# Effects of Atrazine and Maize Dwarf Mosaic Virus Infection on Weight and Macro and Micro Element Constituents of Maize Seedlings in the Greenhouse

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Tabular data (as replication means) for both experiments are available upon request from Herbert Cole, Buckhout Laboratory, The Pennsylvania State University, University Park 16802.

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ABSTRACT

The criteria of maize dwarf mosaic expression and virus transmissibility as indicators of maize dwarf mosaic virus (MDMV) infection showed that the resistant maize hybrid Pa 54 × Pa 11 and the partially resistant hybrid WF9 × B14 became progressively more susceptible to MDMV with increasing levels of atrazine (2-chloro-4-ethylamino-6-isopropylamino-*s*-triazine) up to 100% infection at 20 ppm atrazine. MDMV inoculation and the addition of 1 ppm or more atrazine resulted in reduced fresh wt. In some instances, the effect of atrazine on fresh wt was interrelated with MDMV inoculation, in that MDMV inoculation counteracted the weight-reducing effect of atrazine at 1 and 5 ppm. The effect of atrazine on element concentrations varied with time, hybrid, MDMV inoculation, and the quantity of atrazine added to the soil. In general, P, K, Ca, Fe, Cu, B, Al, Sr, and Zn within the foliar tissues increased in the presence of atrazine. MDMV inoculation effects on foliar element levels were related to other factors, but over-all, P, K, Mn, Cu, and B increased in inoculated plants. Phytopathology 60:272-279.

Cole et al. (3, 4) studied the effect of several fungicides, nematicides and persistent chlorinated insecticides on corn and bean plants. Element analysis of the foliage of pesticide-treated plants showed significant shifts in accumulation of macro and micro element constituents of these crop plants.

A few instances of predisposition of and/or synergism with plants to virus infection by pesticides has been reported. Ulrychova & Blattny (25) described a synergistic effect between 2-chloro-4, 6 bis [ethylamino]-triazine (Simazine) and plant viruses causing a decline of Simazine-treated, virus-infected plants. A synergistic effect between Simazine and plant viruses was observed for tobacco plants infected with tobacco mosaic virus, for alsine affected with viruslike "jaundice" (similar to aster yellows), and for hop and potato plants with certain other viruses. Millikan et al. (16) reported reduced zinc and RNase activity and an increase in RNA when dwarf-mosaic-virus-infected plants were watered with a mixture of 1-ppm solution of 3-amino-1,2,4-triazol (Amitrole) and Simazine. Amitrole and Simazine, singly or combined, did not increase host sensitivity to the viral infection.

Maize dwarf mosaic (MDM) symptoms were first observed in the Ohio River Valley in 1962. The subsequent rapid increase in reported collections of maize dwarf mosaic virus (MDMV) probably reflects increasing awareness of the disease more than its continued spread. Two strains of MDMV have been reported (13, 15), and the combined geographic distribution of strains A and B includes most of the corn belt of the United States. The potential destructiveness of MDMV is difficult to assess. Estimated losses to MDMV for 1964 in Ohio totaled 5,000,000 bushels of corn worth $5,850,000 (12). Cole et al. (5) reported field experiments which indicated 43.7% reduced total green wt with 100% MDMV infection of a susceptible hybrid. Protracted, MDMV infection in that experiment would have accounted for a loss of 9.6 tons of silage/acre.

Intensive breeding efforts to obtain MDMV-resistant hybrids have been initiated in many states in an effort to replace MDMV-susceptible varieties. Because of the widespread use of atrazine on corn fields for weed control, and in light of the apparent synergism of viruses and certain herbicides, it seemed appropriate to determine if any interrelationships could be demonstrated between MDMV and atrazine.

The two experiments reported here were undertaken to study the effects of MDMV infection and atrazine both alone and in combination on the growth of 3 single-cross dent corn hybrids in the greenhouse during and immediately after the seedling stage. At this stage, corn plants appear to be most susceptible to MDMV infection. Growth criteria employed were fresh and dry wt and accumulation of 11 macro and micro elements.

MATERIALS AND METHODS.—Experimental procedures were similar for both experiments. The soil mix was composed of 3 parts Hagerstown silty clay loam: 1 part sand: 1 part peat. After steam treatment in a stationary bin for 30 min at 100 C, soil lots were blended to remove any heterogeneity caused by steam treatment. Soil moisture content after steaming approximated field capacity. After blending and allowing to cool to room temperature, atrazine was mixed with soil on a chemical wt to soil wt at field-capacity moisture-level basis to achieve the desired ppm concentration. The atrazine employed was an 80% w.p. commercial formulation with quantities computed on the basis of active ingredients. Atrazine was blended with soil in a cement mixer, and the soil-atrazine mixture apportioned by wt to new polystyrene pots. Each treatment consisted of four pots. Five seeds were planted/pot. The seedlings were manually inoculated with MDMV strain A (15) (isolate "Wooster") by Corundum-gauze pad rubbing at the three-leaf stage with infective homogenate from MDMV-infected SX60 hybrid seedlings. The check plants were rubbed with phosphate buffer only. Each pot was thinned 7 days later to four plants/pot in the first experiment and three plants/pot in the second. Both experiments were factorial in design. For the seedlings' wt and symptom data, each pot was a replicate. Thus, each treatment consisted of four replicates. All plants in a pot were handled together regardless of the differential expression of symptoms within a pot. The factorial design allowed statistical evaluation of the main effects of the tested factors as well as evaluation of all possible statistical interactions between factors. Suitable checks were included for all factors studied within each experiment to permit evaluation of the influence of any one or more factors. Data were analyzed statistically by "Analysis of Variance", Model 2 assumption, with an IBM 7074 computer. A confidence level of 95% or more was selected as indicative of statistically differing means.

