EFFECTS OF EVAPORATIVE COOLING IRRIGATION ON *BRASSICA* SPECIES AND SOIL APPLICATION OF HERBICIDES ON MINERAL COMPOSITION OF PEA (*PISUM SATIVUM*)

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EFFECTS OF EVAPORATIVE COOLING IRRIGATION ON BRASSICA SPECIES AND SOIL APPLICATION OF HERBICIDES ON MINERAL COMPOSITION OF PEA (PISUM SATIVUM)

presented by

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ABSTRACT

EFFECTS OF EVAPORATIVE COOLING IRRIGATION
ON *BRASSICA* SPECIES
AND
SOIL APPLICATION OF HERBICIDES ON
MINERAL COMPOSITION OF PEA (*PISUM SATIVUM*)

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Part I

The objective of this investigation was to evaluate the influence of evaporative cooling on production and the quality of *Brassica* crops. The investigation was carried out during the summers of 1969 and 1970 on mineral and organic soils, respectively. Evaporative cooling applications reduced the plant temperature up to 5 C. Only cabbage and kohlrabi showed a beneficial effect from evaporative cooling. Cauliflower was severely affected by bacterial soft rot, especially where it was grown on organic soil.

The K content and the percentage of dry weight were reduced in the plants under mist. However, Na was markedly increased. Ca was slightly increased in the edible parts of *Brassicas*.

It was concluded that there are different moisture tolerances among *Brassica* crops and the evaporative cooling should be applied according to the needs of every crop during its life cycle. Atmospheric conditions did not markedly influence plant water stress in 1969 and 1970; consequently, evaporative cooling was of very limited value.

Part II

Previous work has indicated that water-stress is frequently associated with reduced Ca in plants. Greenhouse and field studies were, therefore, undertaken to determine the effect of various combinations of soil applied herbicides (simazine, dinoseb, dichlobenil and trifluralin) and Ca on the mineral-element accumulation of the foliage of pea (*Pisum sativum*). Forty of 44 comparisons with related controls indicated pronounced significant effects of treatment on the accumulation of one or more of the following elements: P, K, Ca, Mg, Na, Fe, Mn, Cu, Zn, and B. Treatment resulted in an increase in dry matter in 8 instances, a reduction in 11, and had no influence in 25.

Either Ca (100 lb/A) or dinoseb (3 lb/A) increased the Ca concentration over 30%. Simazine ($\frac{1}{8}$ lb/A) increased it from 10 to 20%, dichlobenil (1 lb/A) had no effect and trifluralin (1 lb/A) reduced it more than 40%. Phosphorus accumulation was enhanced over 25% by some dinoseb treatments but was not markedly influenced by simazine, dichlobenil or trifluralin. Potassium accumulation was increased by simazine in some comparisons but was not influenced by the other herbicides. Magnesium accumulation was increased more than 25% by dichlobenil, by a lesser amount by simazine, but was decreased by over 25% by the other two herbicides. On field mineral soil, trifluralin reduced growth by about 50% but reduced the accumulation of Na by over 80%. Dinoseb, although not reducing growth, reduced Na accumulation by 65%.

In the greenhouse with soils containing 25% peat, the application of all four herbicides in many comparisons resulted in increased Mn accumulation of from 30 to 60%. Accumulations of Cu and Zn were increased by over 25% by herbicide combinations involving dinoseb and by over 50% by dichlobenil but were not influenced by the other two chemicals. Iron accumulation was enhanced by application of either dinoseb or trifluralin with simazine, but was reduced when dichlobenil was applied with simazine. Boron accumulation was increased by dichlobenil with Ca, but was reduced in tests on field mineral soil with trifluralin.

The above observations related to the influence of herbicidal chemicals on pea plant composition indicated that the plant is rather tolerant to a wide variation in nutrient accumulation, and that organic and inorganic chemicals markedly modify its inherent ability to accumulate mineral elements. The mechanisms responsible may be related to alterations in the exchange capacity or the permeability of the plant's roots, or in modification of the activity of certain enzymes, by the heavy metals absorbed, that influence nutrient transport from the roots to the foliage. The problem, one of considerable complexity, is of great interest to plant nutritionists and cellular physiologists. An extension of these investigations to other crops and with other chemicals should aid in solving some of the perplexing problems in the physiology of weed control and help in resolving some inconsistencies frequently observed in plant mineral composition analyses.

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A THESIS

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To my wife, my son and my parents

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PART I

EFFECTS OF EVAPORATIVE COOLING IRRIGATION ON *BRASSICA* SPECIES

INTRODUCTION

Water plays an essential role in the life and production of a crop with plant growth related directly to the water balance in tissues. If water stress is too high, physiological processes are disturbed, and growth and yield are affected. Furthermore, water is involved directly or indirectly in most biochemical reactions in the plant, as a constituent or in regulating those reactions.

The use of evaporative cooling techniques has been shown to be an effective method of regulating plant water stress during atmospheric stress periods, resulting in more vigorous plant growth (Carolus, 1970). The application of "mist" irrigation increases the relative humidity around the plant, reduces air and plant temperatures and decreases water loss by transpiration (Van Den Brink *et al.*, 1965).

The purpose of this work (during the summers of 1969 and 1970) was to determine the effects of "mist" irrigation on the growth and quality of *Brassica* crops.

LITERATURE REVIEW

Water should be supplied as required to minimize water stress in plants. Logically the loss of water vapor by the plants is increased when the atmospheric factors, temperature, radiation and air movement are high and humidity is low.

Evaporative Cooling Experiments

Water is used for increasing soil moisture and can be used for decreasing atmospheric stress which diminishes productivity of crops due to excessive transpiration. Carolus *et al.* (1965) found that "misting" is a better cultural practice than periodical saturation of the soil with water. In experiments, sprinkler irrigation at the rate of 0.04-0.06 inch per hour during high atmospheric stress periods improved the growth and development of tomato, muskmelon and cucumber (Bible *et al.*, 1968).

Van Den Brink *et al.* (1965) applied mist irrigation to lettuce and tomato and obtained a substantial temperature reduction and an increase in relative humidity of 20% in the microclimate of the plant. Gubbels (1967) reported that the application of "mist" on celery plants resulted in higher total fresh and dry weights with a reduction in transpiration up to 27%. According to Bible et al. (1968), misting reduced plant temperature by 16 F, and this cooling effect continued for several hours after the misting was discontinued in spite of a high atmospheric stress.

Recently Gilbert (1970), using evaporative cooling in the San Joaquin Valley of California (90 F and 25% r.h.), observed a substantial temperature reduction of 15 to 25 F in grape leaves and an ambient air increase in relative humidity of 10 to 20%. Unrath (1970) reported temperature reductions of 12 F in apple fruit tissues when the evaporative cooling (.056 inch of water/hr) was applied. Carolus (1969) indicated desirable effects of misting in the productivity of green bean, potato, onion, strawberry, cucumber, muskmelon, tomato, and lettuce.

