TRIAZINE HERBICIDES ON CORN AND THEIR RESIDUAL EFFECTS ON FOLLOWING CROPS

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TRIAZINES ON CORN

CHOUDHARY

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AN ABSTRACT OF THE THESIS OF

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Title: Triazine herbicides on corn and their residual effects on following crops.

Six triazine herbicides, namely atrazine, simazine, prometryne, GESARAN, GESAPRIM 1798, and GESAPRIM 1802, were applied each at the rates of 2.5, 5.0, and 12.5 kg (a.i.) per hectare as pre- and post-emergence sprays on corn at the Agricultural Research and Education Center in the Beqa'a plain, Lebanon, in 1965. Data on forage, grain, and other agronomic characteristics of corn were collected. In 1966 only three promising herbicides, atrazine, simazine, and GESAPRIM 1802, were sprayed on forage corn at the rates of 0.62 and 1.25 kg (a.i.) per hectare. In addition unweeded and hand weeded plots were included in each experiment. Residual effects of the herbicides applied in 1965 were studied on wheat, oats, and vetch planted in autumn, and onions, sugar beets, and soybeans planted in the following spring.

Pre-emergence applications of 1.25 and 2.5 kg (a.i.) per hectare of atrazine proved to be the most effective and economical herbicide to be used for the control of broad-leaved weeds in corn. Simazine had an equal or slightly inferior effect at these rates. Also GESAPRIM 1802 showed promise at the rate of 1.25 kg (a.i.) per hectare. Prometryne, GESARAN, GESAPRIM 1798, and GESAPRIM 1802 caused injury to corn at the rates of 2.5 kg (a.i.) per hectare and above.

Among the crops following corn treated with atrazine or simazine at the rate of 2.5 kg per hectare, which caused significant increases in corn yields, sugar beets was injured whereas no injury to any of the remaining five crops was observed.

Post-emergence applications of triazine herbicides on corn were not effective and none of the treatments increased corn yields significantly over the

unweeded plots.

Wheat, oats, vetch, and sugar beets were injured mostly when following corn treated with post-emergence sprays; however onions and soybeans had no visible injury except at the two higher rates of atrazine or simazine and at the highest rate of GESAPRIM 1798 and 1802 tested in 1965.

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I. INTRODUCTION

Corn (*Zea mays* L.) is one of the major feed and food crops of the world. In Lebanon the climatic conditions of the Beqa'a plain are suitable for the growth of this crop. However, water shortage is an acute problem due to the low and untimely distribution of rainfall. Therefore the presence of weeds, a competitor for soil moisture, becomes one of the major limiting factors in the production of corn. In addition, the weeds compete with the crop for nutrients, light, and space resulting in low yields.

Cultivation and handweeding are the only methods of weed control which have been practiced by farmers in Lebanon. Cultivation is not effective in controlling weeds within the rows and handweeding is becoming uneconomical due to the shortage of manual labor. The development of new selective herbicides in corn has made striking progress in the last few years and possibilities are now open for their commercial use. Herbicidal action, however, is influenced by soil type, climate, and time and method of application. Furthermore, the residues may remain in the soil for variable periods of time and may cause injury to subsequent crops that follow in the rotation. It is therefore important to evaluate the herbicides under local conditions in order to give exact recommendations for their use. Todate no experimental work on chemical weed control in corn has been reported in Lebanon.

The purpose of this study was to evaluate the selectivity of different formulations of triazine herbicides in corn and to observe their residual effects on subsequent crops, namely wheat, oats, and vetch planted in the autumn, and onions, sugar beets, and soybeans planted in the following spring. The phytotoxic effects of herbicides on corn, weeds, and the following crops were observed. Forage, grain, and stover yields of corn along with other agronomic characteristics were recorded. The experiments were conducted at the Agricultural Research and Education Center of the American University of Beirut during the years 1965 and 1966.

II. REVIEW OF LITERATURE

Triazine herbicides are widely used in corn for the control of a number of weed species. Depending upon the climatic conditions, soil properties, and formulations and rates of herbicides, toxic residues have been found to persist in the soil for variable periods of time, and injury is caused when sensitive crops follow corn in the rotation. The available literature pertaining to the different aspects of triazine herbicides used in this study is rèviewed.

Mode of Action of Triazine Herbicides

Water solubility is an important property of this group of herbicides (28, p. 107). The solubilities of different triazines in water have been reported. 2-Chloro-4,6-bis-(ethylamino)-s-triazine (simazine) has a solubility of 3.5 ppm (3, p. 1); 2-chloro-4-ethylamino-6-isopropylamino-s-triazine (atrazine), 70 ppm (4, p.1); 2-methylmercapto-4,6-bis-(isopropylamino)-s-triazine (prometryne), 48 ppm (5, p. 1); 2-methylmercapto-4-isopropylamino-6-(γ-methoxypropylamino)-s-triazine (GESARAN) less than 0.1% (6, p. 1); and 2-ethylamino-4-isopropylamino-6-methylmercapto-s-triazine (ametryne)

185 ppm (7, p. 1). Due to the low water and lipoid solubilities of simazine, its phytotoxicity through foliage application is low or negligible (44, p. 292). Davis _et al_. (30) observed that simazine was readily absorbed by the roots of corn, cotton, and cucumber plants but almost no absorption occurred through the intact leaves. Sheets (66, p. 6) showed that C^{14} accumulated in the oldest leaves of a cotton plant grown in a solution containing C^{14}-labelled simazine. It was concluded, therefore, that simazine was carried upward in the transpiration stream and that phloem movement of molecular simazine out of the mature leaves into the growing point probably did not occur. Crafts and Yamaguchi (29, pp. 74-78) found that both simazine and atrazine are absorbed by bean and barley leaves but their movement is acropetal in the apoplast, with no movement taking place in the symplast. Roots of the two plant species absorb these compounds and translocate them to the top of the plant via the xylem.

It has been found by several workers that simazine and its analogs inhibit photosynthesis because they interfere with the Hill reaction. With simazine, 50 per cent inhibition of the Hill reaction was obtained at a concentration of 7×10^{-7}M. In this test atrazine was 1.8 to 2.1 times as effective in its inhibition as simazine (34, p. 117); ametryne was 6.1 and prometryne was 6.1 to 9.1 times as effective (44, p. 333). Moreland *et al*. (56) found that simazine inhibited the photochemical activity of isolated chloroplasts and that a supply of exogenous glucose can overcome the toxicity symptoms of simazine in intact barley plants. It was observed by Allen and Palmer (1) that toxic effects of simazine to barley were avoided by feeding plants with sucrose, glucose, aspartate, or maltose. Similarly Eastin *et al*. (31) observed that both glucose and sucrose supplied to the treated plants protected a susceptible inbred line of corn from the toxic effects of atrazine and simazine.

Ashton *et al*. (19) reported that simazine inhibited CO_2 fixation in the light in *Phaseolus vulgaris* L., the red kidney beans. Atrazine inhibited the CO_2 fixation by red kidney beans in the light but had no effect on the dark CO_2 fixation (83). Atrazine also showed a complete blockage of sucrose synthesis in the light. Ashton *et al*. (18) observed a drastic alteration in the structure of the chloroplasts of atrazine-treated *Phaseolus* plants kept in the light, but there was no effect on the chloroplasts in plants kept in the dark. It was, therefore, proposed that these changes are brought about by the formation of a toxic substance or substances which involve the interaction of atrazine and light in the presence of chlorophyll. Ashton (16) found also that the degree of injury by atrazine was a function of the light intensity. The higher the light intensity the greater was the injury. Studies on the action spectrum indicated that chlorophyll was the principal absorbing pigment involved (16). In a recent publication, Ashton et al. (17) found no effect of atrazine on the structure of chloroplasts of Chlorella. The reason might be that the Chlorella plants are grossly different phylogenetically than Phaseolus and exist in a different environment (17).

Attempts have been made to find out the factors which are responsible for the different sensitivities of various test plants to triazine herbicides. Davis et al. (30) found that simazine moved readily into the roots of resistant and susceptible plants. The resistance of plants to the triazine herbicides, therefore, cannot be explained by the amount of chemical absorbed. It has been shown that the conversion of simazine to hydroxysimazine, 2-hydroxy-4,6-bis(ethylamino)-s-triazine, rendered the compound non-phytotoxic (26, 45). However hydroxysimazine is not the only degradation product since it has been observed that the plants treated with C^{14}-labelled simazine respire $C^{14}O_2$ (39). Similar degradation products of atrazine have been reported (55, 58).

Tolerance of corn to chloro-triazines has been ascribed to its ability to detoxify the herbicides (45, 55, 58). Roth, as reported by Crafts (62, p. 121), observed that extracted juice of corn metabolized simazine within 100 hours. In contrast, over 90 per cent of the simazine added to juice of wheat, a susceptible plant, could be recovered. Montgomery and Freed (55) found that simazine and atrazine were metabolized by corn plants _in vivo_. Only trace amounts of these compounds remained unchanged in the plant. Hamilton and Moreland (45) found that simazine is converted to hydroxysimazine by corn _in vivo_ and _in vitro_. Negi _et al_. (58) tested a wide variety of plants ranging from extremely resistant, such as corn, to susceptible plants such as oats. All plants were able to convert some atrazine to hydroxyatrazine, 2-hydroxy-4-ethylamino-6-isopropylamino-s-triazine, and the amount of hydroxyatrazine formed correlated positively with plant resistance.

Only one report is available on the metabolism of methylmercapto-triazines by corn. Freed, as reported by Montgomery and Freed (37), observed that corn has a limited ability to metabolize prometryne.

The work so far reviewed reveals that the major site of action of triazine compounds is a blockage in photosynthesis. Corn is able to detoxify the chlorotriazines but has a limited ability for the breakdown of methyl-mercapto analogs. Apparently the system responsible for the conversion of chloro-triazines to hydroxytriazines is not active in the case of methyl-mercapto derivatives.

Factors Affecting Availability and Persistence of Triazines

Adsorption and movement in the soil play an important role in the availability and persistence of herbicides. Correlations between certain soil properties and herbicidal activity in the soil have been reported (46, 67, 76).

The organic matter content of the soil seems to be the most important factor in the effectiveness of soil-applied triazines. Upchurch and Mason (76) observed that adsorption of twelve different herbicides, including simazine, occurred in various types of soils and greatly affected their toxicity. Approximately five times more herbicide was required in soils having 20 per cent organic matter than in soils with 4 per cent organic matter to give equal toxicity, regardless of the herbicide involved (76). It has been observed that with an increase in the organic matter content of the soils the extent of adsorption of herbicides is increased; consequently less amount is available to affect plants (43, 46, 47, 67, 74).

Sheets (65) observed that the toxicity of simazine was higher in a sandy loam soil than in a clay loam. In heavy soils simazine remained in the upper 0 to 4 cm layer of soil even after considerable precipitation (24). Increased amounts of organic matter and/or clay in a soil generally were associated with increased adsorption (21, 57, 74). On the other hand Harris and Sheets (46) and Sheets et al. (67) found poor correlation between adsorption and clay content. Grover (43) observed that at high moisture levels in the soil, changes in the relative amount of clay did not affect the toxicity of simazine. Adsorption is also affected by the type of clay (74). The highest adsorption of simazine or atrazine took place on montmorillonite with no adsorption detected on kaolinite. Illite was intermediate in its adsorptive capacity.

Simazine ED_{50} values (effective dose to reduce the fresh weight by 50%), using oats as a test plant, have been positively correlated with cation exchange capacity (67, 76). Correlation coefficients between per cent adsorption of simazine and cation exchange capacity of the soil were highly significant (46).

The effect of pH on adsorption and toxicity of triazine herbicides has been reported. Burnside et al. (23) observed that low pH caused a significant deactivation of simazine in water suspension. In simple correlation analysis, the simazine ED_{50} values were negatively correlated with pH. But the multiple regression analysis indicated that the negative correlation between the simazine ED_{50} and pH was a consequence of the correlation between organic matter and pH (67). Correlation between adsorption and pH was poor but there was a significantly negative correlation between simazine ED_{50} values and pH (46). Increasing the pH resulted in decreased adsorption of atrazine and simazine (74). Nearpass (57) found that adsorption of simazine by 18 soils was not correlated with soil pH but was highly correlated with titratable acidity.