Experiment 1 involved the factors MDMV inoculation (strain A), atrazine 1, 5, 10, and 20 ppm, and the maize single crosses Pa 54 × Pa 11 (resistant to MDMV), WF9 × B14 (intermediate in reaction to MDMV), and PAG SX60 (susceptible to MDMV). A total of 480 plants was employed. The pots were seeded 10 July 1967, and the resulting plants were harvested 30 days after seeding. Frequency of occurrence of virus symptoms and types of symptoms appearing were recorded and virus transfers were attempted from all plants. This was done to determine if symptom development could be used as a criterion for indicating virus transmissibility from seedling corn plants. Following the visual evaluation and virus transmission procedures, the seedling plants were cut at the soil line, washed, weighed individually, oven dried (60 C), and reweighed. A mean fresh and dry wt per pot was calculated. The plants within a pot were combined to obtain sufficient material for emission spectrometric analysis of phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), manganese (Mn), iron (Fe), copper (Cu), boron (B), aluminum (Al), strontium (Sr), and zinc (Zn). The method of Baker et al. (1) was employed for sample preparation and analytical procedures.

Experiment 2 included the factors MDMV (strain A), atrazine at 5 ppm, plant age (3, 4, 5, and 6 weeks), and the single cross hybrids Pa 54 × Pa 11, and SX60. The seeds were planted 7 August 1967, seedlings were inoculated at the three-leaf stage, and symptoms were recorded for each plant prior to harvest. Harvest dates were 3, 4, 5, and 6 weeks after planting. Fresh wt, dry wt, and element analyses were conducted as described for the first experiment. The total number of plants involved was 384.

RESULTS.—*Experiment 1.—Symptoms.*—In the absence of atrazine, 100% of the SX60 seedlings and 75% of the WF9 × B14 seedlings developed typical mosaic within 14 days after inoculation with MDMV strain A (Fig. 1-A). Twelve per cent of the Pa 54 × Pa 11 seedlings exhibited chlorotic streak symptoms (associated with virus resistance), and the remaining 88% had no symptoms. No symptoms were observed in the buffer-rubbed check seedlings. Atrazine doses of 1, 5, 10, and 20 ppm with SX60 continued to result in 100% of the inoculated plants with symptoms. With WF9 × B14 at atrazine levels of 1, 5, 10, and 20 ppm, 69, 87, 94, and 100% of the plants showed symptoms, respectively. With Pa 54 × Pa 11 (normally considered very resistant to MDMV) at atrazine doses of 1, 5, 10, and 20 ppm, 19, 38, 94, and 100% of the inoculated plants exhibited symptoms, respectively. At the lower atrazine levels, chlorotic streak symptoms prevailed, while at the higher levels, typical mosaic symptoms similar to the SX60 reaction predominated. Attempted isolations at harvest time from inoculated plants including all symptomless and symptom-expressing types showed without exception that the presence or absence of visual symptoms accurately predicted our ability to transmit or not transmit the virus. Successful transmission was obtained from all seedlings exhibiting symptoms. We were not able to transmit virus from the symptomless plants.

*Weight.*—Significant differences between hybrids' fresh wt were detected, suggesting differing growth rates. SX60 plants weighed less than Pa 54 × Pa 11; WF9 × B14 was intermediate. Atrazine concentration affected all three hybrids similarly, resulting in reduced fresh wt as well as higher moisture contents as the concentration of atrazine increased. The data indicated that SX60 was more drastically affected by atrazine than the other two hybrids.

A trend in wt reduction due to MDMV inoculation was noted in the absence of atrazine and at the 10 and 20 ppm atrazine levels. At 1 and 5 ppm atrazine, however, an opposite effect was noted. At these two dosages, virus inoculation tended to counteract the wt-reducing effects of the atrazine.

*Elemental analysis of dry tissues.—Phosphorus.*—The P concentration of the SX60 seedlings inoculated with MDMV was not significantly distinct from the buffer-rubbed check; however, phosphorus levels in Pa 54 × Pa 11 and WF9 × B14 inoculated with MDMV increased significantly (Fig. 1-B, C). Similarly, increasing atrazine (within limits) was associated with increasing P concentration for all hybrids. The effects of MDMV inoculation and atrazine dosage were interre-