Water Relations in Brassica Crops

There is no general agreement in the results of studies of water relations in *Brassica* crops. Singh (1966) stated that the greatest reduction in the yield of marketable cabbage occurs when periods of high soil moisture stress coincide with high atmospheric stress. Yield of cabbage improved as the irrigation intervals decreased from 16 to 8 days (Jadhav, 1968). Peck (1956) reported that cabbage had a peak rate of 0.167 inch per day of evapotranspiration in mid August. Drew (1966) concluded that water stress for periods up to 5 weeks during the first 9 weeks after planting had little effect on the final yield of cabbage, but dry periods of 3 weeks later in the life of the crop drastically reduced yield. Somos (1956) studied the effect of irrigation on cabbage and claimed that flooding was a better practice than sprinkling. After three years of study, yield increases were obtained of 280 to 430% with supplementary water applications of 25-50 mm. Of the 450-500 mm water required in this experiment, 250 mm were applied by supplementary irrigation. He also suggested (1957) that the yearly rainfall in Hungary, which is 500-600 mm, is insufficient for vegetables with as high a water requirement as cabbage. Similarly, Borna (1965) has indicated that 50 mm applied 62 and 69 days after transplanting gave the highest cabbage yields. Strydom (1968), working with the same crop, determined that no difference in yield was apparent when the available soil moisture ranged from 23 to 48% and calculated that the total consumption was about 14 inches. Bagrov (1965) showed that the highest cabbage yields were obtained when the available soil moisture was 80 to 85% during the vegetative period and 70 to 75% at the maturing period.

Salter (1961) observed that irrigation improved the yield of cauliflower and water application 5-10 days before harvest was particularly beneficial. In England, Winter (1968) reported that better yields of summer cauliflower were obtained by never allowing the soil moisture deficit to exceed one inch. Maximum yields were obtained by transplanting into a soil near field capacity and then applying one inch of water just prior to harvest, with the crop receiving only normal rainfall during the rest of the season. Jyotishi (1967) found that cauliflower produced the best yield when irrigation intervals were spaced 36 days apart and the lowest yield at 12 days.

Dreibrodt (1960) reported that when equal amounts of water were applied to cauliflower and kohlrabi, the highest yields were obtained when water was supplied during the latter stages of growth. With reference to kohlrabi, Springer (1966) reported that small fluctuations (8 to 15%) in soil moisture content were more favorable than a constant soil moisture content. Duffek (1965) reported that kohlrabi should be grown in soil maintained at 75 to 80% of available soil moisture in sunny weather and in cool, cloudy weather at 60 to 65%. Frohlich (1962) stated that the soil moisture level should not fall below 60% of field capacity for kohlrabi.

Robinson (1968) reported that sprinkler irrigation of 3 mm/hr was more effective than furrow irrigation for cabbage and radishes in the Colorado desert area. Riethus et al. (1958) suggested that the highest yields with most vegetable crops are obtained if the soil water saturation is maintained at 50 to 75%.

Massey (1962) indicated that broccoli yields were doubled under irrigation but that the percent of dry matter was reduced by treatment. Rider (1957) indicated that the typical loss of water on sunny days for Brussels sprouts was 4 mm. Stanhill (1958) indicated that three distinct levels of soil moisture were desirable for turnips. When the plants were seedlings, a wet period increased edible roots at harvest, during root enlargement it was detrimental to the final yield and at the end of the season it resulted in the greatest increase in yield.

Effects of Irrigation on the Mineral Composition of Brassicas

Little work has been reported on the effect of irrigation on the nutrient composition of *Brassicas*. From a comparative study of cabbage, cauliflower, kohlrabi and Brussels sprouts, Lokovnikova (1966) concluded that the species differed from each other in leaf composition. The variability appeared to be more inherent than a result of soil and climatic conditions. Sheets *et al.* (1955) studied the application of different levels of moisture on turnip plants and indicated that the P content of their leaves was increased by irrigation, Ca was decreased, Fe was unaffected and N showed erratic results.

MATERIALS AND METHODS

Experimentation at the Horticulture Research Center, 1969

During the spring and summer of 1969 an experiment was undertaken with broccoli "Waltham 29", cauliflower "Snowball" and cabbage "Greenback" to study the influence of mist irrigation.

The plants were seeded in flats in the greenhouse in a mix of 1:1 soil-peat on March 21, April 23 and May 22, 1969. The seedlings were transplanted (2 × 2 inches) to other flats on April 2, May 5 and June 5, 1969, respectively, and transplanted to the field on May 15, June 6 and July 1, 1969.

This experiment was conducted on a sandy loam soil with a pH of 5.8 and a soil test of 3-NO_3-N, 8-P, 300-K, 500-Ca and 90-Mg pp2m, respectively. The soil tests were run by the soil testing laboratory of M.S.U. using Bray P_1 extractant for P, normal neutral ammonium acetate for K, Ca, Mg and 0.1 N HCl for Mn. Before planting, 8-10 tons of manure and 300 lb of triple superphosphate were applied, and 20 lb of N/A was applied as a side dressing on July 3, 1969.

The field was divided into two sections, mist section (0.04-0.06 inch/hr) when atmospheric conditions dictated and conventional sprinkler section when soil available moisture dropped below 50% of field capacity. A distance of 40 feet was provided between the two systems of irrigation. Forty-five to 50 plants per variety were planted in each section at the three planting dates. No chemical weed control was used.

Evaporative cooling was practiced from 10 a.m. until 3 p.m. when the temperature during the day exceeded 80 F. Conventional irrigation was applied six times for 2 hours (0.5 inch/hr) on June 17, 22, 27, and July 9, 12, 16.

Daily temperatures and precipitation readings were obtained and are summarized in Figure 1.

Research at the Muck Experimental Farm, 1970

In the spring and summer of 1970, an investigation was conducted on the Muck Experimental Farm 13 miles northeast of Lansing, to evaluate the influence of evaporative cooling on various *Brassica* crops.

Two replicated plantings on misted and nonmisted areas of cauliflower, cabbage and brocoli were made, one using transplants and the other by direct seeding on May 29. Single replicated

