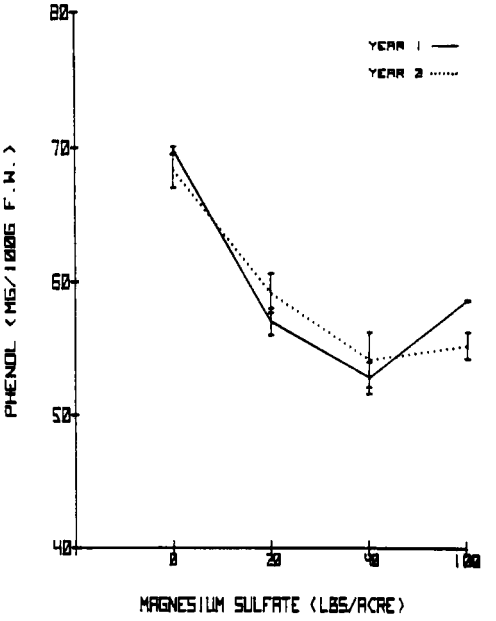

Figure 3. Effect of magnesium fertilization on the phenolic content of cortex tissue from Katahdin potatoes.

to stem and then divided into cortex (including the periderm) and pith sections. Cortex tissue was used for all determinations since this is the area of highest metabolic activity.

Determination of Discoloration. Color measurements were made on potato tissue using the Hunter Color Difference Meter as described by Mondy et al. (1967). Triplicate determinations were made on each treatment.

Determination of Total Phenols. The method described by Mondy et al. (1966) was used for phenol determinations. Triplicate determinations were made on each treatment.

Determinations of Lipid Content. The method described by Mondy et al. (1963) was used for the extraction of the crude lipid. Duplicate determinations were made on each treatment. Crude lipid was fractionated by using the method previously described by Mondy et al. (1965).

Determination of Fatty Acid Composition. Fatty acid composition of the phospholipid portion of each sample was determined following alkaline hydrolysis and fatty acid esterification using methanolic HCl (3 N). A Varian Aerograph (Series 2100) gas chromatograph employing a flame detector cell was used to separate methyl esters of the fatty acids. The stationary phases used were apiezon L., a nonpolar saturated hydrocarbon, and diethylene glycol succinate, a polar polyester of succinic acid. The preparation of the columns and the operating parameters for the instrument have been described in detail by McNair and Bonelli (1967). The techniques described by James (1959) and Hawke et al. (1959) using the relative retention volume on a polar and nonpolar stationary phase and establishing a grid using known acids were employed to identify the fatty acids. The acids were quantitated by peak area integration. Triplicate determinations were made on each sample.

Statistical Analysis. Data were analyzed by using analysis of variance and the L.S.D. multiple test which compares all treatments with each other (Steel and Torrie, 1960).

RESULTS AND DISCUSSION

Yield. For each of the 2 years, maximum yield accompanied the application of magnesium sulfate ($MgSO_4$) at the level of 20 lb/acre, but the yield was depressed when the level of Mg exceeded 40 lb/acre (Figure 1). This finding is in agreement with Sawyer and Dallyn (1966). Generally the yields obtained at all levels of magnesium fertilization were higher during the first year of the study. This was probably due to seasonal variation.

Discoloration. Tubers receiving 40 lb/acre $MgSO_4$ discolored significantly less ($p < 0.05$) than controls (Figure 2). These results are in agreement with those found previously in our laboratory (Mueller, 1976).

Phenols. During both years of the study all levels of magnesium application reduced significantly ($p < 0.05$) the total phenolic content of tubers (Figure 3). Mondy et al. (1967) observed a significant positive correlation ($r = +0.83$) between total phenolic content and tuber discoloration. Lower phenolic content not only reduces susceptibility of tubers to black spot but also reduces the bitter taste (Mondy et al., 1971).

Lipid Composition. During both years of the study, tubers receiving 40 lb/acre $MgSO_4$ were significantly higher ($p < 0.01$) in crude lipid and phospholipid contents (Fig-

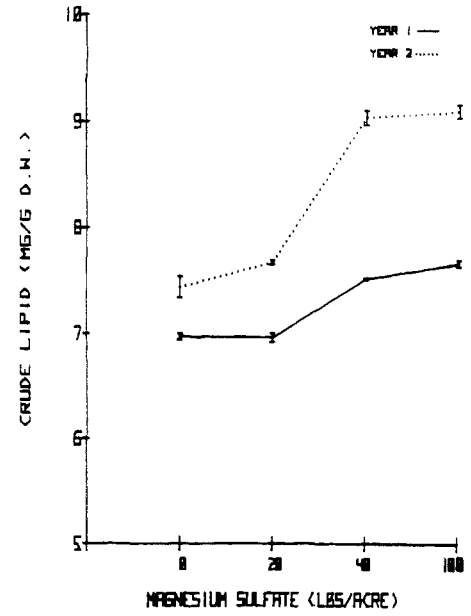

Figure 4. Effect of magnesium fertilization on the crude lipid content of cortex tissue from Katahdin potatoes.