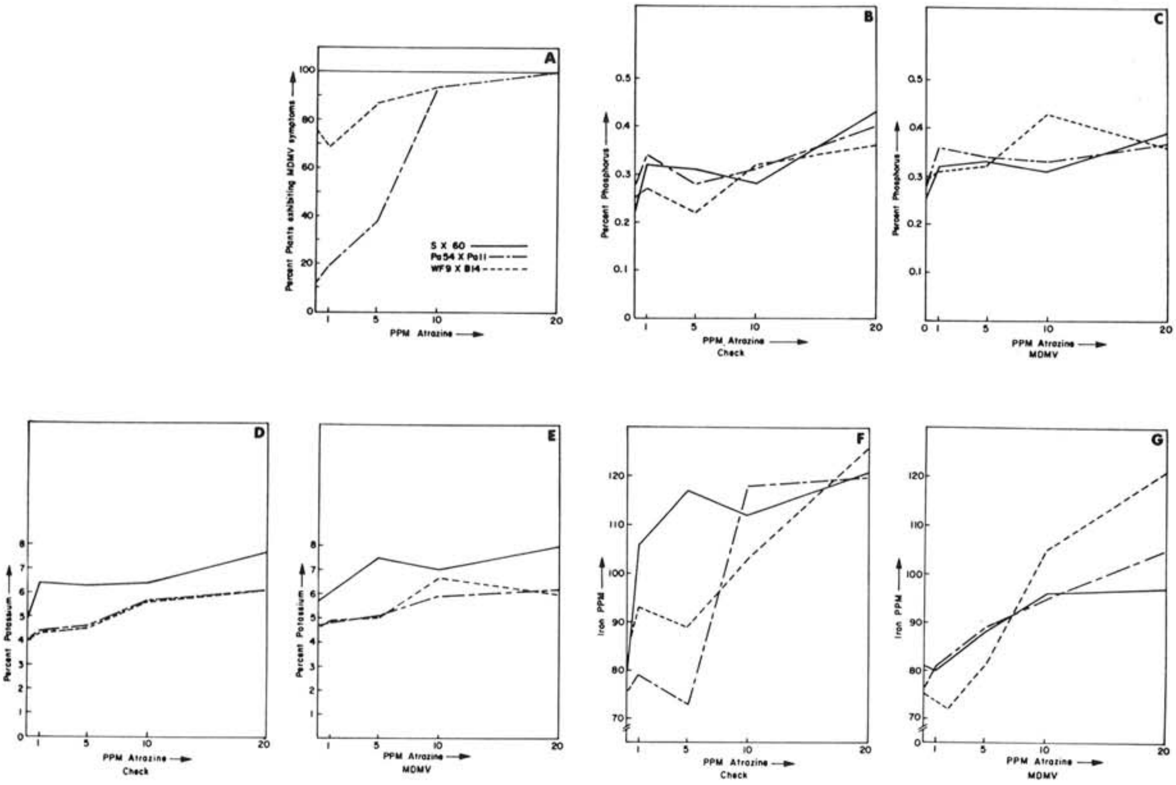


**Fig. 1. A)** Per cent maize seedlings of three single cross hybrids exhibiting maize dwarf mosaic (MDM) symptoms when grown in soil mix amended with differing concentrations of atrazine. Effects of atrazine-soil mix on seedlings of three maize hybrids for the foliar concentration of phosphorus, **B)** noninoculated, and **C)** inoculated with MDMV. Corresponding representation of effects of atrazine and MDMV inoculation on potassium and iron concentrations **D, E,** and **F, G,** respectively.

lated. At 0 and 1 ppm atrazine, no statistically significant difference between the MDMV-inoculated seedlings and check seedlings was evident, but the data suggested an increase in P due to inoculation. At 5 and 10 ppm atrazine, the MDMV-inoculated seedlings contained significantly more P than their noninoculated counterparts. At 20 ppm, no difference was detected.

*Potassium.*—An increase in K was associated with MDMV inoculation (Fig. 1-D, E). The level of K increased as the atrazine dose increased, although hybrid differences were again noted. The concentration of K increased in the inoculated SX60 seedlings, increasing with increasing atrazine up to 20 ppm, while for inoculated Pa 54 × Pa 11 and WF9 × B14 seedlings, K increased with increasing atrazine up to 10 ppm. The increased dosage between 10 and 20 ppm atrazine produced no increase in K for these latter two hybrids.

*Calcium.*—MDMV inoculation and atrazine altered Ca concentration (Fig. 2-A, B), and both factors were independent of each other. MDMV inoculation decreased Ca levels in SX60 seedlings only. No statistically significant shifts in Ca concentration by the addition of atrazine at 5 ppm or less were detected among the hybrids tested. Atrazine at 10 and 20 ppm was associated with marked increases in Ca concentration for Pa 54 × Pa 11 and WF9 × B14, and to a significantly lesser extent for SX60.

*Magnesium.*—Atrazine at 20 ppm reduced levels of Mg with SX60 seedlings, but tended to raise the levels in the other hybrids. MDMV inoculation did not significantly affect Mg levels.

*Manganese.*—The hybrids differed in response to both MDMV inoculation and atrazine (Fig. 2-C, D). With the noninoculated plants, the general effect was a prominent increase in Mn concentration at 1 and 5 ppm atrazine. MDMV inoculation modified this response, resulting in a suppression of Mn concentration. MDMV inoculation in the absence of atrazine resulted in increased total Mn levels.

*Iron.*—Increasing concentrations of atrazine resulted in increased concentrations of Fe (Fig. 1-F, G). This effect was hybrid-dependent. Noninoculated SX60 responded to a greater extent to the lower levels of atrazine than did Pa 54 × Pa 11 or WF9 × B14. However, at 20 ppm atrazine, the effect was the same on all hybrids. MDMV inoculation caused reduced Fe concentration in SX60 seedlings, but not Pa 54 × Pa 11 or WF9 × B14 seedlings.

*Copper.*—Cu response to increasing amounts of atrazine varied. Increasing atrazine was associated with increased copper in noninoculated WF9 × B14 and Pa 54 × Pa 11; however, with SX60 Cu, levels dropped at the 10- and 20-ppm dosage. The effects of MDMV inoculation on Cu were dependent on the hybrid and