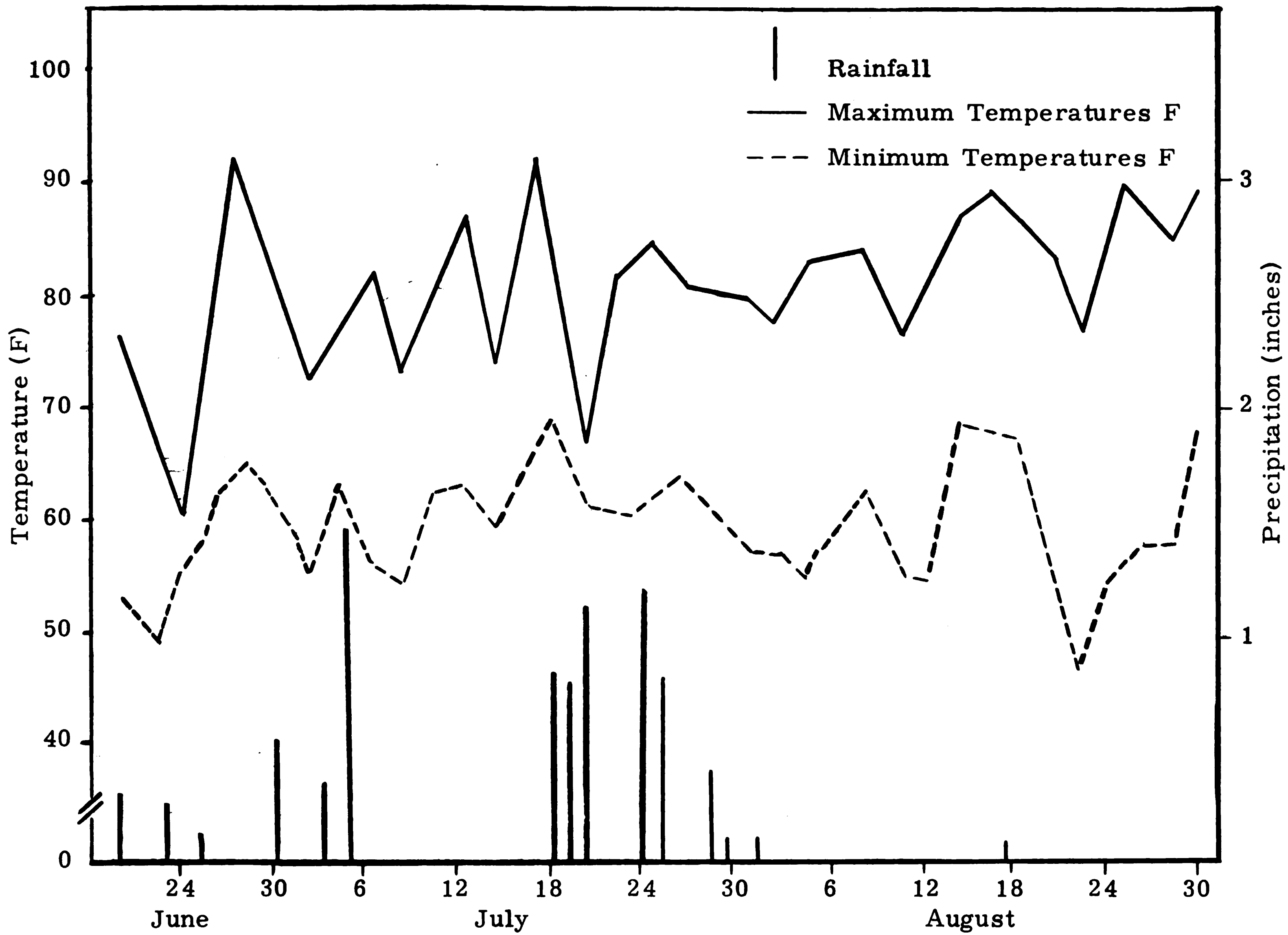

Figure 1. --Rainfall, maximum and minimum temperatures for June, July and August, 1969, at the Horticulture Research Farm, East Lansing.

plantings of kohlrabi, turnips and Brussels sprouts were made on June 10 and July 1.

Before planting, 1000 lb/A of 5-10-20 + 2% Mn as $MnSO_4$ was applied over the entire field.

The herbicide nitrofen was used at the rate of 4 lb/A in two applications immediately and 30 days after seeding on cauliflower, broccoli and cabbage.

The mist irrigation (0.04-0.06 inch/hr) was turned on from 10 a.m. to 3 p.m. (7 min. every 30 min.) when the temperature was over 80 F. Conventional irrigation was applied once during the growing season.

In the mist and conventional sections, temperatures were taken by thermocouples (every $\frac{1}{2}$ hour from 11:00 a.m. until 2:30 p.m.) during mid August (13-19th) in broccoli plants ready for harvest. The readings were made in leaf petioles located on the inside and the outside of the plants and a reading of the soil temperature one inch deep under the plant.

In the middle of the season, 2 lb/A of $MnSO_4$ was sprayed over the plants, causing a considerable burning of the leaves, especially those plants under mist irrigation.

Approximately 60 to 80 plants per crop, section and planting reached maturity. Forty plants were harvested at random from each treatment under mist and conventional irrigations from each replicate.

Broccoli, cauliflower and cabbage were harvested on August 12, 18, 23 and September 19, 1970. Kohlrabi "Early White Vienna" was harvested August 7 and turnips "Purple Top White Globe" and Brussels sprouts "Jade Cross" were harvested on August 20 and October 16, 1970, respectively.

Samples in triplicate were taken from the plants (tips of leaves and edible parts) for mineral analysis at harvest. Fifty grams (fresh weight) of each sample was oven dried at 120 F. A complete mineral analysis was made, except for nitrogen. Potassium was determined by the flame photometer and all the other elements, P, Na, Ca, Mg, Mn, Fe, Cu, B, Zn, Al, spectroscopically.

Daily temperatures and precipitation taken at the Muck Farm, during the summer of 1970, are summarized in Figure 2.

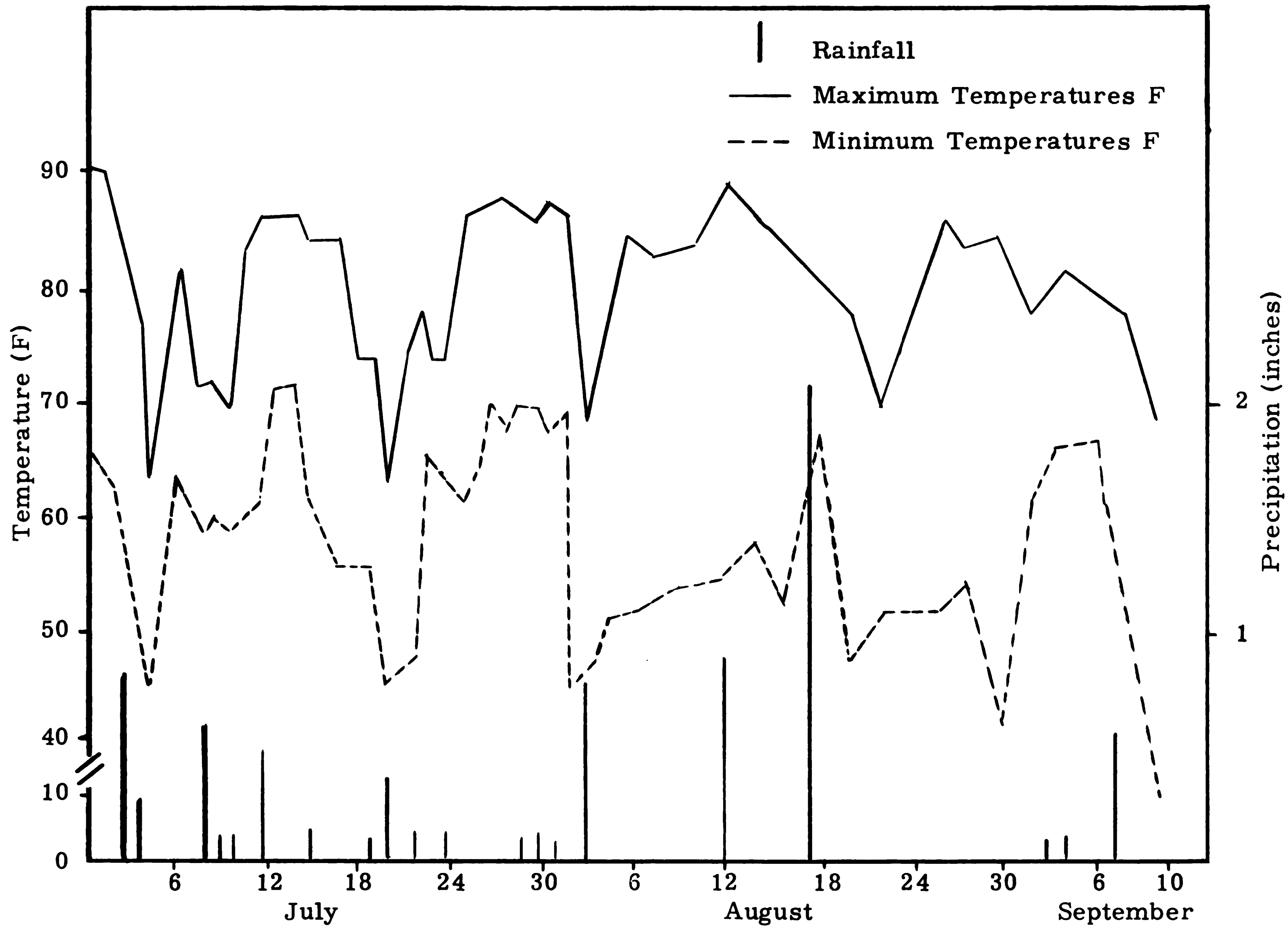

Figure 2. --Rainfall, maximum and minumum temperatures for July, August and September, 1970, at the Muck Experimental Farm.