Water plays an important role in the availability as well as the persistence of herbicides in soils. Burnside and Behrens (21, p. 153) observed an increase in weed kill with an increase in the amount of water applied. Foy (36) found that foliar penetration and acute toxicity of the five chlorotriazines and prometone, following drop application to several crops including corn, appeared to be correlated with their water solubilities. Toxicity of simazine was reduced with a reduction in the soil moisture content (43).

Burnside _et al_. (23) found that simazine was leached into Waukegan silt loam by percolating water, indicating that this could be a factor in simazine dispersion into the soil. It was observed that under high rainfall conditions disappearance of triazine herbicides was relatively rapid as compared to that of low rainfall on the same soil (20, 47).

Apart from the effect of the amount of water, the method of application is important. Ashton (15) observed that urea and triazine herbicides applied to the soil surface and subjected to furrow irrigation, in the absence of rain or overhead irrigation, remained close to the soil surface. When triazines were incorporated in the soil there was some downward movement, however lateral movement was much pronounced (15). Water solubility of individual herbicides is important. Atrazine showed more leaching than did simazine (22).

Microorganisms play an important role in the decomposition of simazine in soils (61, pp. 81-83). Deactivation of simazine occurred under conditions conducive to microorganism growth (23, 24, 73), and was highly dependent on temperature and the amount of humus present (24).

Uptake and decomposition by plants is another source of the loss of herbicides from the soil. Repeated cropping of soybeans in simazine containing soil resulted in reduced toxicity to subsequent crops (23).

It appears, from the work reviewed above, that cation exchange capacity of the soil,organic matter, amount of water applied, and solubility of the particular herbicide involved are most important factors in the availability and persistence of triazines. In addition the method of application of water and favorable conditions for microorganism growth have an important bearing on herbicide residues in the soil. Clay content and pH of the soil have been subjects of controversy concerning their effect on the herbicidal action of soil-applied triazines.

Effects of Herbicides on Corn and Weeds

Chloro-triazines: McWhorter and Holstun (54) found seven chlorotriazines, including atrazine and simazine, to be effective in their selectivity for weed control in corn at low to moderate rates. Stohr (70) observed that atrazine at 1.5 kg per hectare or simazine at 1.5 and 2.0 kg per hectare applied as pre-emergence sprays in conjunction with interrow cultivation increased the fresh weight of corn significantly. Stroube *et al.* (71) found that both atrazine and simazine,each at 2 or 3 lb per acre,gave at least 90 per cent control of weeds in corn infested mainly with *Amaranthus retroflexus* and annual grasses. Kos and Ansorge (49) have reported that atrazine at 3 kg or simazine at 4 kg per hectare, applied as a pre-emergence spray, increased significantly the yield of dry matter of corn grown for silage over that obtained from cultivated plots. The increases in yield were 7 and 5 per cent respectively for the two herbicides. On uncultivated plots the treatments resulted in considerable increases in yield. Atrazine at 3 lb per acre gave a significantly higher yield in corn over the cultivated check, rotary-hoed twice (69). The pre-emergence application of simazine 50 WP at 3 kg per hectare controlled _Amaranthus_ _retroflexus_ and _Chenopodium_ _album_; however _Sinapsis_ _arvensis_ showed some resistance (8). Weiss (78) observed an increased grain yield by the application of atrazine at 2 to 4 lb per acre, the surplus yields being the result of an increase in size but not in number of ears. Eddows and Harpur (32) observed that atrazine applied as a pre-emergence spray at 1.0 to 1.5 lb per acre gave good control of annual weeds and was superior to simazine at equivalent rates tested. Both atrazine 50 WP and simazine 50 WP gave good weed control at 5 kg per hectare when applied as a pre-emergence spray, but the yield of corn treated with simazine was slightly less than that of atrazine treated plots (11). Pejka and Kukowski (60) compared corn sprayed with atrazine 50 WP or simazine 50 WP at the rate of 3 kg per hectare as a pre-emergence application on a soil which was highly infested with weeds. It was found that the herbicides reduced the dicotyledonous weeds to 0.1 and 38.0 per cent, and the corn yields were 239 and 210 per cent of that of the check, respectively. However at another location, where the weed population was low, the corn yields were 104 and 96 per cent.

Freeman (38) found that the application of 2 and 3 lb per acre of atrazine to corn at the four to five leaf stage gave complete control of the broad-leaved weeds including <u>Amaranthus</u> <u>retroflexus</u>. Kuthe and Krantz (50) observed that 1.6 kg per hectare of both atrazine and simazine gave good results when applied as a post-emergence spray to corn up to three leaf stage. However the corn yields were reduced when applications were made at later growth stages. In further trials on corn grown for silage, atrazine at 1.6 kg per hectare was more effective in increasing yield when applied at the one to three leaf stage than at the two to three leaf stage. Gentner (40) applied atrazine and simazine at the rates of 2, 4, and 8 lb per acre when the corn was 3.5 inches tall. In an injury rating made 21 days after treatment (0 equalled no effect and 100 indicated death of the plant), it was found that the rating in case of corn was 13, 13, and 20 for the three levels of atrazine while for simazine it was 0, 0, and 20. For <u>Amaranthus</u> <u>retroflexus</u> plants, 1 inch tall, the injury rating was

33, 83, and 98 for the three levels of simazine while atrazine gave a complete kill even at the lowest level. Atrazine applied at 0.5 lb per acre as a post-emergence spray, when weeds were 1 inch high, appeared almost as effective in controlling the weeds as were the rates which were two to four times greater (2).

Methylmercapto-triazines: Triazines containing methylmercapto radicals have low selectivity in corn (54), and as such very few trials have been conducted with these compounds. GESARAN used at the rates of 2 and 4 lb active ingredients (a.i.) per acre in "post directed treatments" in corn to control late emerging weedy grasses, gave 90 and 99 per cent control, respectively (9). In the same experiment, prometryne proved inferior to GESARAN and gave 20, 40, and 90 per cent grass control at the rates of 1, 2, and 4 lb per acre respectively. Corn receiving prometryne at 1 lb per acre shortly after emergence gave a higher yield over the check in a loam soil, but a lower yield was obtained in a sandy loam (78). Prometryne also tended to reduce the stand of corn (78). At 2 kg per hectare, corn tolerated prometryne 50 WP under high rainfall conditions but the weed control was not good, Amaranthus, Chenopodium, Diplotaxis, and Convolvulus not being entirely controlled (12). Weiss and Hall (79) observed that the pre-emergence application of prometryne caused relatively little damage to corn and, in most trials, rates of 1.0 to 1.5 lb per acre gave 95 per cent control of weeds. The selectivity of prometryne to corn was reduced after crop emergence. It was found that corn tolerated 3 kg per hectare of prometryne 50 WP when applied as a pre-emergence spray but was injured when the same rate was applied at post-emergence (14).

Mixtures of chloro- and methylmercapto-triazines: GESAPRIM 1798 or GESAPRIM 1802, at the rate of 2.5 kg per hectare, controlled *Amaranthus retroflexus*, *Chenopodium album*, and *Sinapsis arvensis* when applied as a pre-emergence spray while causing no injury to the corn. The best results, however, were obtained with rates of 2 to 3 kg per hectare of either product at the early post-emergence application, that is, when the corn was in the two to three leaf stage. In late application, when the corn had reached the seven to eight leaf stage, injury and a lower yield was observed. However, the crops were assessed as good. In other trials with the two products some weeds among the *Cirsium* and *Convolvulus* spp. were found to be resistant (8). GESAPRIM 1798 and 1802 were applied at the rates of 3.0 and 2.2 kg per hectare respectively as pre-emergence applications to corn grown in a loamy sand soil, whereas the post-emergence applications were done at the rates of 2.2 and 1.7 kg per hectare. Both herbicides were effective against a high population of weeds and gave double the yield of silage corn as compared to untreated plots (10). However, at another location on a sandy loam soil with a low weed population the two products, when applied at the rates of 2.5 and 2.0 kg per hectare respectively as pre-emergence applications, caused a slight injury to corn resulting in reduced yield as compared to the check (10). Similar results were obtained on forage corn by Pejka and Kukowski (60) using the same two herbicides. In pre-emergence trials of GESAPRIM 1802 at the rate of 3 kg per hectare applied on a light sandy loam soil the plots were nearly free of weeds except for a few plants of *Tribulus terrestris* (13). In the same trials, GESAPRIM 1798 at 3 kg per hectare was less effective in controlling weeds as compared to GESAPRIM 1802. Kwizda (51) observed a temporary growth retarding effect on corn after the application of GESAPRIM 1798 and 1802 but no effect was observed on the final yield.

The foregoing reports, on the effects of triazines on corn and weeds, show that chloro-triazines are highly selective in corn and control a large number of weed species. Methylmercapto-triazines are low in selectivity, whereas mixtures of chloro- and methylmercapto-triazines when applied at low rates are promising as selective weed killers in corn. In post-emergence applications, injury may occur to corn if the crop has reached the seven to eight leaf stage.

Residual Toxicity to Subsequent Crops

Very little work has been reported on the residual toxicity of triazines to subsequent crops. The literature available is mainly related to the chloro-triazines. Stroube and Bondarenko (72) applied simazine to corn as a pre-emergence spray on a silty clay loam soil at the rates of 2, 4, and 8 lb per acre. After harvesting the corn, the treated plots were planted with wheat in the autumn and soybeans in the following spring. No effect was observed on wheat or soybeans when the application to corn was 2 lb per acre, but the rates of 4 and 8 lb per acre caused significant reduction in yield. Zaharchuk (80) observed that atrazine applied to corn at the rates of 0.5, 1, 2, and 3 lb per acre as a pre-emergence spray, or at the rates of 1, 2, 4, and 6 lb per acre as a post-emergence spray, 28 days after planting, caused no injury to wheat, oats, or beans planted in the following autumn after plowing to a depth of 8 inches. Engel (33) reported that spring wheat, planted after corn which was treated with GESAPRIM (atrazine 50% a.i.) at the rate of 1.5 to 2.0 kg per hectare, showed discoloration and withering of leaves, and in some cases complete crop failure resulted. Zemanek (81) applied atrazine to corn at the rates of 2 and 5 kg per hectare. When sugar beets and soybeans were planted in the following spring, injury was observed on the sugar beets following the 2 kg per hectare application while the beans were not affected. At 5 kg per hectare injury resulted in both crops. Burzar (25) concluded from his studies that atrazine 50 WP, GESAPRIM 1798 and GESAPRIM 1802 could be applied at rates up to 3 kg per hectare to corn without any damage to the following crop of wheat. However, atrazine 50 WP at 4 kg per hectare was found to depress the subsequent wheat yield. Similar results on wheat were obtained by Panic (59) in a region with relatively frequent rainfall. In the case of sugar beets planted the following spring, injury resulted from all the three products even at 2 to 3 kg per hectare. It was concluded, therefore, that sugar beets were not suitable as a crop to follow triazine-treated corn (59).

Residual toxicity of triazine compounds to other crops have been reported. Of nine forage grasses and legumes tested, only tall fescue and Korean lespedeza were tolerant when grown on soil treated the previous year with atrazine or simazine at 1 lb per acre. Significant yield reductions occurred with orchardgrass, timothy, bromegrass, alfalfa, red clover, ladino clover, and sweet clover at the rate applied. However, when the soil was treated with 2 or 4 lb per acre, with either of the two chemicals, significant yield reductions occurred in all the crops (35). In various trials barley, rye, and cucumbers were found to be susceptible to atrazine or simazine residues, whereas peas were resistant (72, 80, 81).

Of the various crops tested for response to residual toxic effects of triazines, sugar beets were most susceptible, whereas wheat, oats, and soybeans showed little to moderate injury depending upon the herbicide and concentration used.