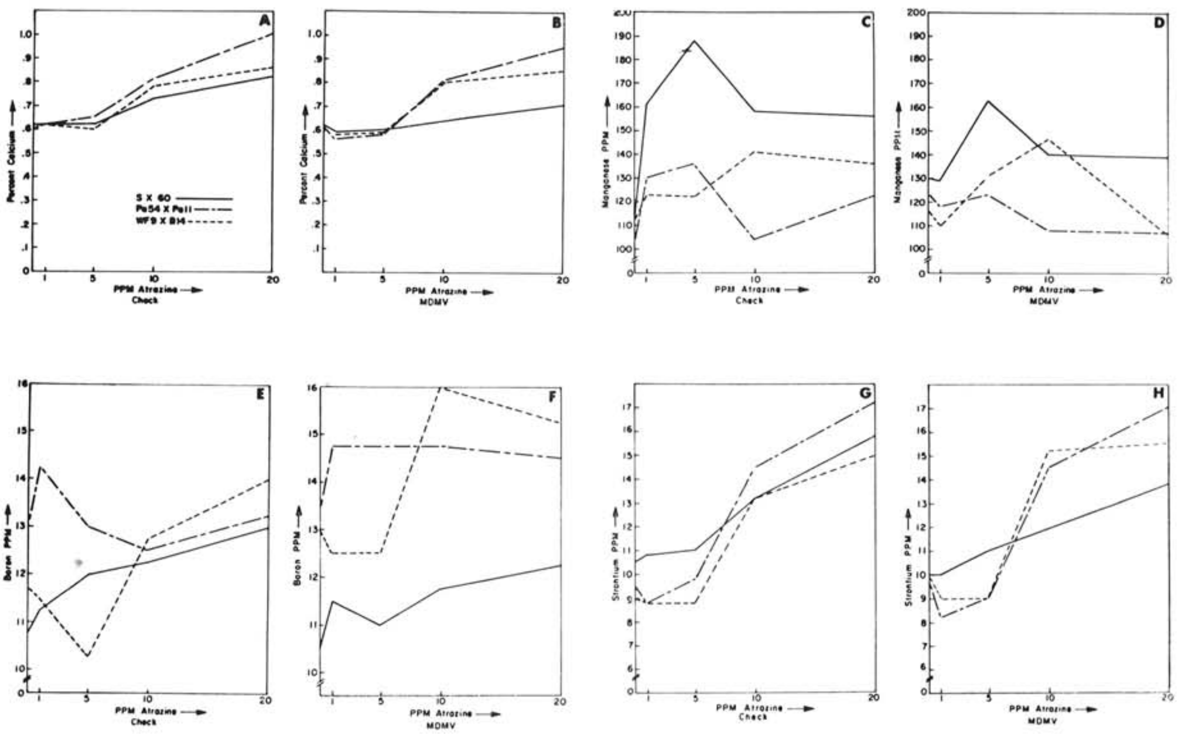


**Fig. 2.** Effects of atrazine-soil mix on seedlings of three maize hybrids noninoculated and inoculated with maize dwarf mosaic virus for the foliar concentrations of calcium, manganese, boron, and strontium **A, B; C, D; E, F;** and **G, H,** respectively.

the atrazine dosage. Inoculation of SX60 resulted in an apparent "sensitivity shift" from 5 ppm toward 10 ppm atrazine, with 20 ppm having the same Cu level as no atrazine.

Inoculation of Pa 54 × Pa 11 and WF9 × B14 partially suppressed the effects of 10 and 20 ppm atrazine on Cu elevation.

*Boron.*—MDMV inoculation resulted in increased B levels in the Pa 54 × Pa 11 and WF9 × B14 seedlings (Fig. 2-E, F). These levels increased with atrazine increases. No response was detected between check and inoculated SX60 seedlings. Increasing atrazine resulted in increased boron in both inoculated and check SX60 seedlings.

*Aluminum.*—In the absence of MDMV, greater quantities of atrazine resulted in a greater concentration of aluminum with all hybrids. The shift from 0 to 1 ppm atrazine resulted in a near doubling of Al levels. The hybrid WF9 × B14, although increasing in Al concentration as atrazine levels increased, exhibited a rapid increase in Al concentration between 5 and 10 ppm atrazine much greater than either of the other two hybrids. The general effect of MDMV inoculation was a suppression of the amount of increase in Al concentration due to atrazine, although the same pattern was evident in inoculated and noninoculated seedlings. One ppm atrazine with inoculated WF9 × B14 and Pa 54 × Pa 11 resulted in a small decrease in Al.

*Strontium.*—High concentrations of atrazine (5, 10, and 20 ppm), gave increased Sr levels (Fig. 2-G, H). This effect differed with the hybrids tested. There was little difference between inoculated and noninoculated plants, although MDMV inoculation, combined with atrazine at 1 and 5 ppm, significantly reduced Sr levels with hybrids Pa 54 × Pa 11 and WF9 × B14, while at 10 and 20 ppm atrazine the results were similar to noninoculated checks. With the inoculated SX60, Sr levels were not decreased, but either remained the same or increased with increasing atrazine across all dosages.

*Zinc.*—Zinc levels increased with 10 and 20 ppm atrazine. MDMV inoculation by itself had little detectable influence on Zn concentration. With inoculated SX60, the Zn level decreased from 0 to 1 ppm atrazine. In the absence of MDMV, Zn concentration was not altered by 1 ppm atrazine relative to the atrazine check.

*Experiment 2.—Symptoms.*—In both the absence and presence of atrazine, typical mosaic symptoms developed on 100% of the SX60 plants within 14 days after inoculation. With Pa 54 × Pa 11 and 0 ppm atrazine, 33% of the plants showed chlorotic streak symptoms, while at 5 ppm atrazine, 50% showed streak symptoms. All equatable comparisons between experiments 1 and 2 indicated that the results were quite similar.