RESULTS

The experiments carried out throughout the summers of 1969 and 1970 were severely damaged by rainfall. In 1969 rainfall was excessive in the first half of the summer (Figure 1). Approximately five inches of precipitation between July 17-28 destroyed more than half of the experiment due to the poor drainage of the soil. Atmospheric stress in both years was considerably less than the 10-year average.

During the summer of 1970, with the rainfall throughout July and August (Figure 2), the application of evaporative cooling irrigation to the *Brassica* crops resulted in a severe infection of bacterial soft-rot (*Erwinia carotovora*), especially in cauliflower, broccoli and turnips. The wet weather dictated the application of conventional irrigation only once during the growing season.

Mist irrigation decreased leaf temperature on broccoli plants with a difference obtained on a sunny day (28 C and 70% r.h.) of 4 C (28-24 C) in an inside leaf and a difference of 5 C (30-25 C) on an outside leaf. The temperature of the soil was 1 C less (25-24 C) than that of the conventional system. On a cloudy day (26 C and 60% r.h.) the maximum difference in temperatures was 1 C (26-25 C) for the inside leaf, 2 C (27-25 C) for the outside leaf, with no change in soil temperature between treatments.

The results obtained for the two years from broccoli and cauliflower indicate that more marketable produce was obtained from conventional irrigation than from the misted areas. Cabbage was benefited from mist irrigation (Table 1).

In the first planting of broccoli there was more flowering in 1969 than in 1970; however, bacterial rot was more severe in 1970 (35%) than in 1969 (20%). In the two seasons, better quality broccoli was produced under conventional irrigation (64% and 81.5%) than under mist (41.5% and 53.5%). In the second planting, a higher percentage of marketable produce was obtained under conventional irrigation (66.5% and 68%) than under mist (44.5% and 54.5%), in 1969 and 1970, respectively.

The first planting of cauliflower under mist resulted in 55% in 1969 and 33% in 1970 of market quality heads. Under conventional irrigation, marketable produce was 67% in 1969 and 48% in 1970. Bacterial infection was more severe in 1970 (60%) than in 1969 (18%) under mist irrigation and under conventional irrigation, 17.5% and 22%, respectively. The second planting yielded 52% in 1969 and 44% in 1970 of marketable cauliflower under mist, but under conventional

Table 1. --Effect of mist and conventional irrigation on total and marketable yield of broccoli, cauliflower and cabbage (from 40 plants/plot).

	Mist (lbs)			Conventional (lbs)		
	Total	Market	Other[a]	Total	Market	Other[a]
1969						
First Planting						
Broccoli	21.4	8.9	12.5	20.0	12.7	7.3
Cauliflower	84.6	40.3	44.3	92.7	58.2	34.5
Cabbage	108.2	108.2	-0.0	95.0	95.0	-0.0
Second Planting[b]						
Broccoli	18.3	8.3	10.0	27.8	18.5	9.3
Cauliflower	51.5	26.2	25.3	82.8	60.5	22.3
Cabbage	55.2	55.2	-0.0	96.8	96.8	-0.0
1970						
First Planting						
Broccoli	23.8	12.5	11.3	27.9	22.5	5.4
Cauliflower	79.7	28.3	51.4	79.8	36.8	43.0
Cabbage	120.6	114.6	6.0	81.7	81.7	-0.0
Second Planting[b]						
Broccoli	31.0	16.8	14.2	23.1	15.8	7.3
Cauliflower	86.6	37.2	49.4	79.5	59.5	20.0
Cabbage	123.4	111.4	12.0	89.2	84.7	4.5

[a]Flowering (broccoli); bacterial soft-rot (all); ricey (cauliflower).

[b]Partly lost because of excessive rainfall and poor soil drainage.

irrigation, 77.5% and 80%, respectively. Bacterial rot was again more severe in 1970 (56%) than in 1969 (20%); and the disease was less severe under the conventional system, with 3% loss in 1969 and 15% in 1970.

The beneficial effect of evaporative cooling in cabbage was demonstrated over the two years. In 1969 the mist section yielded 11% and in 1970 the yield was almost 30% more under mist than under conventional irrigation. A similar result was obtained in the second planting, although the crop was partly lost in 1969 because of the heavy rainfall and poor drainage.

The effect of mist irrigation in other Brassica crops is shown in Table 2. A beneficial effect from mist as compared to conventional irrigation was observed in kohlrabi and turnips, but not in Brussels sprouts.

Table 2. --Effect of mist and conventional irrigation on the yield of Brussels sprouts, kohlrabi and turnip. Replicate 40 plants plots.

	Mist (lbs)	Conventional (lbs)
Brussels sprouts (buds)	15.5	21.0
Kohlrabi (swollen stems)	28.0	24.2
Turnip[a] (roots)	11.8	9.3

[a]Bacterial soft-rot 15% under mist.

The mineral analysis of Brassica plants grown on muck soil is shown in Table 3. The statistical analysis of these data showed that irrigation resulted in significant differences in the percent dry weight, K, Na and Mn.

The mineral composition among crops (leaves and edible parts) was significantly different for concentration values based on dry weight for K, P, Na, Ca, Na, Mg, Mn, Fe, Cu and B. Zinc and Al were not significant.

Table 3. --Effect of mist and conventional irrigation on the mineral nutrition of the different parts of <u>Brassica</u> plants grown on muck soil (average sample from three plants).

	Percent Dry Wt.						ppm Dry Wt.			
	DW[a]	K	P	Na	Ca	Mg	Mn	Fe	Cu	B
Mist Irrigation										
Broccoli leaves	22.6	2.78	.73	.07	3.91	.24	40	53	7.9	57.5
Brussels sprouts leaves	21.4	2.78	.53	.02	3.69	.45	43	56	6.5	62.3
Cauliflower leaves	23.0	1.26	.89	.09	5.50	.41	68	59	9.3	62.9
Kohlrabi leaves	23.6	3.90	.42	.08	3.98	.33	56	68	7.2	41.0
Broccoli head	21.0	3.36	.88	.04	0.50	.14	43	65	7.9	52.7
Brussels sprouts buds	13.8	5.30	.89	.10	0.82	.25	28	59	2.9	37.9
Cauliflower head	19.0	4.40	.89	.12	0.37	.21	23	56	4.3	34.1
Kohlrabi swollen stem	11.8	4.76	.70	.07	0.37	.08	6	12	2.9	46.6
Conventional Irrigation										
Broccoli leaves	25.6	3.70	.65	.07	4.25	.21	28	59	7.9	68.3
Brussels sprouts leaves	22.2	3.36	.51	.02	5.16	.34	28	59	7.9	86.4
Cauliflower leaves	26.0	1.90	.85	.06	5.67	.39	43	94	9.3	63.5
Kohlrabi leaves	27.0	4.40	.51	.06	3.82	.32	37	91	7.2	45.4
Broccoli head	22.6	3.48	.88	.05	0.47	.14	28	50	9.3	46.6
Brussels sprouts buds	14.6	4.88	.89	.07	0.72	.25	27	59	4.3	40.4
Cauliflower head	19.8	4.52	.89	.08	0.22	.17	26	68	4.3	31.6
Kohlrabi swollen stem	13.6	5.30	.81	.05	0.60	.11	9	24	5.8	40.4
Mist vs Conventional	*	*	NS	*	NS	NS	*	NS	NS	NS
Among crops	*	*	*	*	*	*	*	*	*	*

[a]Dry weight expressed as %.