III. MATERIALS AND METHODS

The experiments were conducted at the Agricultural Research and Education Center (A.R.E.C.) of the American University of Beirut during 1965 and 1966. The A.R.E.C. is located in the northern central Beqa'a plain, Lebanon. The soil is clay in texture with a high cation exchange capacity and has an organic matter content of 2.2 per cent. The pH ranges from 8.0 to 8.4 with a high calcium carbonate content indicating that the soil is highly calcareous (68, p. 27).

Field Methods

The plots were under barley-vetch pasture before planting them to corn. Nitrogen and phosphorous fertilizers were applied uniformly at the rates of 12 kg of nitrogen and 20 kg of P_2O_5 per dunum.[1] In 1965, the corn plants received two additional side dressings, each of 4 kg of nitrogen per dunum, one two weeks before tasseling and the second a month after the first. In 1966 only the side dressing before tasseling was made since the crop was harvested for forage.

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1. One dunum is equal to 1000 square meters.

The experiments were laid out in a randomized complete block design with each treatment replicated three times in 1965 and four times in 1966. In 1965 the plots consisted of two rows, each 4 meters long. In 1966 the plots consisted of four rows, each 3 meters long. The rows were spaced 75 cm apart in both years. In 1965 three meters in the center of one of the rows was harvested for forage and the other for grain. In 1966 two central rows, each 2.25 meters in length, were used to determine forage yield leaving borders on each end and sides.

The corn hybrid 'Indiana 620' was planted thickly in hills, at the end of April, and then thinned to one plant per hill when the corn was 15 to 20 cm tall. The plant populations were 5000 per dunum and 5333 per dunum in 1965 and 1966 respectively. Sprinkler irrigation was used weekly during the first eight weeks after planting, after which furrow irrigation was the method used.

Two separate but adjacent experiments were laid out each year. In one the herbicides were applied as pre-emergence sprays to corn, while in the other the applications were made as post-emergence. Apart from the time of application there was no difference in the two experiments in both years. The herbicides were applied one and three days after planting corn for pre-emergence treatments, whereas the post-emergence applications were made five and eight weeks after planting in the years 1965 and 1966 respectively.

Six formulations of triazine herbicides were tested in the year 1965, each at three rates, while in 1966 three of the promising herbicides tested in 1965 were used at lower rates. The common or commercial names, formulated products, and rates of the herbicides tested are given in Table 1. Unweeded check and hand-weeded plots, sprayed with water, were included in each experiment in both years.

The herbicides were applied at a constant pressure, using a knapsack sprayer equipped with a one-nozzle boom. Spraying operations were carried out always in the mornings when there was little air movement. In 1965, applications were made in 50 cm bands over the row leaving 25 cm unsprayed between the rows, whereas in 1966 overall sprays were made

Weed Species

Most of the weed population[1] consisted of annuals with the exception of _Sonchus nymanni_ which is a biennial, and _Anchuza italica_, _Convolvulus althaeoides_,

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1. Complete list of the weed species found in the experimental plots is given in Appendix "A".

Table 1. Triazine herbicides tested on weeds in corn at A.R.E.C. in 1965 and 1966.

Common or commercial name[3]	Active ingredients	Formulated product used	Rates of herbicides tested kg (a.i.) per hectare	
			1965[1]	1966[2]
Atrazine	50.0%	A 1294 WP	2.5, 5.0, 12.5	0.62, 1.25
Simazine	50.0%	A 384 WP	"	"
Prometryne	50.0%	A 1114 WP	"	-
GESARAN	(25.0% G36 393)	A 1404 WP	"	-
GESAPRIM 1798	(33.3% atrazine + 16.7% prometryne)	A 1798 WP	"	-
GESAPRIM 1802	(33.3% atrazine + 16.7% ametryne)	A 1802 WP	"	0.62, 1.25

1. Used in 2166 liters of water per hectare.

2. Used in 1083 liters of water per hectare.

3. Chemical names of the herbicides are given on page 3.

Convolvulus arvensis, *Lepidium chalepense*, and *Lolium perenne* which are perennials. The weed species most commonly found in the experimental plots were *Amaranthus retroflexus*, *Chenopodium opulifolium*, *Portulaca oleracea*, and *Sinapsis arvensis*. Of the remaining weed species *Carthamus flavascens*, *Cirsium acarna*, and *Convolvulus arvensis* were present in considerable numbers.

Data Recording and Statistical Analysis

In 1965, the weed counts were made one month after the herbicidal applications in the total sprayed area i.e. 4 square meters per plot. In addition other agronomic characteristics on corn were observed. The date of tasseling was recorded when 75 per cent of plants had tasseled. The plant height was measured in centimeters from the base of the plant at the ground level to the point of attachment of the tassel with the stalk. The total number of ears in a unit area were recorded. The full stand of corn consisted of 11 plants in each row harvested, but few herbicides killed or affected the plants to such an extent that they did not bear any ears. The number of ears harvested, from one row were counted, and on the assumption that these ears came from 11 plants, calculations were made to convert these figures to number of ears per 100 plants. The ear weight was obtained by dividing the weight of ears harvested from a single row by the number of ears in that row and then adjusted to a uniform 15.5 per cent moisture. For determining the moisture percentage of grain, the central portion of the ears of a representative sample from each treatment was taken immediately after harvest, and was placed in an oven at 70°C for 48 hours. The grain yields were adjusted to a uniform 15.5 per cent moisture according to the methods described by Kiesselbach (48, pp. 35-38). A visual rating from 1 to 5 was given for the extent of ear filling, 5 referred to the completely filled and 1 to the least filled ears. Harvesting for forage was done in the late dough stage and for grain when the plants were fully mature. A representative chopped sample of 1 kg was taken and air-dried for 40 days for the determination of the moisture percentage in order to calculate the forage and stover yields on dry matter basis.

In 1966, the weed population was very low and was not well distributed, therefore weed counts were not made. Phytotoxicity notes were taken on weeds and corn and the agronomic characteristics observed on corn were limited to that of the forage. Thickness of the middle portion of the stalk was measured by a Vernier caliper. A count of the number of tillers, including the main stalk, was made. The crop was harvested for forage in the late dough stage and the yields were calculated on a dry weight basis after placing the samples in an oven at 70°C for 48 hours as reported by Schmidt and Colville (64).

The statistical analysis was done according to the methods described by LeClerg et al. (52, pp. 137-144). The least significant differences were calculated at the 5 per cent level for making comparisons between different treatments and the check.

Residual Effects[1]

After corn harvesting in 1965, the stubble was removed with a fork without disturbing the soil. Rows of corn were divided into 3 longitudinal portions each 1.33 meters in length. The winter crops including Florence Aurore wheat, Nortex oats, and local vetch were planted in mid-November 1965 in the row harvested for forage. The spring crops namely Souri onions, Pedigree SSA sugar beets, and Clark soybeans were planted in the row harvested for grain on March 9 and 30, and April 20, 1966, respectively. Irrigation was done with sprinklers at weekly intervals starting from the end of April, 1966. Later it was followed by furrow irrigation until the end of the growing

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1. The varieties of different crops used in this study were those which had shown promise at the A.R.E.C.

season.

Phytotoxicity observations due to the residual effects of triazines on the winter sown crops were made in the middle of February and May, and on the spring crops on June 24 and August 1, 1966.

IV. RESULTS AND DISCUSSION

Phytotoxic Effects on Corn and Weeds

The phytotoxic effects of pre- and post-emergence applications of triazine herbicides on corn and weeds for the years 1965 and 1966 are summarized in Tables 2 to 5.

Pre-emergence applications: The two chloro-triazines, atrazine and simazine, gave excellent weed control in the year 1965 at all rates tested (Table 2). Atrazine showed the maximum selectivity in corn being injurious only at the highest rate used, whereas simazine gave partial and complete kill of corn at the rates of 5.0 and 12.5 kg per hectare, respectively. At 2.5 kg per hectare simazine-treated corn plants looked normal and stout at the beginning but showed very slight yellowing and stunting seven to eight weeks after. In 1966 (Table 3), when the two herbicides were tested at the lower rates no injury occurred to corn but few of the weed species showed some resistance to atrazine at both rates, and to simazine only at the lower rate; however, the number of uncontrolled weeds, although not recorded, was very low. These results obtained with atrazine and simazine in both years are in agreement with those of McWhorter and Holstun (54)

Table 2. Phytotoxic effects of pre-emergence applications of herbicides on corn and weeds in 1965.

Herbicide	Rate Kg/ha (a.i.)	Toxicity index		Weed counts one month after application		Weed species not controlled
		Corn	Weeds	No. per 10 sq. meters	Per cent control	
Atrazine	2.5	-	+++	4	98.4	--
	5.0	-	+++	6	97.6	--
	12.5	+	+++	2	99.2	--
Simazine	2.5	+	+++	8	96.8	--
	5.0	++	+++	27	89.3	--
	12.5	+++	+++	12	95.3	--
Prometryne	2.5	++	++	28	88.9	A.retroflexus, C.arvensis+.
	5.0	+++	++	11	95.6	C.althaeoides+,C.arvensis+.
	12.5	+++	+++	0	100.0	--

(Table 2 Continued)

GESARAN	2.5	++	++	43	83.0	C. arvensis, L. chalepense.
	5.0	+++	++	25	90.1	C. arvensis, L. chalepense.
	12.5	+++	++	18	92.9	C. arvensis.
GESAPRIM 1798	2.5	++	+++	5	98.0	--
	5.0	+++	+++	3	98.8	--
	12.5	+++	+++	0	100.0	--
GESAPRIM 1802	2.5	++	+++	4	98.4	--
	5.0	++	+++	3	98.8	--
	12.5	+++	+++	0	100.0	--
Unweeded check	0.0			253	0.0	

- No toxicity.
+ Little injury and stunting.
++ Chlorosis and partial kill.
+++ Extreme injury, wilting, and ultimate kill.
-- All species present controlled.

Table 3. Phytotoxic effects of pre-emergence applications of herbicides on corn and weeds in 1966.

Herbicide	Rate Kg/ha (a.i.)	Toxicity index Corn	Toxicity index Weeds	Weed species not controlled
Atrazine	0.62	-	++	C. althaeoides⁺, P. oleracea, T. terrestris.
	1.25	-	++	C. althaeoides⁺, T. terrestris⁺.
Simazine	0.62	-	+	A. retroflexus, P. oleracea, T. terrestris.
	1.25	-	+++	--
GESAPRIM 1802	0.62	-	++	H. bovei, P. oleracea, T. terrestris.
	1.25	-	++	C. althaeoides, C. arvensis.

- No toxicity.
+ Little injury and stunting.
++ Chlorosis and partial kill.
+++ Extreme injury, wilting, and ultimate kill.
-- All species present controlled.

who had found chloro-triazines to be effective at low to moderate rates in their selectivity in weed control in corn.

Methylmercapto analogs, prometryne and GESARAN, were very toxic to corn at all rates and were tested only in the year 1965 (Table 2). The results are in agreement with the previous reports cited in the literature (37, 54). The two herbicides controlled a majority of weed species, but a few showed some resistance. The results for prometryne support an earlier report from Yugoslavia (12) where at a lower rate prometryne could not control Amaranthus and Convolvulus spp.

The mixtures of chloro- and methylmercapto-triazines, GESAPRIM 1798 and 1802, also gave excellent weed control but were toxic to corn at the rates tested in 1965 (Table 2). Although GESAPRIM 1802 was slightly better than GESAPRIM 1798, the rates tested in the case of the two herbicides were not safe for corn. Apparently the amounts of methylmercapto-triazines present in the mixtures, constituting one third of the active ingredients, were sufficient to kill the corn plants. GESAPRIM 1802, when used at lower rates in 1966, gave good control of weeds without having any toxic effect on corn (Table 3). However, few weed species showed resistance. These results are in agreement with an earlier report (8) but are in contradiction to another report from Greece (13) where a few plants of *Tribulus terristris* showed resistance at 1.5 kg (a.i.) per hectare on a sandy loam soil. It is possible that the conditions in Greece were such that little herbicide was available to the plants. This is further supported by the fact that *Tribulus terristris* showed resistance at 0.62 kg per hectare under the conditions in which the present study was conducted.