*Weight.*—The effect of atrazine on plant wt was similar to experiment 1. The moisture contents decreased and dry matter increased with increasing plant age of all hybrids. Pa 54 × Pa 11 gained dry matter at a more rapid wt than SX60. Inoculation with MDMV in the absence of atrazine resulted in a consistent trend of decreased wt when compared with noninoculated for

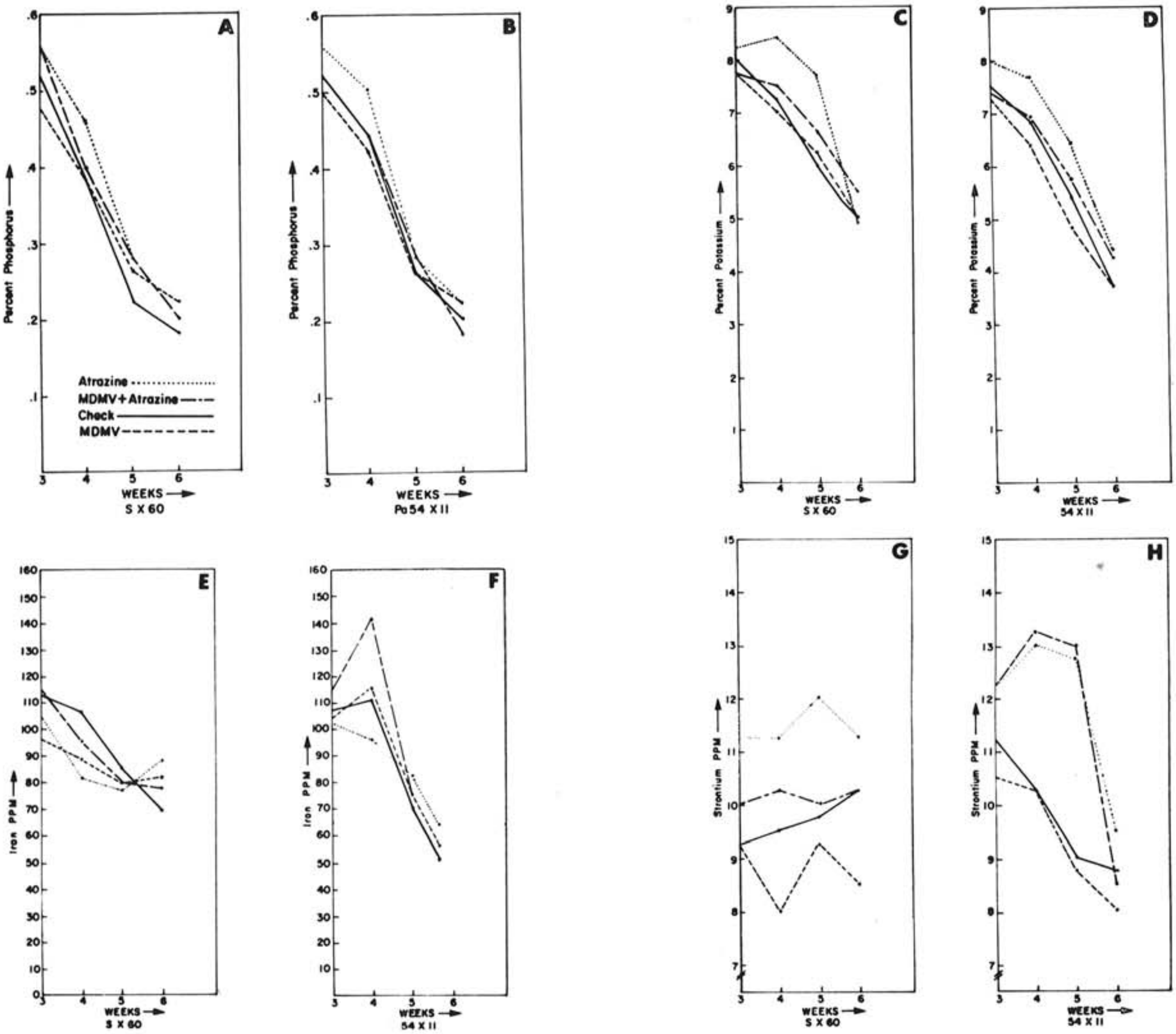


**Fig. 3.** Effects of atrazine-soil mix, maize dwarf mosaic virus inoculation, and time on seedlings of two maize single crosses for the foliar concentrations of phosphorus, potassium, iron, and strontium **A, B; C, D; E, F;** and **G, H,** respectively.

both hybrids at all ages. With 5 ppm atrazine, the results were not as clear-cut; the weight of SX60 was reduced at all plant ages when MDMV and no virus were compared, but Pa 54 × Pa 11 did not indicate any clear trend.

*Elemental analysis of dry tissues.—Phosphorus.*—P concentration decreased with increasing plant age (Fig. 3-A, B). This decrease was affected by both virus inoculation and the presence of atrazine. No differences in P concentration between the MDMV-inoculated and the noninoculated check seedlings were detected at 3, 5, and 6 weeks. However, at 4 weeks' growth stage, the MDMV-inoculated seedlings were significantly lower in P concentration than their check counterparts. The atrazine-treated seedlings at 3 weeks contained significantly more P than the no-atrazine checks. This difference became less and less apparent with time, until no significant difference between the treatments was detected after 6 weeks. When one statistically compares all hybrids irrespective of time, an MDMV × atrazine interaction for phosphorus is apparent. Atrazine and MDMV inoculation in combination, although significantly greater in P content than the no atrazine-no virus check plants, were significantly less than the atrazine-no virus plants. This relative decrease could not be accounted for by a simple additive effect of MDMV inoculation. No significant effect of MDMV inoculation alone was detected.