DISCUSSION AND SUMMARY

The objective of this investigation was to evaluate the influence of evaporative cooling on the growth and quality of Brassica crops. The data suggest that evaporative cooling during the summers of 1969 and 1970 was of little value due to excessive rainfall. Considering the substantial reduction of temperature obtained in plants (86) when evaporative cooling has been applied, it is reasonable to speculate that this technique would help the growth and development of crops classified as "cool season crops" in warm seasons, especially when atmospheric stress conditions are present. Unfortunately, during these two summers there was a lack of weather stress conditions. Although the results showed a detrimental effect of mist, a plant temperature reduction was obtained when evaporative cooling was practiced.

The only crops that showed a beneficial effect from evaporative cooling were cabbage and kohlrabi. According to the literature (35, 21), these two crops need high levels of moisture for high production. However, the growth and yield of cauliflower was improved with a lower moisture level, which is in agreement with other studies (36, 87).

The presence of bacterial soft-rot, extremely severe in 1970, can be related to high humidity and, probably, unfavorably close planting for beneficial effects from evaporative cooling.

Misting reduced the K concentration in the leaves of Brassica crops, which may have been due to leaching from the foliage. On the other hand, Na was increased as a result of the water, which undoubtedly contained Na. Calcium concentration was reduced in the leaves by mist, although Ca was slightly increased in the edible parts. The percentage of dry weight was lower in the plants under mist, indicating more succulent tissues (16).

Data collected in this experiment suggest that the application of water for evaporative cooling was excessive. Probably a beneficial effect could have been obtained from mist irrigation if atmospheric stress had been more prevalent.

Cauliflower may do better with lower levels of soil moisture than were maintained in these experiments and is more sensitive to bacterial infection in the presence of high humidity; however, cabbage appears to be benefited under the humid conditions. This suggests that there is a difference in the tolerance of crops to moisture levels and if mist irrigation is applied, it should be specifically adjusted to the particular crop's needs during its growth period.

PART II

SOIL APPLICATION OF HERBICIDES ON MINERAL COMPOSITION OF PEA (*PISUM SATIVUM*)

INTRODUCTION

Some evidence is available concerning the influence of herbicides on the mineral nutrition of plants grown in soil cultures. These chemicals at non-lethal rates probably have beneficial or detrimental effects on growth associated with their influence on mineral accumulation. Epstein (1959) wrote: "Land plants withdraw elements from the soil in a selective fashion bearing no obvious relation to the proportions of the elements in the soil solution. . . ."

Previous investigations (85) have demonstrated that some of the physiological disorders in plants may be related to a reduction in the content of soluble calcium in metabolically active tissues of plants, especially under water stress conditions (17).

The influence of four herbicides[1] on mineral nutrition was investigated using pea (*Pisum sativum* cv. Lincoln) as a test plant, to determine their effects on the accumulation of calcium and other minerals. Work was done under greenhouse conditions on soil

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[1] 2-chloro-4, 6 diethylamino-1, 3, 5-triazine (Simazine)
2, 6-dichlorobenzonitrile (Dichlobenil)
2, 6-dinitro-NN-dipropyl-4-trifluoromethylaniline (Trifluralin)
2-(1-methylpropyl)4, 6-dinitrophenol (Dinoseb)

cultures and in the field on both mineral and organic soils during 1970.

LITERATURE REVIEW

Influence of Herbicides on Mineral Nutrition

No research work on the influence of dichlobenil on the uptake of minerals by plants was found. A study by Price (1969) indicates some relationship between dichlobenil and Ca in maintaining plant membranes' integrity in beet roots. He observed that dichlobenil induced betacyanin leakage but in the presence of Ca, it was reduced, especially if compared with the effect of dinitrophenol.

The effect of dinitrophenol on the uptake of K and Na was studied in water cultures by Nwachuku (1968) in *Ricinus communis* roots. He observed that K uptake was inhibited by dinitrophenol, but Na absorption was increased. It was suggested that the mechanisms for absorption of K and Na are independent and different.

The effect of dinoseb on the accumulation and incorporation of phosphorus-32 externally applied to tomato leaf disks was studied by Wojtaszek (1966). Dinoseb inhibited both phosphorus-32 accumulation and ATP generation. It had almost no effect on P-32 retention and the chemical apparently exerted its effect by inhibiting oxidative phosphorylation.

The influence of simazine on the mineral nutrition of plants has been studied with reference to nitrogen and protein accumulation. There is evidence that simazine affects the nitrogen status in several species (Ries, 1963, 1964, 1965, 1967; Freney, 1965; DeVries, 1963; Tweedy, 1966; Minshall, 1969; McReynolds and Tweedy, 1970; Fink, 1967). These reports indicate that low rates of simazine seem to have a pronounced influence on the nitrogen content of lettuce, cucumber, peas and corn.

Adams (1965), working in greenhouse experiments in soil, reported that simazine at 0.05, 0.2 and 0.3 ppm interacting with calcium phosphate in the culture medium at 13, 26, 52 and 104 ppm reduced the growth of soybeans, oats and foxtail compared with treatments which received only high levels of phosphorus. The mineral analysis showed that the interaction of simazine with phosphorus in soybeans increased Fe sharply and also increased K, Mn and Si, but reduced P and Ca, Mg, B, Sr, Mo, Co and Ba by more than 50% of that found at the highest level of P.

Millikan et al. (1966) grew soybeans in soil containing 0, 0.5, 1 and 2 ppm of simazine. The first true leaves were harvested and analyzed for major and minor elements. Increases in dry weight and P were associated with an increase in simazine levels. Simazine had no effect on K or Mg; however, Ca and Mn were decreased and Zn increased at high levels of application.

The phosphorus uptake of Pinus resinosa in the presence of simazine was studied by Dhillon et al. (1967) in water cultures. Phosphorus transport was stimulated by 5 and 10 ppm of simazine but was decreased at higher concentrations. Simazine increased the P translocation from roots to stem and needles. Zavarzin et al. (1968) reported that the available P and NO_3-N were increased in the soil by simazine rates between 4 and 12 Kg/Ha in a cultivated peach orchard.

The absorption of ^{35}S by oat plants was inhibited by simazine application at the rate of 0.25 mg per 250g-air-dry-soil (3 Kg/Ha), 11 and 17 days after emergence of the plants. There was an increase of ^{35}S uptake by the green parts of the oats 6 days after emergence (Zurawski et al., 1969). Simazine applied at 0.06 ppm in solution culture increased the yield of corn tops by 36%, the uptake of N by 37%, P by 25%, Mg by 24% and K by 41% (Freney, 1965).

There are no reported effects of trifluralin on mineral nutrition of pea; however, the use of the chemical resulted in some controversial increases in yield. Trunkenbolts et al. (1967), working in France, showed that this herbicide gave the best results in weed control on pea crops at the rate of 1000 g/Ha at sowing or 900 g/Ha applied preemergence. On the other hand, Ilnicki et al. (1968) reported that trifluralin at 0.5 lb/A on peas controlled weeds satisfactorily but reduced the yield. Taylor et al. (1969), in New Zealand, have indicated that an application of trifluralin at 1 lb/A, incorporated in a silt-loam soil before sowing, adequately controlled weeds and increased pea yields by 47% over the controls. Predenville et al. (1967) made the observation that when trifluralin is absorbed in pea plants through the stem, it causes severe inhibition of root growth.