Post-emergence applications: In 1965, all herbicides gave excellent weed control except for the two lower rates of prometryne which left few weed species uncontrolled (Table 4). GESARAN which could not control *Lepidium chalepense* in pre-emergence treatments gave good control in the post-emergence application, possibly due to contact injury to the foliage. *Convolvulus arvensis* which was also not controlled by GESARAN in the pre-emergence treatment was almost absent in this experiment. In general the pattern of toxicity to corn was the same as that of the pre-emergence applications, except in a few cases where the injury to corn was slightly lower. Apparently the corn plants at the time of the post-emergence applications were well established and could detoxify the herbicides better than those at comparable rates in the plots which received the pre-emergence applications. Atrazine at 2.5 kg per hectare was an

Table 4. Phytotoxic effects of postemergence applications of herbicides on corn and weeds in 1965.

Herbicide	Rate Kg/ha (a.i.)	Toxicity index		Weed counts one month after application		Weed species not controlled
		Corn	Weeds	No. per 10 sq. meters	Per cent control	
Atrazine	2.5	+	+++	16	95.7	--
	5.0	-	+++	2	99.5	--
	12.5	+	+++	0	100.0	--
Simazine	2.5	+	+++	42	88.6	--
	5.0	+	+++	23	93.8	--
	12.5	+	+++	7	98.1	--
Prometryne	2.5	++	++	11	97.0	_A. retroflexus_, _L. perenne_, _P. oleracea_, _S. arvensis_, _E. gaillardoti_.
	5.0	++	++	13	96.5	_A. retroflexus_, _L. perenne_, _P. olerecea._
	12.5	+++	+++	0	100.0	--

(Table 4 Continued)

GESARAN	2.5	++	+++	17	95.4	--
	5.0	+++	+++	1	99.7	--
	12.5	+++	+++	0	100.0	--
GESAPRIM 1798	2.5	++	+++	6	98.4	--
	5.0	++	+++	3	99.2	--
	12.5	+++	+++	0	100.0	--
GESAPRIM 1802	2.5	+	+++	2	99.5	--
	5.0	++	+++	0	100.0	--
	12.5	+++	+++	0	100.0	--
Unweeded check	0.0			368	0.0	

- No toxicity.
+ Little injury and stunting.
++ Chlorosis and partial kill.
+++ Extreme injury, wilting, and ultimate kill.
-- All species present controlled.

exception. In this case injury to foliage was observed approximately one week after spraying, which was distinctly different from the injury symptoms usually caused by triazine herbicides. It is possible that the sprayer used could not be washed and drained completely, thus contamination from some other herbicide occurred which proved injurious to corn. This is further supported by the fact that no visible injury occurred at the rate of 5.0 kg per hectare of atrazine. In 1966, GESAPRIM 1802 caused injury to the corn foliage at both rates tested (Table 5). The corn plants showed yellowing and withering of leaf tips but later in the season recovered to some extent. The results are in agreement with those reported by other workers (8, 10). The other two herbicides used did not show any visible signs of injury to corn. The weed control was good for atrazine and GESAPRIM 1802. Simazine had an inferior effect to atrazine at both rates tested, probably due to the low water solubility and contact injury of simazine (44, p. 292).

Forage Yield and Related Agronomic Characteristics

The results of the effects of triazine herbicides on the forage yield and related agronomic characteristics of corn studied during the years 1965 and 1966 are presented in Tables 6 to 9. No tillers were observed in

Table 5. Phytotoxic effects of post-emergence applications of herbicides on corn and weeds in 1966.

Herbicide	Rate Kg/ha (a.i.)	Toxicity index Corn	Toxicity index Weeds	Weed species not controlled
Atrazine	0.62	-	++	*A. retroflexus*+, *P. oleracea*+.
	1.25	-	++	*C. arvensis*+.
Simazine	0.62	-	-	*A. retroflexus*, *A. italica*, *D. erucoides*, *H. bovei*, *P. oleracea*.
	1.25	-	+	*A. retroflexus*, *C. althaeoides*, *P. oleracea*.
GESAPRIM 1802	0.62	+	++	*H. bovei*, *T. terrestris*.
	1.25	+	+++	--

- No toxicity.
+ Little injury and stunting.
++ Chlorosis and partial kill.
+++ Extreme injury, wilting, and ultimate kill.
-- All species present controlled.

any of the experimental area in 1966, except for those on one or two plants, and the number of tillers per plant are not reported.

Pre-emergence treatments:

Forage yield: In 1965, the corn plots treated with atrazine and simazine at the rates of 2.5 kg per hectare gave significantly higher yields than did the unweeded check, and were comparable to those of hand weeded plots (Table 6). These results are in agreement with those of Kos and Ansorage (49), who found that the application of atrazine and simazine at 3 and 4 kg per hectare, respectively, resulted in a much higher yield of dry matter content of corn grown for silage than that of uncultivated plots. These results differed from their findings in that the yields of plots treated with herbicides were significantly increased over the cultivated plots. However, when it is considered that cultivation is not as effective in controlling weeds as is hand weeding, it becomes evident that quite a number of weeds must have been left to compete with the corn, thus lowering the yields. Atrazine at 5.0 kg per hectare caused a considerable increase in forage yield over check, but the differences were not significant at the 5 per cent level. GESAPRIM 1802 at 2.5 kg per hectare proved almost

Table 6. The effect of pre-emergence applications of herbicides on plant height and forage yield of corn in 1965.

Herbicide	Rate Kg/ha (a.i.)	Plant height Cm	Forage yield Kg/du[1]
Atrazine	2.5	193	1485
	5.0	198	1461 a
	12.5	190	1159 a
Simazine	2.5	189 a	1520
	5.0	167	542
	12.5	0	0
Prometryne	2.5	166	462
	5.0	0	0
	12.5	0	0
GESARAN	2.5	166	395
	5.0	0	0
	12.5	0	0
GESAPRIM 1798	2.5	183 a	497
	5.0	0	0
	12.5	0	0
GESAPRIM 1802	2.5	164	816 a
	5.0	156	372
	12.5	0	0
Hand weeded	0.0	194	1494
Unweeded check	0.0	182	1144
LSD 5%	-	8	338

a Do not differ from check at 5 per cent level of significance. All other figures listed in the same column are significantly different.

1 Air-dried weight.

significantly inferior to check. Atrazine at 12.5 kg per hectare was close to the check which means that corn plants were benefitted by the kill of weeds, but were handicapped with the injury caused to them by the high rate of the herbicide. All other treatments were significantly lower in yield than the check due to the herbicide injury and are in agreement with the observations recorded in the phytotoxicity chart as shown in Table 2.

In 1966, when the weed population was low, the herbicidal treatments in general gave higher yields than the unweeded check plots but were lower in yield than the hand weeded plots (Table 7). However, the results were not significant at the 5 per cent level. Pejka and Kukowski (60) have reported similar results with triazine products when applied on plots with a low weed population. In their study, the yields of corn forage were 104, 96, 99, and 105 per cent of the check for atrazine, simazine, GESAPRIM 1802, each at 1.5 kg (a.i.) per hectare, and hand weeded plots respectively. This was further supported by a recent report from Sweden in which Granstrom and Dahlkvist (42, p. 14) summarized the results of a large number of experiments and concluded that the yield after spraying increased with increasing weed frequency on untreated plots. It is interesting to note that GESAPRIM 1802 at 1.25 kg

Table 7. The effect of pre-emergence applications of herbicides on forage yield and agronomic characteristics of corn in 1966.

Herbicide	Rate Kg/ha (a.i.)	Plant height Cm	Thickness of stem Cm[1]	Forage yield Kg/du[2]
Atrazine	0.62	200	2.00	1245
	1.25	202	1.99	1393
Simazine	0.62	201	1.98	1315
	1.25	201	1.94	1280
GESAPRIM 1802	0.62	202	1.96	1302
	1.25	195	1.93	1375
Hand weeded	0.00	207	2.01	1475
Unweeded check	0.00	197	1.89	1253
LSD 5%	-	NS	NS	NS

1 Taken from the middle internode.

2 Air-dried weight.

per hectare was as effective as atrazine at a comparable rate in increasing the forage yield (Table 7). Simazine had an inferior effect to that of atrazine at 1.25 kg per hectare. This is in agreement with the results reported by Eddowes and Harpur (32). The higher yields observed in the case of hand weeded plots as compared to the herbicidal treatments may be due to soil variation and is evident from the non-significant F-values for the different treatments. This is further supported by the fact that almost equal yields of forage were observed at 2.5 kg per hectare of atrazine and hand weeded plots in 1965.

Plant height: In 1965, the effects of herbicides on plant heights were similar to those on the forage yields (Table 6). However, the heights of plants receiving 2.5 kg per hectare of GESAPRIM 1798 and 12.5 kg per hectare of atrazine were exceptions. GESAPRIM 1798 had killed quite a number of plants (Table 2), and it seems that the surviving plants, taking advantage of the low stand, had almost equal height as the check. In the case of atrazine at the highest rate tested, corn plants grew vigorously at the beginning, but later on in the season showed yellowing. It seems that the plants were able to metabolize the herbicide at the start, but as the season advanced a greater amount of the herbicide was absorbed, which affected the growth of the corn plants. However, it was late to have any effect on the height.

In 1966, no significant differences were observed in plant height (Table 7). Plants in the hand weeded plots were the tallest which correlated with the highest yield obtained. The corn plants treated with GESAPRIM 1802 at 1.25 kg per hectare, which had given a fairly high yield, had lower height than the check. In the light of the results of 1965 where GESAPRIM 1802 had killed quite a number of plants (Table 2), it is possible that even at this rate it could have a little stunting effect at the beginning of the growing season although no harmful effect on the ultimate yield was observed.

Thickness of stem was recorded only in 1966 and is shown in Table 7. In general, stem thickness was associated with the forage yield and plant height, with no significant differences observed between different treatments. The lesser thickness observed in the case of plants treated with GESAPRIM 1802 at 1.25 kg per hectare as compared to other herbicidal treatments supports the view presented earlier about the initial retarding effect of GESAPRIM 1802.

Post-emergence treatments: In general the post-emergence applications did not prove as effective in increasing yields as the pre-emergence sprays. Part of this could be attributed to the time of application, the sprays being made five and eight weeks after corn planting in

1965 and 1966 respectively. Thus the weeds stayed for few weeks before they were cleared off. Since the vegetative development of the weeds is at a maximum during the first few weeks after emergence, four to five weeks in case of Sinapsis arvensis (41, pp.172-173), and the earlier growth period is critical for corn, the yields obtained were not very high.

However, this does not explain the lower yields observed in the case of hand weeded and unweeded plots. In 1965, a possible reason for the low yields could be the harmful effect of the strong and continuous wind, which was always blowing from the southern side of the post-emergence plots. This is evident from the highly significant differences observed in the plant height of the different blocks,[1] being lowest in the block facing the southern wind. In 1966, the soil was not levelled and two of the blocks seemed to receive less irrigation water. As a result significant differences were observed in the stem thickness and highly significant differences were observed between different blocks in the forage yields and plant heights.[2]

Forage yield: In 1965 atrazine at 5.0 kg per hectare and hand weeding resulted in higher yields than

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1. See Table 17, Appendix B.

2. See Table 18, Appendix B.

the unweeded check (Table 8). Simazine at the two lower rates was almost equal to the check. Such a result for the post-emergence application of simazine was not unexpected, because it takes a long time to kill the weeds due to the low solubility of the herbicide in water. Corn treated with atrazine at 2.5 kg per hectare gave a lower yield as compared to the check. This was possibly due to injury caused by contamination with some other herbicide as was explained earlier while discussing the phytotoxic effects. Lower rates of GESAPRIM 1798 and 1802 showed an improvement over the pre-emergence treatments at comparable rates but were still toxic, thus lowering the yields of forage. The results were in agreement with the phytotoxic effects observed on these treatments as shown in Table 4.