*Potassium.*—The effects of atrazine and MDMV inoculation on K were influenced by time (Fig. 3-C, D). The concentration of K decreased over time, but was affected by both MDMV inoculation and the presence of atrazine for both hybrids. The same statistical interaction pattern was present for K concentration as affected by MDMV inoculation as was described for phosphorus. Significant variation occurred at 4 and 5 weeks, but not at 3 and 6 weeks. Conversely, the interaction of the effects of atrazine over time for K were exactly opposite those noted for P. No significant difference between the presence of 5 ppm atrazine and no atrazine at 3 weeks was detected. After 4 weeks, significantly more K was present in the seedlings growing in atrazine-amended soil. This effect also appeared at the 5- and 6-week harvest dates. A statistical interaction between atrazine and MDMV inoculation was evident, and the pattern observed was identical to that described for phosphorus. Noninoculated seedlings treated with 5 ppm atrazine showed significantly increased K concentration over the no-atrazine checks. MDMV inoculation negated the effect of 5 ppm atrazine. This effect could not be accounted for by a simple additive effect of MDMV inoculation. MDMV inoculation alone had no detectable effect on K concentration.

*Calcium.*—The results obtained with Ca were quite similar to experiment 1. The effects did not significantly vary with corn plant age for any of the factors tested.

*Magnesium.*—Mg levels increased with plant age. Atrazine accentuated the increase in SX60 independently of MDMV inoculation. The effect of atrazine on Pa 54 × Pa 11 was dependent on MDMV inoculation.

*Manganese.*—Mn concentration decreased with increasing plant age. After 6 weeks' growth, the amount of decrease was influenced by both the presence of atrazine and MDMV inoculation. Both treatments together decreased Mn levels over the atrazine and MDMV plants singularly. The other results were similar to experiment 1.

*Iron.*—The foliar concentration of Fe decreased with increasing time (Fig. 3-E, F). The rate of decrease was a function of the presence of atrazine and MDMV inoculation with the hybrids responding differently. Noteworthy was the significant increase in Fe concentration of Pa 54 × Pa 11 at 4 weeks' growth attributed to the presence of 5 ppm atrazine and MDMV inoculation. This indicates the importance of time of harvest when attempting to detect factor interactions.

*Copper.*—Cu concentrations decreased with plant age, and the decrease was independent of hybrids, MDMV inoculations, and atrazine treatment.

*Boron.*—B decreased with plant age. Atrazine-treated seedlings declined in B concentration more rapidly than did their counterpart check seedlings to the 4 weeks' stage, after which the atrazine-treated seedling rate of decrease was comparable to the checks. MDMV inoculation resulted in increased boron concentration for both SX60 and Pa 54 × Pa 11 in this experiment.

*Aluminum.*—Atrazine plus MDMV inoculation resulted in greater quantities of Al than in the noninoculated plants. Al generally decreased with plant age through 5 weeks, after which the Al levels increased with all treatments.

*Strontium.*—Sr levels remained constant over time in SX60, and decreased in Pa 54 × Pa 11 (Fig. 3-G, H). Atrazine increased Sr levels in both hybrids. Inoculation with MDMV had no effect.

*Zinc.*—Zn levels decreased with time. Atrazine resulted in increased Zn much the same as experiment 1, but this difference tended to decrease with time. Inspection of the data suggests that MDMV inoculation in both SX60 and Pa 54 × Pa 11 after 6 weeks' growth induced increases in Zn which might have been quite large if the experiments had been continued for a longer period.

DISCUSSION.—Using the criteria of symptom expression and virus transmissibility as evidence of disease susceptibility, the resistant single cross hybrid Pa 54 × Pa 11 and the partially resistant hybrid WF9 × B14 became progressively more susceptible to MDMV with increasing levels of atrazine. Whether this effect is synergism or predisposition we cannot say.

MDMV inoculation resulted in a mean wt reduction for all Pa 54 × Pa 11 plants, even though only 12% of the plants developed symptoms. These results are in agreement with those of Cole et al. (5), who reported that in field experiments MDMV inoculation reduced the green wt of Pa 54 × Pa 11 plants in the absence of symptoms development or transmissibility. Symptoms in Pa 54 × Pa 11 did not appear at any time during the growing season in that experiment.

The effect of MDMV inoculation in partially counteracting the wt-reducing effects of 1 and 5 ppm atrazine supports the puzzling results obtained by Cole et al. (5) in the field, where 6 ppm atrazine soil treatment in the MDMV noninoculated plots resulted in a green wt increase over the no-atrazine plots. The inoculated atrazine-treated plants did not achieve the wt of plants growing in the absence of atrazine, although wt increase did occur. In this experiment, the roots were in a container rather than in a field situation where the roots at least partially outgrew the atrazine-treated area and thus dosages were not comparable. Further experiments are needed to define this interaction, which may be of significance in field use of atrazine in MDMV problem areas.

In the present series of experiments, the experimental design did not lend itself to separation of plants within a treatment. Thus, in a treatment such as inoculated Pa 54 × Pa 11 with 5 ppm atrazine, the seedling wt data as well as the plant analysis data represented the mean of all the plants in the treatment replicates, even though only 38% of the plants developed MDM symptoms. This may have reduced the differences between inoculated and noninoculated plants from those which would have occurred if only the symptom-exhibiting plants were used.

The plant analysis data may be grouped in three categories: (i) main effects from atrazine alone; (ii) main effects from MDMV inoculation alone; (iii) interaction effects of atrazine plus virus inoculation.

It is not possible to make broad generalization in these areas. Effects on macro and micro elements differed with the hybrid. In most instances the levels of P, K, Ca, Fe, Cu, B, Al, Sr, and Zn increased with increasing atrazine levels, although there were exceptions to this depending on the hybrid in question and the atrazine level. MDMV inoculation alone increased P, K, Mn, Cu, and B. This differs somewhat from the previous results of MacKenzie & Cole (14), who reported that Fe and Al were also elevated by MDMV inoculation of Pa 54 × Pa 11 in greenhouse studies.