The recommended uses of the herbicides mentioned in horticultural and field crops in Michigan are presented by Putnam (1970) and Meggitt (1970). Dichlobenil is used as a herbicide under fruit trees. Dinoseb is used in cucumbers, peas, beans, potatoes, gladiolus and tulips. Simazine is used for weed control in asparagus, corn, grapes, blueberries, apples, pears, cherries, alfalfa, roses and peonies; trifluralin in peas, brassicas, snap beans, field beans, soybeans, peppers and tomatoes.

Recommendations for the use of dinoseb in peas have been reported by several researchers in different countries: Boyce (1964), New Zealand; Marlow (1966), East Germany; King (1965), England; Bouvet (1966), France; Fiveland (1970), Norway; Kennedy (1966), Tasmania.

Relation of Calcium to Physiological Disorders

The occurrence of some physiological disorders in vegetables and fruits is related to the calcium status in the plant tissues. Abnormalities such as tipburn in lettuce and cabbage, brownheart of escarole, blackheart of celery, blossom end rot in tomatoes and peppers, bitter pit of applies, can be minimized by spraying salts or chelates of calcium (Thibodeau et al., 1969; Millikan et al., 1965; Maynard et al., 1962; Faust and Shear, 1968).

Water stress during the growth period may limit the availability of calcium to the plant. Calcium deficiency has been reported to cause degeneration of the meristematic cells in roots of peas (Sorokin, 1929 and 1940). Marinos (1962) also suggested that lack of Ca affects the formation of cell wall structure and the maintenance of permeability of the cell membrane systems. Calcium is transported by a process of exchange reactions in the conducting tissue (Bell, 1963; Jacoby, 1967). Calcium exchange is not specific, with lignin playing an important function as a possible site for exchange (Ito, 1967; Shear, 1970). Probably, most of the calcium is translocated through the xylem (Biddulph, 1961; Mason, 1931); and as there is no retranslocation, it is imperative to have a continuous supply of calcium for the metabolically active centers (Biddulph, 1958).

Ririe (1952) has observed that Ca is transported preferentially into young leaves of tomato, alfalfa, red clover and wheat. Cain (1948) also has indicated that Ca is deposited principally in the laminae of expanding leaves of apples, although Ca is accumulated in mature leaves in relation to their age. This last concept is in agreement with Shear (1970), who showed that the affinity of Ca for ligneous materials may be responsible for the accumulation of calcium in older leaves in direct relation to their age. Shear also stated that Ca moves readily into the active tissues of expanding young leaves.

Calcium remains mostly immobile in the leaves and can be translocated only under special circumstances. Calcium moved more readily when it was injected into the midrib of the leaves and with special chemical treatments (Millikan, 1965). But in leaves of Brussels sprouts, the movement of Ca was more restricted, especially from surface applications (Millikan, 1969). The above experiments indicated that Ca movement may be partially controlled genetically and that Brussels sprouts have more sites for Ca fixation than beans, peas or subterranean clover.

Powers (1961) reported a tipburn of the leaves of cabbage that may be caused by a lack of calcium and an excess of potassium and indicated that breeding seems to be the only solution to the problem. In a similar report, Maynard (1965) related resistance to cabbage tipburn to the efficiency of calcium uptake by the plant.

Geraldson (1954) discussed celery blackheart and concluded that some factors prevented the movement of calcium from the soil to the root and also mentioned the influence of organic acids in the translocation of Ca. Cannell et al. (1959) related blackheart to drier soils and found it was possible to control blackheart with irrigation and low fertilization.

Gerard and Hipp (1968) related the incidence of blossom end rot of tomatoes to extreme atmospheric stress with fruits low in calcium and high in potassium. These researchers indicated the need for lowering transpiration, in order to increase the calcium content. Excessive transpiration caused the collapse of the tissues and produced blossom end rot.

Geraldson (1957) observed that blackheart of celery and blossom end rot of tomatoes and peppers are related to the nutritive status in the soil. Excessive soluble NH_4, K, Mg or Na produced a deficiency of calcium. He recommended periodical sprays of Ca to prevent these disorders. Also, he stated that the role of irrigation can be considered as secondary. Wet soils accumulate nitrogen as NH_4. In agreement with the last statement, Carolus (1965) showed that the highest leaf Ca in tomatoes was obtained with irrigation (70% available soil moisture). With values over or under 70%, the leaf calcium was reduced. Photosynthesis can be reduced by water stress also (Brix, 1962).

Sorensen (1964) compiled information relative to lettuce tipburn and concluded that water balance is definitely related to tipburn. The disorder is most severe after hot days and cool, damp nights. Light is also related to tipburn, with plants developing tipburn in 7 days at 1750 foot candles and only very few plants showing the disorder after 11 days at 75 foot candles. High temperature alone can cause tipburn, 4 hours at 90 F being enough to induce symptoms. Struckmeyer (1965) suggested that the symptoms of tipburn are more related to boron deficiency than calcium.

Thibodeau and Minotti (1969) found that foliar sprays of soluble $Ca(NO_3)_2$ applied directly over the young expanding leaves controlled tipburn completely. They indicated that the cause for tipburn is the lack of soluble calcium, when environmental conditions result in rapid growth. This environmental condition, when present for very short periods of time, induced tipburn. The application of organic salts increased the abnormality in the order of oxalate > citrate > acetate in close relation to their water solubility. Oxalate is the result of the fourth oxidation step in the Krebs cycle and seems to be the principal agent of tipburn initiation. These investigators concluded that the practical application of calcium sprays in the field to correct the trouble would be difficult to achieve, due to the immobility of calcium and the immature leaves in the interior of the head.

Faust (1968), in a review of literature pertaining to physiological disorders of apples, concluded that the prevention of water stress will aid in maintaining the correct level of calcium in the tissues. The decrease in uptake or translocation of calcium and/or boron increases the disorders. Perring (1968) found that apple disorders can be associated with low levels of Ca; and Wilkinson (1968) indicated that Ca movement out of the fruit may occur in periods of dry weather, conditions that are associated with physiological disorders. Shear (1970), studying Ca translocation in apples, suggested that the translocation of calcium in tree species seems to be similar to that reported for annual plants.

MATERIALS AND METHODS

Greenhouse Studies

During the winter of 1969, an experiment was carried out under greenhouse conditions to study the influence of four herbicides that might influence the accumulation of Ca and other minerals in pea plants. One hundred and eight pots with 5 Kg of unsterilized soil 2:1:1 (loam, peat, sand) were used. A soil test on this mixture gave a pH of 6.8 and O.M. content of 3% and available P-57, K-82, Ca-715, Mg-103 and Mn-8 pp2m. The herbicides were dichlobenil (dic) at the rate of 1 lb/A, trifluralin (trif) at $\frac{1}{2}$ lb/A, dinoseb (din) at 3 lb/A and simazine at $\frac{1}{8}$ (S_1) and $\frac{1}{4}$ (S_2) lb/A. The chemicals were applied preemergence on December 24, and 10 pea seeds per pot were sown on December 26, 1969; dinoseb was applied postemergence on January 15, 1970, when the plants had 2 to 4 leaves.