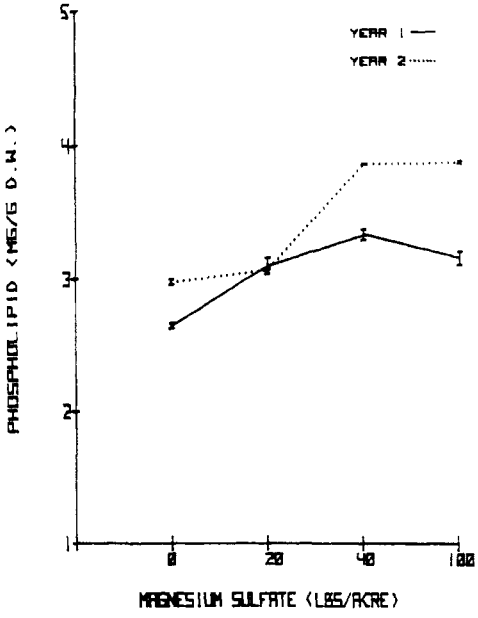

Figure 5. Effect of magnesium fertilization on the phospholipid content of cortex tissue from Katahdin potatoes.

ures 4 and 5). Magnesium may affect lipid synthesis by functioning as a cofactor in the formation of CoA derivatives which are involved in fatty acid synthesis. Magnesium is required for the carboxylation of pyruvic acid to form acetyl-CoA. It is also involved in the acetic thiokinase system during acetyl-CoA production from ATP and acetate and is required for the production of malonyl-CoA from acetyl-CoA. In addition, magnesium is necessary for the esterification of phosphorus into ATP and during the inclusion of phosphorus into phospholipids by mitochondria (Mazelis and Stumpf, 1955).

Lipids are extremely important in the structure and functioning of membranes found in the potato tuber and may play a role in determining potato tuber susceptibility to discoloration. Darkening of tuber results from the reaction of phenolic substances with polyphenol oxidase. Tubers with a higher lipid content have been shown to be less susceptible to damage following bruising (Mondy and Koch, 1978). Reduced rupturing may therefore decrease the opportunity for phenolase enzymes to interact with

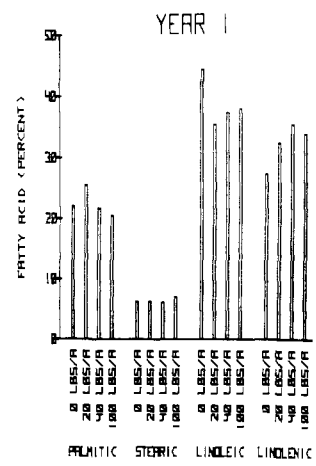

Figure 6. Effect of magnesium fertilization on the fatty acid composition of cortex tissue from Katahdin potatoes grown during the 1978 (year 1) growing season.

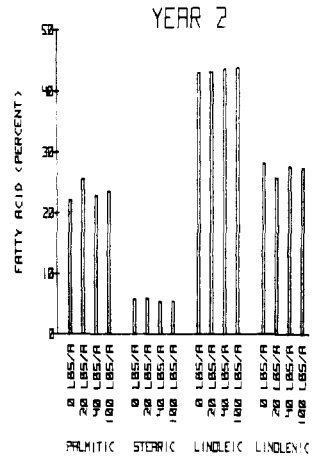

Figure 7. Effect of magnesium fertilization on the fatty acid composition of cortex tissue from Katahdin potatoes grown during the 1979 (year 2) growing season.

phenolic substances which are normally separated by vacuolar membranes, thus resulting in reduced enzymatic discoloration. An increase in both crude lipid and phospholipid contents of Katahdin potatoes following magnesium fertilization is in agreement with preliminary studies from our laboratory (Mueller, 1976).

The content of linoleic acid in potatoes treated with $MgSO_4$ was significantly reduced ($p < 0.05$), while the content of linolenic acid was significantly increased ($p < 0.05$) during year 1 (Figure 6). However, no significant changes were observed in any of the fatty acids during year 2 (Figure 7). These differences may be attributed to seasonal variation.