In 1966, no significant differences were observed between the various treatments (Table 9). Hand weeded plots gave a higher yield than the check. GESAPRIM 1802 was lower in yield, due to the injury caused by the herbicide as was discussed under the phytotoxic effects. The reduction in yield was proportional to the concentration of the herbicide applied. All other herbicidal treatments gave a yield which was almost equal to the unweeded check but lower than the hand weeded plots. This may be due to the low weed population and the slight retardation effect as evident from the plant height and

Table 8. The effect of post-emergence applications of herbicides on plant height and forage yield of corn in 1965.

Herbicide	Rate Kg/ha (a.i.)	Plant height Cm	Forage yield Kg/du[1]
Atrazine	2.5	171 a	930 a
	5.0	180 a	1273 a
	12.5	170 a	1096 a
Simazine	2.5	178 a	1135 a
	5.0	177 a	1149 a
	12.5	173 a	894 a
Prometryne	2.5	158	731
	5.0	138	180
	12.5	0	0
GESARAN	2.5	162 a	442
	5.0	0	0
	12.5	0	0
GESAPRIM 1798	2.5	168 a	1091 a
	5.0	149	798 a
	12.5	0	0
GESAPRIM 1802	2.5	175 a	1062 a
	5.0	161 a	798 a
	12.5	135	200
Hand weeded	0.0	181 a	1275 a
Unweeded check	0.0	182	1143
LSD 5%	-	22	374

a Do not differ from check at 5 per cent level of significance. All other figures listed in the same column are significantly different.

1 Air-dried weight.

Table 9. The effect of post-emergence applications of herbicides on forage yield and agronomic characteristics of corn in 1966.

Herbicide	Rate Kg/ha (a.i.)	Plant height Cm	Thickness of stem Cm[1]	Forage yield Kg/du[2]
Atrazine	0.62	171	1.83 a	1027
	1.25	168	1.78 a	1044
Simazine	0.62	170	1.78 a	1030
	1.25	172	1.83 a	1065
GESAPRIM 1802	0.62	162	1.79 a	975
	1.25	165	1.69	923
Hand weeded	0.00	180	1.94	1131
Unweeded check	0.00	169	1.83	1028
LSD 5%	-	NS	0.10	NS

a Do not differ from check at 5 per cent level of significance. All other figures listed in the same column are significantly different.

1 Taken from the middle internode.

2 Air-dried weight.

particularly the thickness of stem.

Plant height: In 1965, no significant differences were observed between the promising treatments and the unweeded check. However, the reduction in height was prominent when lower forage yields were observed (Table 8).

In 1966 the heights, though non-significant, were generally in agreement with the yields observed (Table 9).

Thickness of stem was recorded only in 1966, and is shown in Table 9. GESAPRIM 1802 at 1.25 kg per hectare resulted in significantly thinner stalks than the check. This shows that the phytotoxic effect of the herbicide on corn was mainly on the thickness of the stalk. In general the stem thickness of all treatments was somewhat comparable to the data observed on the forage yield. It is interesting to note that at 1.25 kg per hectare, the three herbicides tested reduced the stem thickness in the order of their solubilities in water. The lowest injury was observed in the case of simazine followed by atrazine and GESAPRIM 1802. This shows that injury of the post-emergence treatments may be increased with an increase in the water solubilities of the triazines.

Grain and Stover Yields and Related Agronomic Characteristics

Pre-emergence treatments: The results of pre-emergence applications of herbicides on grain and stover yields and related agronomic characteristics of corn in 1965 are presented in Table 10.

Grain yield: Atrazine and simazine at 2.5 kg per hectare resulted in significantly higher yields than the unweeded check. The results are in agreement with an earlier report from Argentina (11). Hand weeded plots also gave a significantly higher yield than the unweeded check, whereas the corn treated with atrazine at 5.0 kg per hectare gave a higher yield than the check but the difference was not significant. All these results are in agreement with those obtained for forage during the same year. Atrazine at 12.5 kg per hectare which had resulted in a forage yield almost equal to that of the check (Table 6), had significantly lower grain yield. This indicates that with the advancement of the growing season a greater amount of the chemical was translocated to the top of the plants, to cause injury and reduction in grain yield. The injury seemed to be porportional to the time for which the plants were exposed to the toxic concentrations of the herbicides. Similarly in all other treatments, the yield reductions were proportional to the phytotoxicity caused by the herbicides (Table 2).

Stover yield: All the treatments had lower stover yields than the check. This was either due to the

Table 10. The effect of pre-emergence applications of herbicides on grain and stover yields and related agronomic characteristics of corn in 1965.

Herbicide	Rate Kg/ha (a.i.)	No. of days to tassel	Extent of ear filling[1]	No. of ears per 100 plants	Ear weight gm[2]	Grain yield Kg/du[3]	Stover yield Kg/du[4]
Atrazine	2.5	75.0	4.7	100.0 a	326	1444	612 a
	5.0	75.3 a	4.3	97.3 a	295	1228 a	564 a
	12.5	84.7	3.7 a	93.6 a	230 a	859	421
Simazine	2.5	83.3	4.3	109.1 a	290 a	1289	585 a
	5.0	86.7	2.3	51.8	222 a	421	283
	12.5	0.0	0.0	0.0	0	0	0
Prometryne	2.5	86.0	2.0	27.3	168	239	159
	5.0	0.0	0.0	0.0	0	0	0
	12.5	0.0	0.0	0.0	0	0	0

(Table 10 Continued)

GESARAN	2.5	85.7	1.7	30.0	213 a	210	197
	5.0	0.0	0.0	0.0	0	0	0
	12.5	0.0	0.0	0.0	0	0	0
GESPRIM 1798	2.5	85.7	2.7 a	57.3	227 a	542	508 a
	5.0	0.0	0.0	0.0	0	0	0
	12.5	0.0	0.0	0.0	0	0	0
GESAPRIM 1802	2.5	86.3	2.7 a	70.0	213 a	583	559 a
	5.0	87.3	1.0	42.7	154	234	294
	12.5	0.0	0.0	0.0	0	0	0
Hand weeded	0.0	74.7	4.3	102.7 a	281 a	1324	600 a
Unweeded check	0.0	77.0	3.3	100.0	249	1079	637
LSD 5%	-	2.0	0.9	19.9	45	207	201

a Do not differ from check at 5 per cent level of significance. All other figures listed in the same column are significantly different.

1 Rating 1 to 5, 5 for best filled ears.

2 and 3 At 15.5 per cent moisture.

4 Air-dried weight.

phytotoxicity caused by the herbicides (Table 2), or due to the higher grain yields observed (Table 10). The latter observation is in agreement with Zuber et al. (82) who found that under less favorable conditions for grain production, the stover weight was higher and grain yields were lower which was true for the unweeded check in the present study.

Number of days from planting to tasseling: Corn plants treated with atrazine at 2.5 kg per hectare and hand weeded plots tasseled significantly earlier than those in the unweeded check plots. The results are in line with those of Chaudhry (27, p. 40), who observed a highly significant delay in tasseling with an increase in plant population from 5000 to 6500 plants per dunum. In the present study corn plants were kept at a density of 5000 per dunum in each treatment but the check plots were over-populated due to the presence of weeds, hence there was a delay in tasseling in these plots. Plants treated with atrazine at 5.0 kg per hectare also took fewer number of days to tassel as compared to the check although the difference was not significant. All other treatments delayed tasseling singificantly as compared to the check. The results are obvious in the light of the phytotoxic effects observed and reported in Table 2. However, it is important to note that simazine at 2.5 kg per hectare delayed tasseling significantly, which shows its retarding effect on growth, although the ultimate yield was not affected to a great extent (Table 10). When it is considered that simazine at 2.5 kg per hectare resulted in a lower grain yield (Table 10) and plant height (Table 6) as compared to atrazine at comparable rates, and to hand weeded plots, it seems convincing that simazine caused some stunting to the plants. As an explanation for the comparable forage yield by simazine to that of plots treated with atrazine at 2.5 kg per hectare and that of the hand weeded plots (Table 6), it seems that the herbicides did not accumulate in sufficient amounts to reduce the vegetative growth and had an ultimate effect on the grain yield. Similar trends were observed in the case of atrazine at the two higher rates tested (Tables 6 and 10).

Extent of ear filling: Atrazine at the two lower rates, simazine at the lowest rate, and the hand weeded plots resulted in significantly better filled ears than those of the unweeded check. The less filled ears in the case of the check plots were probably due to the competition of the weeds and are in line with the results obtained by Termunde et al. (75). It seems that the injury caused by the lowest rate of simazine was minor and the plants were not affected much which is evident from the extent of ear filling. In all other treatments, reductions in ear filling occurred, and this correlated with the toxicity caused by the herbicides.

Number of ears per 100 plants: No significant differences were observed in the case of atrazine at all rates tested, simazine at the lowest rate, and hand weeded plots as compared to the unweeded check. All other treatments resulted in significantly fewer number of ears as compared to the check due to the partial or complete kill of corn plants which was caused by the toxic action of the herbicides and was the main cause of the poor grain yields observed in these treatments.

Ear weight: In general the effects of the herbicides on the ear weights were in agreement with their effects on ear filling. The results are similar to those reported by Weiss (78) who found that atrazine had no effect on the number of ears and the increase in the grain yield of treated plots was due to the increase in the size of the ear.

Post-emergence treatments: The results showing the effects of post-emergence treatments on grain and stover yields and other agronomic characteristics of corn are reported in Table 11.

Grain yield: In general the grain yields were quite low as compared to the pre-emergence treatments. This may be due to the injury caused by the herbicides to the floral primordia, which has been reported to start initiation 2 to 3 weeks after germination (53, p. 103).

Table 11. The effect of post-emergence applications of herbicides on grain and stover yields and related agronomic characteristics of corn in 1965.

Herbicide	Rate Kg/ha (a.i.)	No. of days to tassel	Extent of ear filling[1]	No. of ears per 100 plants	Ear weight gm[2]	Grain yield Kg/du[3]	Stover yield Kg/du[4]
Atrazine	2.5	77.7 a	2.3 a	100.0 a	172 a	698 a	330 a
	5.0	76.3 a	2.3 a	100.0 a	159 a	670 a	304 a
	12.5	79.0 a	2.3 a	102.7 a	150 a	662 a	328 a
Simazine	2.5	79.7 a	3.0 a	100.0 a	227 a	980 a	396 a
	5.0	79.7 a	2.3 a	100.0 a	195 a	839 a	324 a
	12.5	79.7 a	2.0 a	97.3 a	132 a	546 a	276 a
Prometryne	2.5	83.7	2.7 a	63.6	240	670 a	363 a
	5.0	86.7	1.0	24.5	141 a	139	141
	12.5	0.0	0.0	0.0	0	0	0

(Table 11 Continued)

GESARAN	2.5	85.7	1.7	45.5	159 a	312	255 a
	5.0	0.0	0.0	0.0	0	0	0
	12.5	0.0	0.0	0.0	0	0	0
GESAPRIM 1798	2.5	83.7	2.0 a	66.4	222 a	586 a	338 a
	5.0	82.3	2.0 a	33.6	204 a	279	178
	12.5	0.0	0.0	0.0	0	0	0
GESAPRIM 1802	2.5	83.7	2.7 a	100.0 a	236 a	1069 a	663
	5.0	86.0	2.3 a	60.9	186 a	492	287 a
	12.5	86.0	2.0 a	39.1	177 a	317	212 a
Hand weeded	0.0	76.0 a	2.7 a	100.0 a	195 a	844 a	490
Unweeded check	0.0	77.3	2.7	100.0	181	800	336
LSD 5%	-	2.5	0.9	18.1	58	287	132

a Do not differ from check at 5 per cent level of significance. All other figures listed in the same column are significantly different.

1 Rating 1 to 5, 5 for best filled ears.

2 and 3 At 15.5 per cent moisture.

4 Air-dried weight.

It has been reported (50) that both atrazine and simazine gave good results when applied to corn up to the three-leaf stage but reduced corn yields when applied at later stages. However when GESAPRIM 1798 and 1802 were applied on corn at the seven to eight-leaf stage the crop was still assessed as good although burns and lower yields were obtained. It is also important to bear in mind that weeds stayed for weeks before they were cleared off, as explained under forage yields, and must have done considerable damage to the normal growth of corn because of their competitive ability for water, nutrients, and light. In addition wind had a harmful effect on the growth and degree of fertilization in corn, although the latter was more pronounced. This explanation is supported by the fact that highly significant differences were observed[1], in the extent of ear filling, ear weight and grain yield in the different blocks; the values being lowest in the block facing the wind.