A randomized block design was used in three experiments. Each experiment consisted of 12 treatments with 3 replicates, as follows:

	Experiment I	Experiment II	Experiment III
1.	Control	Same as Experiment I	Same as Experiment I
2.	Ca		
3.	S_1		
4.	S_1 + Ca		
5.	S_2		
6.	S_2 + Ca		
7.	Din	Dic	Trif
8.	Din + Ca	Dic + Ca	Trif + Ca
9.	Din + S_1	Dic + S_1	Trif + S_1
10.	Din + S_1 + Ca	Dic + S_1 + Ca	Trif + S_1 + Ca
11.	Din + S_2	Dic + S_2	Trif + S_2
12.	Din + S_2 + Ca	Dic + S_2 + Ca	Trif + S_2 + Ca

Before planting, all the cultures were fertilized at the rate of 100 lbs/A of N-P-K on an area basis, and the treatments with calcium received 100 lbs/A of Ca as $CaSO_4$, $2H_2O$. The cultures were thinned to 4 plants and harvested seventy days after planting, on March 5, 1970, and the fresh weight without roots or pods recorded. After drying and grinding, a mineral analysis of the plants was made, except for nitrogen, by methods described previously.

Field Research

During the summer of 1970, two experiments were carried out to study the effect of dinoseb, trifluralin and Ca on the mineral nutrition of pea plants. One experiment was planted on the Muck Experimental Farm on May 19, 1970, under mist and conventional irrigation. The soil was fertilized with 1000 lb/A of 5-10-20 + 2% of Mn as $MnSO_4$. A soil test of the muck soil showed a pH of 6.3 and O.M. content of 56% and available P-23, K-138, Ca-6005, Mg-635 and Mn-5 pp2m. The treatments in duplicate were control, Ca 100 lb/A from $CaSO_4$, dinoseb (1.5 lb/A postemergence) and dinoseb + Ca.

A second experiment was conducted at the Horticulture Research Center using a randomized block design with 3 replicates. The seed was sown on May 20, 1970, in double rows 10 inches apart and 10 feet long. The field was fertilized with 1000 lb/A of 12-12-12, and a soil test showed a pH of 6.7 and O.M. content of 2.3% and available P-17, K-104, Ca-1105, Mg-169 and Mn-17 pp2m. The treatments applied were Ca at the rate of 100 lb/A as $CaSO_4$, dinoseb 4 lb/A (preemergence) and trifluralin 1 lb/A (preemergence and incorporated into the soil immediately).

Both experiments were harvested July 24, 1970, and the fresh weight of the plants, without roots and pods, was recorded. For mineral analysis, 50 grams of fresh tissue was taken from each treatment, oven dried and the weight recorded. The mineral analysis was made in the same way as indicated previously.

RESULTS

The effects of the four herbicides on the mineral nutrition of pea under greenhouse conditions are indicated in Tables 6, 7 and 8 (Appendix). There were highly significant differences in mineral composition related to many of the treatments.

Calcium and Simazine Effects

The statistical analysis of the simazine-related treatments, combined from the three experiments of which they were a part, showed that this herbicide did not influence growth on an average of both Ca levels or the concentration of P, B and Al. However, the concentration of K, Ca, Mg, Mn and Zn was significantly increased by S_1 and Na and Fe by S_2 (Table 4).

Calcium application increased Na, Ca and Mg significantly but decreased Cu. The interactions of simazine levels 0, 1, 2 with Ca 0, 1 influenced dry weight, K, Ca and Mg significantly (Figure 3).

The concentration of K and Mg from simazine application showed a positive linear response with addition of Ca and a quadratic response when Ca was absent; however, Ca exhibited a negative linear response when Ca was added and a quadratic response when it was not applied. The dry weight was increased with simazine without the application of Ca, but a negative quadratic response was obtained when Ca at 100 lbs/A was added.

Table 4.--Significant effects of simazine on the mineral concentration of pea (means from nine replications).

Treatments	D.W.[a]	% of Dry Wt.				ppm Dry Wt.			
		K	Ca	Mg	Na	Mn	Fe	Cu	Zn
Control	4.3	3.6	2.7	0.77	0.15	74	86	21	46
Ca ($CaSO_4$)[b]	5.4	3.8	3.6	0.82	0.15	76	93	20	43
$Simazine_1$	5.0	4.0	3.1	0.92	0.17	94	95	23	57
Sim_1 + Ca	4.6	3.8	3.3	0.85	0.20	91	100	17	51
$Simazine_2$	5.2	3.9	2.9	0.77	0.17	84	100	20	45
Sim_2 + Ca	4.7	3.9	3.1	0.93	0.21	79	105	19	47
Significant Effects[c]									
Simazine	NS	**	**	**	**	**	**	NS	**
Ca	NS	NS	**	*	**	NS	NS	**	NS
Sim × Ca	**	*	**	**	NS	NS	NS	NS	NS

[a]Total dry weight per plant.

[b]100 lb/A.

[c]NS (not significant), * (5%), ** (1%).

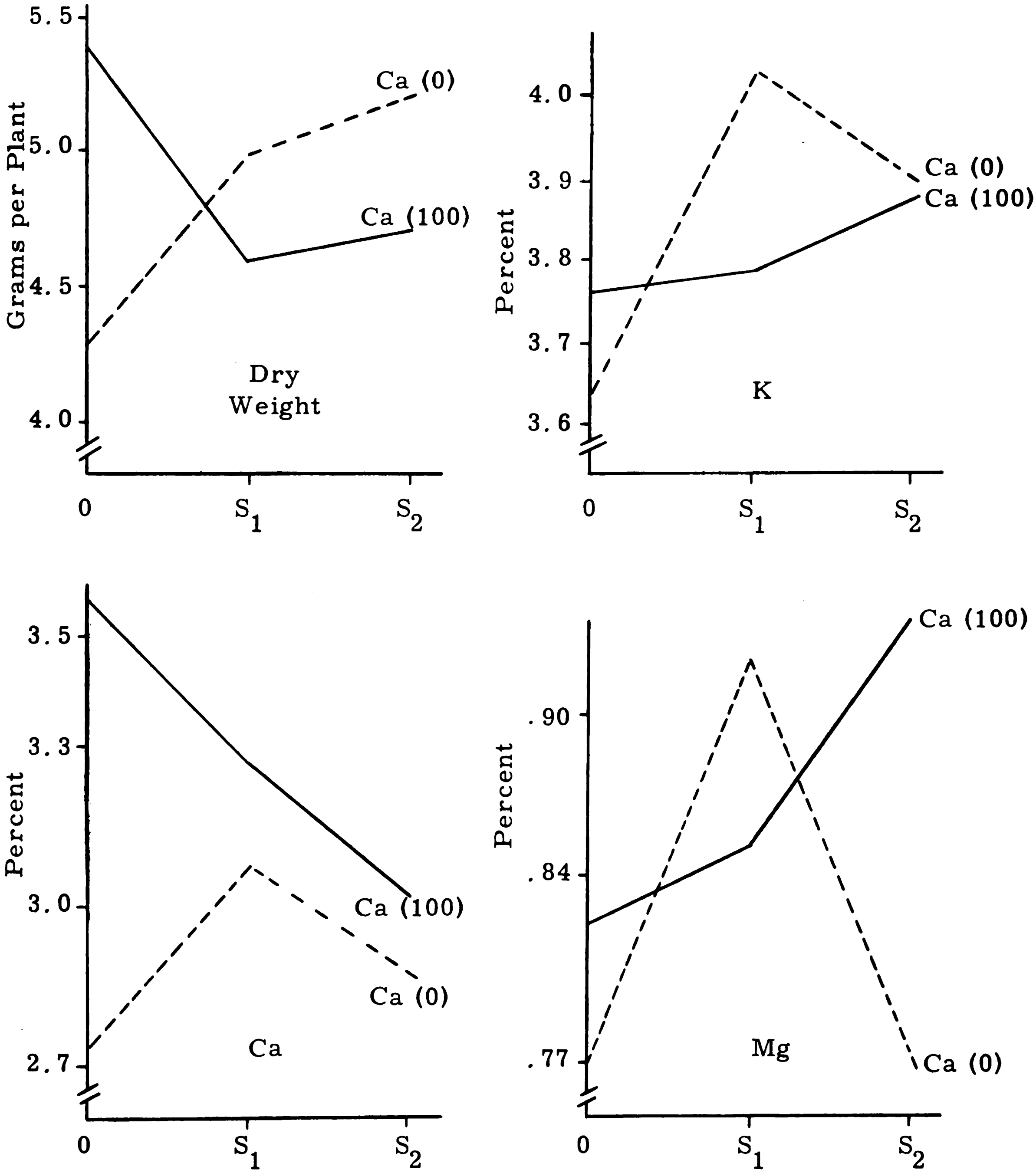

Figure 3. --Effect of the interactions simazine × Ca on the growth and mineral composition of pea.