Plant age affected element levels, and it was noted that Mg increased with plant age, while P, K, Mn, Fe, Cu, B, Sr, and Zn decreased as plant age increased. MDMV inoculation and atrazine modified these changes, but the general direction of the change with time was not shifted in most instances.

Interpretation of the effects of atrazine and MDMV on maize physiology is difficult. It is apparent from our work as well as from that of others that atrazine has complex and varied effects within the plant.

Inhibition of the Hill reaction by *s*-triazines has been reported by Moreland & Hill (17) in isolated chloroplasts from both *s*-triazine tolerant and susceptible species. Maize, a species tolerant to *s*-triazines, is believed to detoxify these compounds to a nonphytotoxic derivative (11, 19). Negi et al. (18) found susceptibility to atrazine roughly correlated with the amount of undegraded atrazine found in the leaves of various species. However, leaf concentrations of unaltered atrazine in maize reported by Wheeler & Hamilton (27) showed a linear increase over time in plants grown in 10 ppm atrazine. They suggested that some components in the corn leaves may bind the herbicide at inactive sites within the leaf tissue or prevent the particular series of reactions which mediate acute toxicity.

In addition to the effect of *s*-triazines on the Hill reaction, atrazine decreased transpiration rates of corn seedlings 44% (20). Atrazine, although not inducing acute toxicity in maize, is not completely inactive.

Zaitlin & Jagendorf (28) described reduced enzymatic activities in the Hill reaction and reduced photosynthetic phosphorylation of isolated tobacco chloroplasts from TMV-infected leaves when compared to healthy chloroplasts.

Increased photophosphorylation associated with turnip yellow mosaic virus in chloroplasts from Chinese cabbage was reported by Goffeau & Bove (6) for local lesion infection. However, once systemically infected, chloroplast activity decreased. These results are in agreement with Spikes & Stout (21), who worked with sugar beet infected with yellows virus.

Tu & Ford (23) reported a 32% increase in respiration 9 days after inoculation with MDMV strain A in systemically infected maize seedlings. This high activity was not maintained, but did remain higher than in comparable healthy leaves. In addition, they found 20 and 25% decreases at 9 and 12 days, respectively, in the photosynthetic rate of systemically infected leaves. Increases in respiration and decreases in photosynthesis were correlated with the appearance of mosaic symptoms. Photosynthesis, which decreased at the time mosaic symptoms were apparent, did not return to the normal rate at any time.

Tu et al. (24) observed that maize and sorghum infected with MDMV strain A and sugarcane mosaic virus strain H not only differed in number, size, and chlorophyll content of chloroplasts, but that the photosynthetic rate was reduced 31%. The decreased photosynthetic rate attributed to virus infection could not be entirely accounted for by decreased chloroplasts and/or chlorophyll in the virus-infected tissues, but was also less efficient than that in healthy leaves.

We feel that the Hill reaction may be a common denominator for the observed breakdown in MDMV resistance of Pa 54 × Pa 11 with increasing atrazine dosage. Wernham & MacKenzie (26) reported that the inheritance of resistance of MDMV strain A in Pa 54 × Pa 11 is conditioned by a single gene. The mechanism(s) conditioned by this gene are not known. It has been suggested that with the Hill reaction reduced or inhibited, cyclic photophosphorylation (i.e., linkage of reductant compounds generated in the light reaction to the electron transport system overstepping the Hill reaction) may be expressed in green plants. Ulrychova & Blattny (25) noted that the synergistic effects of Simazine and plant viruses were observed in the spring and fall, but not in the summer. Perhaps light and therefore photosynthetic rates may be an important factor.

We do not intend to exclude other environmental factors. In some instances, the results of one experiment appear to contradict the results of another. This may, in fact, be more of a reflection of the influence of the environment on the host or age of the host, etc., in addition to the factors we have tested. All of these factors must contribute to the physiological state of a plant, and hence to its constituent elements.

Accumulation of macro and micro elements in maize is conditioned genetically (2, 7, 8, 9, 10, 22). Alteration of element levels by atrazine and MDMV as described in this paper now permit evaluation of these elements as indications of physiological alteration. Interpretation of each element shift is, at this time, impossible. However, certain specific interactions such as those observed for Cu, Mn, P, and other elements, suggest directions for future research, and lend supporting evidence for hypotheses.

With increasing use of foliar analysis and foliar element levels as criteria for fertilization programs in many types of crops, it is apparent that work of this sort must take into account modification of foliar element levels by herbicide treatments as well as systemic virus diseases of the crop and possible interactions between the two.

## LITERATURE CITED

1. Baker, D. E., G. W. Gorsline, C. B. Smith, W. I. Thomas, W. E. Grube, & J. L. Ragland. 1964. Technique for rapid analysis of corn leaves for eleven elements. Agron. J. 56:133-136.
2. Barber, W. D., W. I. Thomas, & D. E. Baker. 1967. Inheritance of relative phosphorus accumulation in corn (Zea mays L.). Crop Sci. 7:104-107.
3. Cole, H., D. MacKenzie, C. B. Smith, & E. L. Bergman. 1968. Influence of various soil incorporated fungicides and nematocides on macro and micro element constituents of *Zea mays* and *Phaseolus vulgaris*. Bull. Env. Contam. and Toxicol. 3:116-126.
4. Cole, H., D. MacKenzie, C. B. Smith, & E. L. Bergman. 1968. Influence of various persistent chlorinated insecticides on the macro and micro element constituents of *Zea mays* and *Phaseolus vulgaris* grown in soil containing various amounts of these materials. Bull. Env. Contam. and Toxicol. 3:141-154.
5. Cole, H., D. R. MacKenzie, & C. D. Ercegovich. 1968. Maize dwarf mosaic—interactions between virus-host-soil pesticides for certain inoculated hybrids in Pennsylvania field plantings. Series 1. Main effects of virus and chemicals on yield. Plant Dis. Reptr. 52:545-549.