None of the treatments resulted in a significantly higher yield than the check. Corn treated with GESAPRIM 1802 at 2.5 kg per hectare gave the highest yield and was close to significance level. It appears that injury caused by this product is not very severe as already reported in the literature (8). Moreover this particular treatment was protected from the wind and had no

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1. See Table 20, Appendix B.

difference in the various blocks due to wind. Of the two chloro-triazines, simazine resulted in higher yields at 2.5 and 5.0 kg per hectare than the check and the comparable rates of atrazine tested. At 2.5 kg per hectare atrazine-sprayed plants were affected as a result of the contamination with other herbicides as explained earlier while discussing the phytotoxic effects. Moreover atrazine has a higher solubility in water than simazine, therefore a greater injury from atrazine is expected when applied to the foliage. This is in agreement with the results obtained by Gentner (40), who observed an injury to corn as a result of the application of 2 and 4 lbs per acre of atrazine, but no injury occurred with simazine at comparable rates. Hand weeded plots also gave a slightly higher yield than the check. All other treatments were lower in yield because of the phytotoxicity and stand reduction of corn.

Stover yield: In all the promising treatments the stover yields were almost equal to the unweeded check except for GESAPRIM 1802 and the hand weeded plots. In the case of GESAPRIM 1802 it seems that plants could detoxify the herbicide quickly and resumed their normal growth. Moreover as mentioned under grain yield, they were not affected by wind. The plants in the hand weeded plots grew quickly because of the early weed control; however, injury by wind was caused later.

Number of days from planting to tasseling: Atrazine and simazine at all rates tested as well as hand weeded plots gave no significant differences from the check. The remaining herbicidal treatments were those having methylmercapto radicals and therefore gave a sufficient injury to the foliage which caused a delay in tasseling that was significant in comparison to the check. It appears that the plants were able to detoxify the lower rate of GESAPRIM 1802 and, therefore, no harmful effect on the ultimate yield was observed.

Extent of ear filling: There were no significant differences in the extent of ear filling except for GESARAN and the higher rates of prometryne and GESAPRIM 1798, which resulted in less filled ears than the check. In general the treatments gave ears which were less filled than those harvested from the pre-emergence treatments. This may be on account of wind, or injury caused by the late application of the herbicides, or both.

Number of ears per 100 plants: GESAPRIM 1802 at the two higher rates and prometryne, GESARAN, and GESAPRIM 1798 at all rates resulted in significantly less number of ears per 100 plants as compared to the check. The reduction in the number of ears is due to the toxic action of herbicides and agrees with the phytotoxic effects (Table 4). All other treatments had approximately the same number of ears.

Ear weight: In general, the ear weights were lower than those obtained in the pre-emergence treatments and are in agreement with the grain yields (Table 11).

Residual Toxicity to Subsequent Crops

Pre-emergence applications: The residual toxicity observed on different crops due to pre-emergence herbicidal applications on corn is shown in Table 12. The two methylmercapto analogs, prometryne and GESARAN, although causing little or no injury to subsequent crops, are of little value being injurious to corn at the rates tested. Of the various crops observed, sugar beets were the most sensitive to triazines and injury was observed with all herbicides except for the lowest rate of prometryne used. The results for sugar beets are in agreement with those reported by Zemanek (81) for atrazine, and by Panic (59) for GESAPRIM 1798. Except for sugar beets, the two chlorotriazines at the lowest rates did not cause any visible injury to any of the other crops. The results are in agreement with those of Stroube and Bondarenko (72) for simazine and Zaharchuk (80) and Zemanek (81) for atrazine, but are in contradiction with those of Burzar (25), Engel (33), and Panic (59). It seems that the particular conditions, under which the experiments are carried out, are most

Table 12. The residual toxicity of pre-emergence applications of herbicides to crops following corn treated in 1965.

Herbicide	Rate Kg/ha (a.i.)	Injury rating					
		Winter crops			Spring crops		
		Wheat	Oats	Vetch	Onions	Sugar beets	Soybeans
Atrazine	2.5	-	-	-	-	+	-
	5.0	-	+	-	-	++	-
	12.5	+	++	+	+	+++	+
Simazine	2.5	-	-	-	-	++	-
	5.0	-	+	+	-	++	-
	12.5	+++	+++	+++	++	+++	+++
Prometryne	2.5	-	-	-	-	-	-
	5.0	-	-	-	-	+	+
	12.5	-	-	-	-	+	+

(Table 12 Continued)

GESARAN	2.5	-	-	-	-	+	-
	5.0	-	-	-	-	+	-
	12.5	-	+	-	-	++	+
GESAPRIM 1798	2.5	-	-	-	-	+	-
	5.0	-	-	-	-	++	-
	12.5	++	++	+	+	++	+
GESAPRIM 1802	2.5	+	-	-	-	+	-
	5.0	++	++	+	-	++	-
	12.5	+++	++	++	+	+++	+

- No toxicity.
+ Little injury and stunting.
++ Chlorosis and partial kill.
+++ Extreme injury, wilting, and ultimate kill.

important in determining the residual toxicity of herbicides.

The low organic matter content of the soil at the A.R.E.C. (68) might be a factor in the low adsorption capacity and persistence of the herbicides. It has been observed by other workers (43, 46, 47, 67, 74) that with an increase in the organic matter content of the soil, the extent of adsorption is increased. The high pH of the soil has also been reported to decrease the adsorption (46, 74). Since the soil on which the present study was conducted was clay in texture, more adsorption and persistence of the herbicides could be expected (21, 57, 74). But it was observed by Grover (43) that at high moisture levels changes in the relative amount of clay did not affect the toxicity of simazine. Since frequent irrigations were given throughout the growing season of corn, the texture of the soil was not an important factor under these conditions, so that a major amount of herbicides were either leached or taken up by the corn and weed plants and the persistence was less. Winter rains had an additional beneficial effect on the leaching of herbicides. This is further supported by the results of Buchholtz (20), and Holly and Roberts (47) who observed that under high rainfall conditions disappearance of triazine herbicides was relatively rapid as compared to that under low rainfall on the same soil.

Simazine at the highest rate tested killed all the subsequent crops, except onions where partial kill was observed, whereas atrazine caused little to moderate injury. Consequently the water solubility of individual herbicides in leaching and residual toxicity is important. This observation is in agreement with the results obtained by Burnside et al. (22). Among the mixtures of chloro- and methylmercapto-triazines GESAPRIM 1798, in general, showed less residual toxicity than comparable rates of GESAPRIM 1802. The only difference in the two products is that GESAPRIM 1798 has prometryne as one of its constituents whereas ametryne has taken its place in the case of GESAPRIM 1802. It appears that ametryne is more toxic to these crops as compared to prometryne. The results obtained with prometryne in the same trial partly support this assumption (Table 12).

Post-emergence applications: The results, as summarized in Table 13, showed, in general, that the toxicity of the triazines on subsequent crops used was much higher than the comparable treatments of the pre-emergence applications, and that the effects were much pronounced in the case of winter crops. This can be attributed to the time of application of the herbicides which was five weeks after planting corn. As a result the corn plants were exposed to the herbicides for a shorter

Table 13. The residual toxicity of post-emergence applications of herbicides to crops following corn treated in 1965.

Herbicide	Rate Kg/ha (a.i.)	Injury rating					
		Winter crops			Spring crops		
		Wheat	Oats	Vetch	Onions	Sugar beets	Soybeans
Atrazine	2.5	++	++	+	-	+++	-
	5.0	+++	+++	+	+	+++	+
	12.5	+++	+++	+++	++	+++	++
Simazine	2.5	+++	+++	+++	-	+++	-
	5.0	+++	+++	+++	++	+++	++
	12.5	+++	+++	+++	+++	+++	+++
Prometryne	2.5	-	++	-	-	-	-
	5.0	+	++	+	-	+	-
	12.5	++	+++	++	-	++	-

(Table 13 Continued)

GESARAN	2.5	+	+	-	-	+	-
	5.0	++	+	-	-	++	-
	12.5	+++	++	++	-	++	-
GESAPRIM 1798	2.5	++	++	+	-	++	-
	5.0	+++	+++	++	-	+++	-
	12.5	+++	+++	++	++	+++	++
GESAPRIM 1802	2.5	++	++	+	-	++	-
	5.0	+++	+++	++	-	+++	-
	12.5	+++	+++	+++	++	+++	++

- No toxicity.

\+ Little injury and stunting.

++ Chlorosis and partial kill.

+++ Extreme injury, wilting, and ultimate kill.

period of time. Consequently a lower amount of herbicide was absorbed by the plants to be detoxified. In addition leaching due to irrigation water was less, as was observed by Ashton (15) that with furrow irrigation, in the absence of rainfall or overhead irrigation, no downward movement of triazines took place. Under the conditions of this study only two sprinkler irrigations were applied to the corn crop after treating it with the post-emergence spray and then was followed by furrow irrigations. It seems that the herbicides remained in the top soil layer without any appreciable downward movement. In the case of pre-emergence treatments the corn crop received eight sprinkler irrigations before starting furrow irrigation, thus allowing the herbicides to move to a sufficient depth in the soil where more leaching might have taken place with furrow irrigation.

This is further supported by the fact that the differences in injury due to pre- and post-emergence treatments are much pronounced in the winter crops, but are much reduced in the spring crops. It appears that winter rains, along with other factors, caused sufficient downward movement of the herbicides before the spring crops were planted.

All the herbicidal concentrations which showed promise in corn injured the winter crops, however onions and soybeans among the spring crops had no visible injury at the lower rates. A possible reason for less injury in soybeans and onions may be due to their relatively shallow root system as compared to that of sugar beets. Simazine showed more injury in these crops than the comparable rates of atrazine.

Economic Evaluation

A comparative economic evaluation of the hand weeded, chemically treated and unweeded check plots was made. Based on the results obtained in the year 1965, only the two most promising herbicidal treatments, atrazine and simazine at 2.5 kg per hectare applied as a pre-emergence spray, were included in the comparison. Data on the average yield, gross income, cost of weed control, and net income are presented in Table 14.

The average moisture content of corn in the various plots was approximately 75 per cent. Therefore the forage yields of the various treatments were standardized to a uniform moisture content of 75 per cent, the value being in the desirable range for making silage. Grain yields were adjusted to a uniform moisture content of 15.5 per cent as already reported in Table 10.

Gross income was calculated at 32.00 L.L. per ton of green forage, and 25 L.P. per kg of grain. The figures are based on the average rate at which the two

Table 14. A comparative economic study of pre-emergence treatments of triazines in corn in the Beqa'a in 1965.[1]

Treatment	Average yield		Gross income		Cost of weed control[6]	Net income	
	Forage[2] Tons	Grain[3] Kg	Forage[4] L.L.	Grain[5] L.L.	L.L.	Forage L.L.	Grain L.L.
Unweeded	4.63	1079	148.16	269.75	0.00	148.16	269.75
Atrazine (2.5 kg/ha)	5.86	1444	187.52	361.00	11.55	175.97	349.45
Simazine (2.5 kg/ha)	6.16	1289	197.12	322.25	11.55	185.57	310.70
Hand weeded	5.81	1324	185.92	331.00	17.85	168.07	313.15

1. All calculations made on per dunum basis.
2. At 75 per cent moisture.
3. At 15.5 per cent moisture.
4. Green forage at 32 L.L. per ton.
5. Dried grain at 25 L.P. per kg.
6. Computed as follows:

Herbicide = L.L. 8.00 (16.00 L.L./kg of commercial product).
Spraying = L.L. 3.55 (including the fixed and operating costs of tractor and sprayer, and labor).
Hand weeded =L.L.17.85(based on study conducted at A.R.E.C. and neighboring villages).

commodities are purchased by A.R.E.C. personnel.[1] While calculating the gross income of the crop harvested for grain, the values for stover were not taken into consideration, because it is not a common practice to purchase stover in the Beqa'a as such no prices were available. Moreover the yields of stover were almost in the same range i.e. 637, 612, 585, and 600 kg per dunum on an air dried weight basis for unweeded, atrazine and simazine treated, and hand weeded plots, respectively.