Alteration in the chemical composition of tubers following the application of magnesium sulfate at the rate of 40 lb/acre resulted in tubers of better quality than the controls. Magnesium fertilization is therefore very important in the metabolism of potatoes and should be carefully controlled for the production of tubers of desirable quality.

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Fate of Radioactive Melengestrol Acetate in the Bovine

Leo F. Krzeminski,* Byron L. Cox, and Ronald E. Gosline

Melengestrol acetate (17-hydroxy-6-methyl-16-methylenepregna-4,6-diene-3,20-dione acetate; MGA; The Upjohn Co.) is an effective oral progestational agent. Studies with orally fed MGA, 21 days for tritium and 7 days for carbon-14 labeled, showed that the radioactivity was eliminated from the heifers via the feces and urine in a 6:1 ratio. Fat contained the highest concentration of the "marker compound" MGA (83% of the total radioactivity or 6 ppb) and was established as the "target tissue". Liver, with the highest level of radioactivity, contained only 29% MGA (3.5 ppb of [^{3}H]MGA) or 37% MGA (3 ppb of [^{14}C]MGA). Radioactivity in the muscle was in most cases below the limit of detection, i.e., 0.5 ppb. The non-MGA fraction in both the tritium and carbon-14 studies contained numerous metabolites, all below 1 ppb.

Melengestrol acetate (17-hydroxy-6-methyl-16-methylenepregna-4,6-diene-3,20-dione acetate; MGA; The Upjohn Co.) has been shown to be an effective oral progestational agent (Zimbelman and Smith, 1966a,b) when incorporated into the diet of feedlot heifers at levels up to 0.5 mg head^{-1} day^{-1} to increase feed efficiency and rate of gain (Bloss et al., 1966). MGA was approved in Feb 1968 by the Food and Drug Administration (FDA) for use in feedlot heifers (*Fed. Regist.*, 1968, 1969) with a dose range of 0.25–0.50 mg head^{-1} day^{-1}.

Since MGA is administered to food-producing animals for 140–185 days, radioactive studies were carried out to determine the fate of MGA in feedlot heifers. Tracer studies were designed (1) to determine the distribution of radioactive MGA in various tissues, (2) to determine whether MGA was present intact in fat, muscle, kidney, and liver, (3) to determine whether the present assay method (Krzeminski et al. 1976) would extract and quantitate all of the MGA present in tissues, (4) to identify the "marker compound" and "target tissue", and (5) to determine the extent of metabolism in the target tissue.

EXPERIMENTAL SECTION

Radioactive [^{3}H]MGA Dose. Two-dose lots of tritium-labeled MGA (Figure 1) (500 mCi/mM; New England Nuclear) were prepared by dilution with unlabeled MGA. This gave a daily dose for one heifer of 105.6 μCi, 0.508 mg/capsule (sp act. 4.79 × 10^2 dpm/ng), and for the other two heifers a daily dose of 102.2 μCi, 0.558 mg/capsule (sp act. 4.06 × 10^2 cpm/ng). All doses were prepared by pipetting aliquots of labeled MGA in acetone onto sugar contained in gelation capsules.

Radioactive [^{14}C]MGA Dose. Carbon-14-labeled MGA (Figure 1) (55.4 mCi/mM; New England Nuclear) was diluted with unlabeled MGA and the specific activity determined by GLC/EC measurement and scintillation counting. The total amount of labeled [^{14}C]MGA was divided among seven capsules to provide a daily dose of 254 μCi, 0.495 mg/capsule (sp act. 1.14 × 10^2 dpm/ng).

Animal Treatment ([^{3}H]MGA). Three young Angus–Hereford heifers were housed in individual box stalls and fed 8 kg of a complete ground ration (nonmedicated) head^{-1} day^{-1} plus 1 lb of the supplement (medicated, 0.5 mg of MGA/lb) head^{-1} day^{-1} for 4 months. The heifers were moved sequentially into the metabolism stall, acclimated for 1 week, and dosed daily with [^{3}H]MGA capsules for 21 days. While on the [^{3}H]MGA treatment, each heifer was fed 4.0 kg of the complete ration (nonmedicated) head^{-1} twice daily. Water was provided ad libitum. Rectal temperature and general physical condition were monitored daily.

Animal Treatment ([^{14}C]MGA). One young Angus–Hereford heifer was housed in an individual box stall and

Biochemistry and Residue Analysis, Agricultural Division, The Upjohn Company, Kalamazoo, Michigan 49001.

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