6. GOFFEAU, A., & J. M. BOVE. 1965. Virus infection and photosynthesis. 1. Increased photophosphorylation by chloroplasts from Chinese cabbage infected with turnip yellow mosaic virus. Virology 27:243-252.

7. GORSLINE, G. W., D. E. BAKER, & W. I. THOMAS. 1965. Accumulation of eleven elements by field corn (*Zea mays* L.) Bulletin 725. The Penn. State Univ., College Agr., Agr. Exp. Sta., Univ. Park. 34 p.

8. GORSLINE, G. W., J. L. RAGLAND, & W. I. THOMAS. 1961. Evidence for inheritance of differential accumulation of calcium, magnesium, and potassium by maize. Crop Sci. 1:155-156.

9. GORSLINE, G. W., W I. THOMAS, & D. E. BAKER. 1964. Inheritance of P, K, Mg, Cu, B, Zn, Mn, Al and Fe concentrations by corn (*Zea mays* L.) leaves and grain. Crop Sci. 4:207-210.

10. GORSLINE, G. W., W. I. THOMAS, D. E. BAKER, & J. L. RAGLAND. 1964. Relationship of strontium-calcium accumulation within corn. Crop Sci. 4:154-156.

11. HAMILTON, R. H. 1964. A corn mutant deficient in 2,4-dihydroxy-7-methoxy-1,4-benzoxazin-3-one with an altered tolerance of atrazine. Weeds 12:27-30.

12. JANSON, B. F., L. E. WILLIAMS, W. R. FINDLEY, E. J. DOLLINGER, & C. W. ELLETT. 1965. Maize dwarf mosaic: New corn virus disease in Ohio. Extension Bulletin 460. Research Circular 137. Cooperative Extension Service, the Ohio State Univ., Columbus, and Ohio Agr. Exp. Sta., Wooster. 16 p.

13. MACKENZIE, D. R. 1967. Studies with maize dwarf mosaic virus from the northeastern United States. M.S. Thesis. The Penn. State Univ., University Park. 48 p.

14. MACKENZIE, D. R., & H. COLE, JR. 1968. The effects of maize dwarf mosaic virus on macro and microelement accumulation in coın tissues of resistant and susceptible hybrids. Phytopathology 58:401 (Abstr.).

15. MACKENZIE, D. R., C. C. WERNHAM, & R. E. FORD. 1966. Differences in maize dwarf mosaic virus isolates of the northeastern United States. Plant Dis. Reptr. 50:814-818.

16. MILLIKAN, D. F., J. A. ROSS, & B. ZAWADZKA. 1966. Effect of amitrole, simazine, and dwarf mosaic virus upon the Zn, RNase, Protein and RNA content of Zea mays. Bull. Acad. Polon. Sci. Ser. Sci. Biol. 14:809-811. Abstracted in Research in Toxicology and Pharmacology. 1967. p. 34.

17. MORELAND, D. E., & K. L. HILL. 1962. Interference of herbicides with the Hill reaction of isolated chloroplasts. Weeds 10:229-236.

18. NEGI, N. S., H. H. FUNDERBURK, JR., & D. E. DAVIS. 1964. Metabolism of Atrazine by susceptible and resistant plants. Weeds 12:53-57.

19. SHIMAHUKURO, R. H. 1967. Atrazine metabolism and herbicidal selectivity. Plant Physiol. 42:1269-1276.

20. SMITH, D., & K. P. BUCKHOLTZ. 1962. Transpiration rate reduction in plants with Atrazine. Science 136: 263-264.

21. SPIKES, J. D., & M. STOUT. 1955. Photochemical activity of chloroplasts isolated from sugar beet infected with virus yellows. Science 122:375-376.

22. THOMAS, W. I., & D. E. BAKER. 1966. Application of biochemical genetics in quality improvement and plant nutrition. II. Studies in the inheritance of chemical element accumulation in corn (*Zea mays* L.) Qualitas Plantarum et Materiae Vegetabiles. Vol. 13:98-104.

23. TU, J. C., & R. E. FORD. 1968. Effect of maize dwarf mosaic virus infection on respiration and photosynthesis of corn. Phytopathology 58:282-284.

24. TU, J. C., R. E. FORD, & C. J. KRASS. 1968. Comparisons of chloroplasts and photosynthetic rates of plants infected and not infected by maize dwarf mosaic virus. Phytopathology 58:285-288.

25. ULRYCHOVA, M., & C. BLATTNY. 1961. L'action synergique de la Simazine et des viroses de plantes en tant que methode de la detection eventuelle des maladies a virus. Biologia Plantarum (Prague) 3:122-125.

26. WERNHAM, C. C., & D. R. MACKENZIE. 1966. Genetics of resistance to maize dwarf mosaic virus. Maize Gen. Coop. Newsletter 40:121-122.

27. WHEELER, H. L., & R. H. HAMILTON. 1968. The leaf concentrations of Atrazine in cereal crops as related to tolerance. Weed Science 16:7-10.

28. ZAITLIN, M., & A. T. JAGENDORF. 1960. Photosynthetic phosphorylation and Hill reaction activities of chloroplasts isolated from plants infected with tobacco mosaic virus. Virology 12:477-486.