The cost of chemical weed control included the cost of the herbicides and spraying operation. The selling price for each herbicides was 16.00 L.L. per kg of the commercial product (50% a.i.).[2] Thus the cost, based on 2.5 kg (a.i.) per hectare, was calculated to be 8.00 L.L. per dunum. Spraying costs, worked out by Ward and Fuleihan as reported by Saghir and Worzella (77, p. 22) including expenditures for fixed and operating costs of the tractor and sprayer, and the labor amounted to 3.55 L.L. per dunum. The cost of labor for hand weeding, as worked out by Saghir and Worzella (63, p.22), was taken at 17.85 L.L. per dunum.

The net incomes due to the pre-emergence applications of atrazine and simazine at 2.5 kg per hectare on corn for forage were approximately 105 and 110 per cent

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1. Personal communication with A.R.E.C. Superintendent.
2. Prices obtained from Comptoir Agricole du Levant, Geigy representatives in Lebanon.

of the hand weeded plots, and 109 and 125 per cent of the unweeded plots, respectively. When the crop was allowed to mature and was harvested for grain, a further increase in the net income was observed in the case of atrazine. The figures were 112 and 130 per cent as compared to hand weeded and unweeded plots, respectively. However, a reduction in the net income was observed with simazine and the values were 99 and 115 per cent of hand weeded and unweeded plots, respectively.

V. SUMMARY AND CONCLUSIONS

The purpose of this study was to evaluate six triazine herbicides, applied as pre- and post-emergence sprays, for their effectiveness in controlling weeds in corn and to observe their residual toxicity on subsequent crops.

The herbicides used were atrazine, simazine, prometryne, GESARAN, GESAPRIM 1798 and GESAPRIM 1802, each at the rates of 2.5, 5.0, and 12.5 kg (a.i.) per hectare during the year 1965. In 1966, only three promising herbicides, atrazine, simazine, and GESAPRIM 1802 were used each at the rates of 0.62 and 1.25 kg (a.i.) per hectare. Unweeded and hand weeded plots were included in each experiment. Phytotoxicity notes on corn and weeds were recorded. Data on forage and grain yields and other agronomic characteristics of corn were collected. After harvesting the corn crop of 1965, the residual toxicity was studied on wheat, oats, and vetch planted in the autumn, and on onions, sugar beets, and soybeans planted in the following spring. An economic evaluation was made between the two most promising herbicidal treatments, atrazine and simazine, applied each at 2.5 kg per hectare as a pre-emergence spray, and compared to the hand weeded and unweeded plots.

Both pre- and post-emergence applications of triazine herbicides gave good weed control in 1965 and 1966. The order of toxicity to corn, among the herbicides tested in 1965, was GESARAN = prometryne = GESAPRIM 1798 $>$ GESAPRIM 1802 $>$ simazine $>$ atrazine. In 1966, only GESAPRIM 1802 caused toxicity to corn when applied as a post-emergence spray.

Post-emergence applications of herbicides, in general, did not prove to be selective in controlling weeds in corn in both years. None of the treatments increased the corn yields significantly as compared to the check.

The residual toxicity, was severe in the case of the three winter crops, wheat, oats, and vetch when followed the post-emergence sprayed corn. Among the spring crops, sugar beets were injured in all cases except when followed corn treated with prometryne at 2.5 kg per hectare. Onions and soybeans did not show any injury at the lowest rates of atrazine and simazine, the two lower rates of GESAPRIM 1798 and 1802, and at all rates of prometryne and GESARAN used in 1965.

Pre-emergence treatments of atrazine and simazine at 2.5 kg per hectare as well as hand weeding caused a significant increase in the forage and grain yields of corn as compared to the unweeded plots in 1965. Atrazine at 5.0 kg per hectare, increased the corn yields. However, this increase was not significantly different from the check. All other rates of herbicides caused sufficient injury to reduce the yields.

In 1966, the pre-emergence treatments did not increase the corn yields significantly over the check. However, atrazine and GESAPRIM 1802 at 1.25 kg (a.i.) per hectare and hand weeding caused an increase in the forage yield over the unweeded plots.

The three herbicidal treatments, atrazine at 2.5 and 5.0 kg and simazine at 2.5 kg per hectare, which resulted in increases in corn yields in 1965, injured sugar beets when planted after the treated corn, whereas oats were injured only at the higher rate of atrazine. All other crops tested were not affected under the conditions of this study when followed corn treated with the above mentioned herbicides.

A higher net income was obtained from forage corn as a result of the pre-emergence applications of simazine and atrazine, each at 2.5 kg per hectare as compared to the hand weeded and unweeded treatments. When the crop was harvested for grain, there was a slight reduction in the net income due to simazine application as compared to hand weeding. However, the net income was higher with atrazine and simazine than that of unweeded corn.

LITERATURE CITED

1. Allen, W.S., and R.D. Palmer. The mode of action of simazine in barley. Weeds. 11, 27, 1963.

2. Alley, H.P., and E.W. Chamberlain. Chemical weed control in corn. Res. Prog. Rep. Western Weed Control Conf. 91, 1964. Abstracted in Weed Abstracts (22). Vol. 15, No. 1, January 1966.

3. Anonymous. Simazin. Information issued by the Pest Control Department, J.R. Geigy S.A., Basle, Sim./e. 72/HAE/Manch/es, 1957.

4. Anonymous. Atrazine. Information issued by the Pest Control Department, J.R. Geigy S.A., Basle, Atr./e. 72/SP/RT/ss, 1959.

5. Anonymous. Prometryne. Information issued by the Pest Control Department, J.R. Geigy S.A., Basle, Prometryne 72/HAE/hh/e., 1962.

6. Anonymous. Toxicology of G36 393. Department of Pharmacology, J.R. Geigy S.A., Basle, Tox. G36 393/e. 1st comm. 2P/Bx/mg, 1963.

7. Anonymous. Toxicology of ametryne (G34 162). Department of Pharmacology, J.R. Geigy S.A., Basle. Tox ametryne 1st comm. 2P/Bx/RT/mg, 1964.

8. Anonymous. Results obtained with A1798 and A1802 in corn (Maize). ITE - Reports, No.72/HA/bl/H64.73. J.R. Geigy S.A., Basle. 1964.

9. Anonymous. Control of late emerging grasses in corn (maize). ITE - Reports, No. 72/HAE/mo/H 64.84. J.R. Geigy S.A., Basle. 1964.

10. Anonymous. Weed Control in silo maize. ITE - Reports, No. 72/HAE/gg/H65.24. J.R. Geigy S.A., Basle. 1965.

11. Anonymous. Weed control in corn (maize). ITE - Reports, No. 72/HAE/gg/H65.62. J.R. Geigy S.A., Basle. 1965.

12. Anonymous. A1798 and A1802 in corn (maize). ITE - Reports, No. 72/HA/gg/H65.118. J.R. Geigy S.A., Basle. 1965.

13. Anonymous. Weed control with triazines in Greece. ITE - Reports, No. 72/HAE/gg/H65.125. J.R. Geigy S.A., Basle. 1965.

14. Anonymous. Weed Control in maize (corn). ITE - Reports, No. 72/BA/be/H66.41. J.R. Geigy S.A., Basle. 1966.

15. Ashton, F.M. Movement of herbicides in soil with simulated furrow irrigation. Weeds. 9, 612, 1961.

16. Ashton, F.M. Relationship between light and toxicity symptoms caused by atrazine and monuron. Weeds. 13, 164, 1965.

17. Ashton, F.M., T. Bisalputra, and E.B. Brisley. Effect of atrazine on Chlorella vulgaris. Amer. J. Bot. 53, 217, 1966.

18. Ashton, F.M., E.M. Gifford, Jr., and T. Bisalputra. Structural changes in Phaseolus vulgaris induced by atrazine. II. Effects on fine structures of chloroplasts. Bot. Gaz. 124, 336, 1963.

19. Ashton, F.M., G. Zweig, and G.W. Mason. The effect of certain triazines on $C^{14}O_2$ fixation in red kidney beans. Weeds. 8, 448, 1960.

20. Buchholtz, K.P. Factors influencing oat injury from triazine residues in soil. Weeds. 13, 362, 1965.

21. Burnside, O.C., and R. Behrens. Phytotoxicity of simazine. Weeds. 9, 145, 1961.

22. Burnside, O.C., C.R. Fenster, and G.A. Wicks. Dissipation and leaching of monuron, simazine, and atrazine in Nebraska soils. Weeds. 11, 209, 1963.

23. Burnside, O.C., E.L. Schmidt, and R. Behrens. Dissipation of simazine from the soil. Weeds. 9, 477, 1961.

24. Burschel, P. Experiments on the breakdown of simazine in the soil. Weed Res. 1, 131, 1961.

25. Burzar, A. Triazines in corn (maize). ITE - Reports, No. 72/HA/bl/H65.17. J.R. Geigy S.A., Basle. 1965.

26. Castelfranco, P., and M.S. Brown. Purification and properties of simazine - resistance factor of _Zea mays_. Weeds. 10, 131, 1962.

27. Chaudhry, N.H. Effect of irrigation schedule and plant population on the yield and other characteristics of hybrid corn. M.S. Thesis. American University of Beirut. Beirut, Lebanon. 1965.

28. Crafts, A.S. _The Chemistry and Mode of Action of Herbicides_. Interscience Publishers, Inc., New York, 1961.

29. Crafts, A.S., and S. Yamaguchi. The autoradiography of plant materials. California Agr. Exp. Sta. Manual 35, 1964.

30. Davis, D.E., H.H. Funderburk, Jr., and N.G. Sansing. The absorption and translocation of C^{14}-labeled simazine by corn, cotton, and cucumber. Weeds. 7, 300, 1959.

31. Eastin, E.F., R.D. Palmer, and C.O. Grogan. Mode of action of atrazine and simazine in susceptible and resistant lines of corn. Weeds. 12, 49, 1964.

32. Eddowes, M., and R.L. Harpur. Chemical weed control in maize. Weed Res. 5, 33, 1965.

33. Engel, H. Is damage to crops following maize treated with Gesaprim avoidable? Gesunde Pflanzen. 15, 141, 1963. Abstracted in Weed Abstracts (27). Vol. 13, No. 1, January 1964.

34. Exer, B. Experientia. 14, 135, 1958. Reviewed in Crafts, A.S. _The Chemistry and Mode of Action of Herbicides_. Interscience publishers, Inc., New York, 1961.

35. Fink, R.J., and O.H. Fletchall. Forage crop establishment in soil containing atrazine and simazine residues. Weeds. 11,81, 1963.

36. Foy, C.L. Volatility and tracer studies with alkylamino-s-triazines. Weeds. 12, 103, 1964.

37. Freed, V.H. Unpublished data. Reviewed by Montgomery, Marvin L., and Virgil H. Freed. Metabolism of triazine herbicides by plants. J. Agr. Food Chem. 12, 11, 1964.

38. Freeman, J.F. Postemergence herbicide treatment in corn. Res. Rep. 18th N . Cent. Weed Control Conf. 60, 1961. Abstracted in Weed Abstracts (645). Vol. 12, No. 3, May 1963.

39. Funderburk, H.H., Jr., and D.E. Davis. The metabolism of C^{14} chain- and ring-labeled simazine by corn and the effect of atrazine on plant respiratory systems. Weeds. 11, 101, 1963.

40. Gentner, W.A. Herbicidal activity of several s-triazines as postemergence sprays. Weeds. 12, 115, 1964.

41. Granstrom, B. Studies on weeds in spring sown crops. Statens Jordbruksforsok. Medd. Nr. 130. Uppsala. 1962.

42. Granstrom, B., and A. Dahlkvist. Weed control in winter cereals in southern Sweden. Reports of the Agricultural College of Sweden. Serie A. Nr 46. Uppsala. 1966.

43. Grover, R. Influence of organic matter, texture, and available water on the toxicity of simazine in soil. Weeds. 14, 148, 1966.

44. Gysin, H., and E. Knusli. Chemistry and herbicidal properties of triazine derivatives. In Metcalf, R.L. (Editor). Advances in Pest Control Research. Interscience Publishers, Inc., New York, Vol. 3, 1960.

45. Hamilton, R.H., and D.E. Moreland. Simazine: Degradation by corn seedlings. Science. 135, 373, 1962.

46. Harris, C.I., and T.J. Sheets. Influence of soil properties on adsorption and phytotoxicity of CIPC, diuran, and simazine. Weeds. 13, 215, 1965.

47. Holly, K., and H.A. Roberts. Persistence of phytotoxic residues of triazine herbicides in soil. Weed Res. 3, 1, 1963.

48. Kiesselbach, T.A. Progressive development and seasonal variation of the corn crop. Agric. Exp. St. University of Nebraska. Res. Bul. 166, 1950.

49. Koss, V., and H. Ansorge. Comparison of different weed killers in maize grown for silage. Albrecht - Thaer - Arch. 7, 901, 1963. Abstracted in Weed Abstracts (1601). Vol. 13, No. 6, November 1964.

50. Kuthe, K., and R. Krantz. Weed control and cultivation in maize. Gesunde Pflauzen. 15, 91, 1963. Abstracted in Weed Abstracts (1508). Vol. 12, No. 6, November 1963.

51. Kwizda, F.J. Triazines as postemergence herbicides in corn (maize) - Evaluation of yields. ITE - Reports, No. 72/TC/be/H66.47. J.R. Geigy S.A., Basle. 1966.

52. LeClerg, E.L., W.H. Leonard, and A.G. Clark. Field Plot Technique. Burgess Publishing Company, Minnesota, 2nd ed., 1962.

53. Leonard, W.H., and J.H. Martin. Cereal Crops. The Macmillan Company, New York, 1963.

54. McWhorter, C.G., and J.T. Holstun, Jr. Phytotoxicity of s-triazine herbicides to corn and weeds as related to structural differences. Weeds. 9, 592, 1961.

55. Montgomery, M., and V.H. Freed. The uptake, translocation and metabolism of simazine and atrazine by corn plants. Weeds. 9, 231, 1961.

56. Moreland, D.E., W.A. Gentner, J.L. Hilton, and K.L. Hill. Studies on the mechanism of herbicidal action of 2-chloro-4, 6-bis (ethylamino)-s-triazine. Plant. Physiol. 34, 432, 1959.

57. Nearpass, D.C. Effects of soil acidity on the adsorption, penetration, and persistence of simazine. Weeds. 13, 341, 1965.

58. Negi, N.S., H.H. Funderburk, Jr., and D.E. Davis. Metabolism of atrazine by susceptible and resistant plants. Weeds. 12, 53, 1964.

59. Panic, M. Triazines in maize/effect on following crop. ITE-Reports, No. 72/HA/gg/H65.25. J.R. Geigy, S.A. Basle. 1965.

60. Pejka, H., and T. Kukowski. Weed control in corn (maize). ITE-Reports, No. 72/BA/bl/H65.99. J.R. Geigy S.A., Basle. 1965.

61. Ragab, M.T.H., and J.P. McCollum. Degradation of C^{14}- labeled simazine by plants and soil microorganisms. Weeds. 9, 72, 1961.

62. Roth, W. Experientia. 14, 137, 1958. Reviewed in Crafts, A.S. The Chemistry and Mode of Action of Herbicides. Interscience Publishers, Inc., New York, 1961.

63. Saghir, A.R., and W.W. Worzella. The effect of herbicides on annual weeds in onions. Faculty of Agricultural Sciences. American University of Beirut. Pub. No. 15, June 1961.

64. Schmidt, W.H., and W.L. Colville. Forage yield and composition of teosinte, corn, and forage sorghum grown under irrigation. Agron. J. 55, 327, 1963.

65. Sheets, T.J. The comparative toxicities of monuron and simazine in soil. Weeds. 7, 189, 1959.

66. Sheets, T.J. Uptake and distribution of simazine by oat and cotton seedlings. Weeds. 9, 1, 1961.

67. Sheets, T.J., A.S. Crafts, and H.R. Drever. Influence of soil properties on the phytotoxicities of the s-triazine herbicides. J. Agr. Food Chem. 10, 458, 1962.

68. Soofi, G.S. Interrelationships of various micro and macro nutrients on the growth and composition of corn. M.S. Thesis. American University of Beirut. Beirut, Lebanon. 1961.

69. Staniforth, D.W., and W.G. Lovely. Preemergence herbicides in corn production. Weeds. 12, 131, 1964.

70. Stohr, W. The influence of herbicides on maize yields. Pflanzenschutz. 12, 156, 1960. Abstracted in Weed Abstracts (1938). Vol. 13, No. 4, July 1964.

71. Stroube, E.W., R.E. Ascheman, and R.E. Hastings. Pre-emergence weed control in corn. Res. Rep. 18th N. Cent. Weed Control Conf. 63, 1961. Abstracted in Weed Abstracts (644). Vol. 12, No. 3, May 1963.

72. Stroube, E.W., and D.D. Bondarenko. Persistence and distribution of simazine applied in the field. Proc. 17th N. Cent. Weed Control Conf. 40, 1960. Abstracted in Weed Abstracts (1221). Vol. 11, No. 4, July 1962.

73. Talbert, R.E., and O.H. Fletchall. Inactivation of simazine and atrazine in the field. Weeds. 12, 33, 1964.

74. Talbert, R.E., and O.H. Fletchall. The adsorption of some s-triazines in soils. Weeds. 13, 46, 1965.

75. Termunde, D.E., D.B. Shank and V.A. Dirks. Effects of population levels on yield and maturity of maize hybrids grown on the Northern Great Plains. Agron. J. 55, 551, 1963.

76. Upchurch, R.P., and D.D. Mason. The influence of soil organic matter on the phytotoxicity of herbicides. Weeds. 10, 9, 1962.

77. Ward, G., and J. Fuleihan. Unpublished data. 1957-58. Cited by Saghir Abdur-Rahman, and W.W. Worzella. The effect of herbicides on annual weeds in onions. Faculty of Agricultural Sciences. American University of Beirut. Pub. No. 15, June 1961.

78. Weiss, P.W. Comparison of various triazine applications in corn (maize). ITE - Reports, No. 72/TC/bl/H65.8. J.R. Geigy S.A., Basle. 1965.

79. Weiss, P.W., and B.J. Hall. An evaluation of herbicidal properties of two new chemicals - prometryne and ametryne. Aust. J. Exp. Agric. Anim. Husb. 3, 338, 1963. Abstracted in Weed Abstracts (1177). Vol. 13, No. 4, July 1964.

80. Zaharchuk, A. Two year studies on residual comparisons of lorox and atrazine on several crops. Proc. 17th N. East Weed Control Conf., 284, 1963. Abstracted in Weed Abstracts (1282). Vol. 14, No. 4, July 1965.

81. Zemanek, J. The study of the influence of triazine herbicides on the subsequent crops. Ochrana Rostlin. 2, 9, 1965. Abstracted in Weed Abstracts (1622). Vol. 14, No. 5, September 1965.

82. Zuber, M.S., G.E. Smith, and C.W. Gehrke. Crude protein of corn grain and stover as influenced by different hybrids, plant populations, and nitrogen levels. Agron. J. 46, 257, 1954.

83. Zweig, G., and F.M. Ashton. The effect of 2-chloro-4-ethylamino-6-isopropyl-amino-s-triazine (atrazine) on distribution of $^{14}CO_2$ fixation in excised kideny bean leaves. J. Exp. Bot. 13, 5, 1962.

APPENDIX A

List of weed species found in the experimental plots

Scientific name	Common names
Amaranthus retroflexus	Red root, Pigweed.
Anchuza italica	Bugloss, Italian Anchuza.
Bupleurum subovatum	Round-leaved Hare's-ear.
Campanula strigosa	Strigose Bellflower.
Carthamus flavescens	Golden safflower.
Chenopodium opulifolium	Maple-leaved Goosefoot.
Cirsium acarna	Yellow Plumed Thistle.
Convolvulus althaeoides	Mallow-leaved Bindweed.
Convolvulus arvensis	Field Bindweed.
Diplotaxis erucoides	White Rocket.
Euphorbia gaillardoti	Gaillardot's Spurge.
Heliotropium bovei	Heliotrope.
Lactuca scariola	Prickly Lettuce, Compass Plant.
Lepidium chalepense	Hoary Cress.
Lolium perenne	Perennial Rye Grass.
Portulaca oleracea	Purslane.
Rapistrum rugosum	Wrinkled Gold of Pleasure
Saponaria vaccaria	Cow herb.

Setaria verticillata	Rough Bristle grass, Bristly Foxtail.
Sinapsis arvensis	Wild mustard, Charlock, Field kale.
Sonchus nymanni	Glaucus Sow Thistle, Spiny Sow Thistle.
Tribulus terrestris	Caltrops, Puncture vine, Malta cross.

APPENDIX B

Table 15. Analysis of variance for plant height and forage yield resulting from pre-emergence applications of herbicides on corn in 1965.

Source of variation	D.F.	M.S.	
		Plant height	Forage yield
Blocks	2	67.32	1562.15
Treatments	19	24625.82**	1075783.20**
Error	38	24.18	41860.94

** Significant at 1 per cent level.

Table 16. Analysis of variance for forage yield and agronomic characteristics resulting from pre-emergence applications of herbicides on corn in 1966.[1]

Source of variation	D.F.	M.S.		
		Plant height	Stem thickness	Forage yield
Blocks	2	0.79	0.0066	46113.17*
Treatments	7	36.36	0.0050	18764.71
Error	14	15.12	0.0049	10606.26

* Significant at 5 per cent level.

1 One complete block discarded due to poor stand.

Table 17. Analysis of variance for plant height and forage yield resulting from post-emergence applications of herbicides on corn in 1965.

Source of variation	D.F.	M.S.	
		Plant height	Forage yield
Blocks	2	1046.15**	102424.02
Treatments	19	14489.26**	685808.47**
Error	38	174.47	51222.14

** Significant at 1 per cent level.

Table 18. Analysis of variance for forage yield and agronomic characteristics resulting from post-emergence applications of herbicides on corn in 1966.[1]

Source of variation	D.F.	M.S.		
		Plant height	Stem thickness	Forage yield
Blocks	2	1107.29**	0.0211*	111174.04**
Treatments	7	88.57	0.0141*	11140.26
Error	14	75.24	0.0036	11663.85

* Significant at 5 per cent level.

** Significant at 1 per cent level.

1 One complete block discarded due to poor stand.

Table 19. Analysis of variance for grain yield and agronomic characteristics resulting from pre-emergence applications of herbicides on corn in 1965.

Source of variation	D.F.	M. S.					
		No. of days to tassel	Extent of ear filling	No. of ears per 100 plants	Ear weight	Grain yield	Stover yield
Blocks	2	1.22	1.25*	28.92	401.22	1395.20	18374.72
Treatments	19	5180.22**	9.74**	5708.22**	48187.34**	854519.84**	207023.70**
Error	38	1.41	0.27	144.91	800.27	15607.32	14742.26

* Significant at 5 per cent level.

** Significant at 1 per cent level.

Table 20. Analysis of variance for grain yield and agronomic characteristics resulting from post-emergence applications of herbicides on corn in 1965.

Source of variation	D.F.	M. S.					
		No. of days to tassel	Extent of ear filling	No. of ears per 100 plants	Ear weight	Grain yield	Stover yield
Blocks	2	3.65	5.06**	472.32*	12018.56**	331245.72**	15912.82
Treatments	19	3383.24**	3.03**	4965.25**	20212.52**	356335.77**	89516.62**
Error	38	2.23	0.29	120.14	1241.02	30187.37	6362.43

* Significant at 5 per cent level of significance.

** Significant at 1 per cent level of significance.