In order to show clearly the influences of dinoseb, dichlobenil and trifluralin and their interactions with calcium and simazine on growth and mineral accumulation, some of the statistically significant data have been evaluated in terms of the relative influences of the various treatments in comparison to related controls.

Dinoseb, Dichlobenil and Trifluralin Effects

The significant effects of the 3 herbicides on dry weight and mineral composition changes are shown in terms of percent variation from the controls in Figure 4a. Dinoseb at 3 lb/A increased dry weight about 15% and calcium about 30% and did not result in a significant change in any other element. Dichlobenil at 1 lb/A neither influenced dry weight nor the accumulation of any mineral element significantly but tended to reduce the concentration of all of them. Trifluralin at $\frac{1}{2}$ lb/A reduced dry weight and P markedly but increased the accumulation of Mn over 70%, Mg over 20% and Ca slightly.

Combination of Herbicides and Ca Compared with Ca Alone

With Ca from $CaSO_4$ at 100 lb/A applied with the herbicides, significant changes were observed in composition of pea plants compared with the composition of peas on plots that had received calcium alone (Figure 4b).

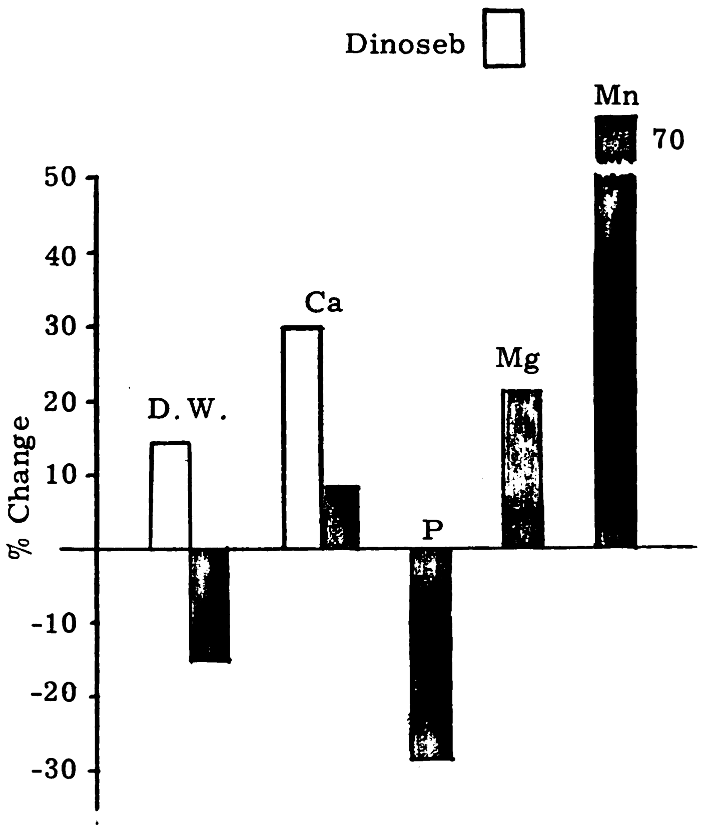

Figure 4a. --Relative effects on composition of pea of the 3 herbicides compared with the control.

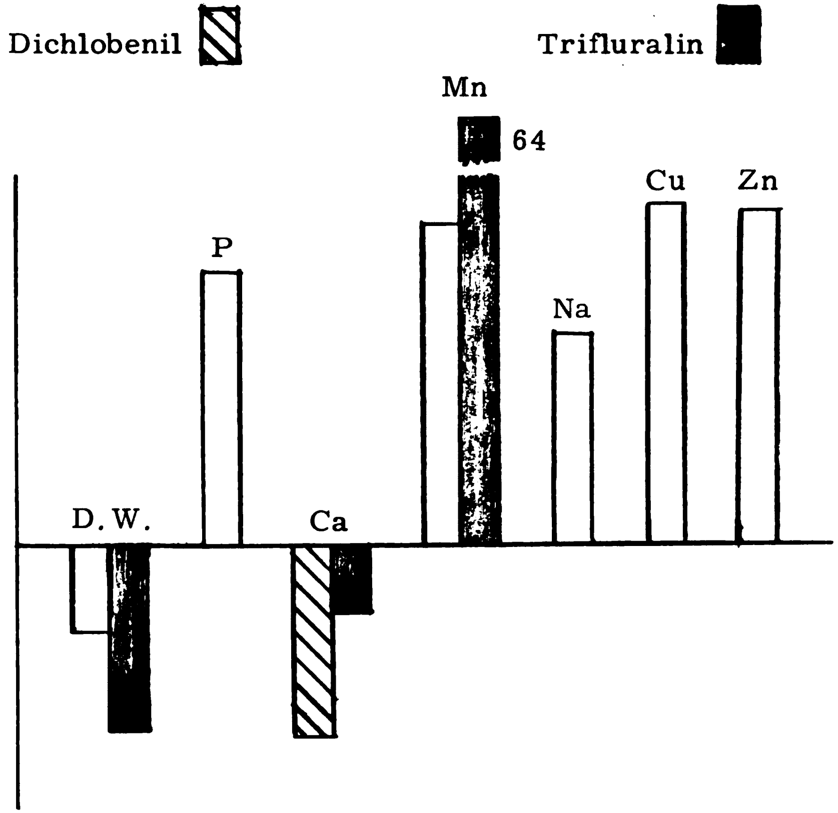

Figure 4b. --Relative effects on composition of pea of the 3 herbicides and Ca compared with Ca treated soils.

Dinoseb with Ca showed a reduction in dry weight of about 12%, but increases of more than 30% in P, Mn, Cu, Zn, and over 20% in Na. Dichlobenil with Ca resulted in no effect on dry weight, but a 25% decrease of Ca was observed. The interaction of trifluralin with Ca resulted in a 25% decrease in dry weight and some decrease in Ca, but a 70% increase in Mn when compared to peas treated with Ca alone.

Combination of the Herbicides and $Simazine_1$ Compared with $Simazine_1$

The effects on dry weight and composition from herbicides interacting with the lower rate of simazine (S_1) compared with plots with $simazine_1$ only are shown in Figure 5a. Dinoseb with simazine did not affect dry weight, but increased P over 40% and reduced Cu about 30%. Dichlobenil with $simazine_1$ did not show any significant effect on pea plant composition; however, trifluralin with $simazine_1$ reduced the dry weight over 20%, Cu over 30% and Ca about 10% as compared with values observed in plants with $simazine_1$ alone.

Combination of the Herbicides and $Simazine_2$ Compared with $Simazine_2$

The $\frac{1}{4}$ lb/A rate of simazine (S_2) interacting with the 3 herbicides resulted in significant differences in composition compared with S_2 alone (Figure 5b). Dinoseb with simazine had no effect on the

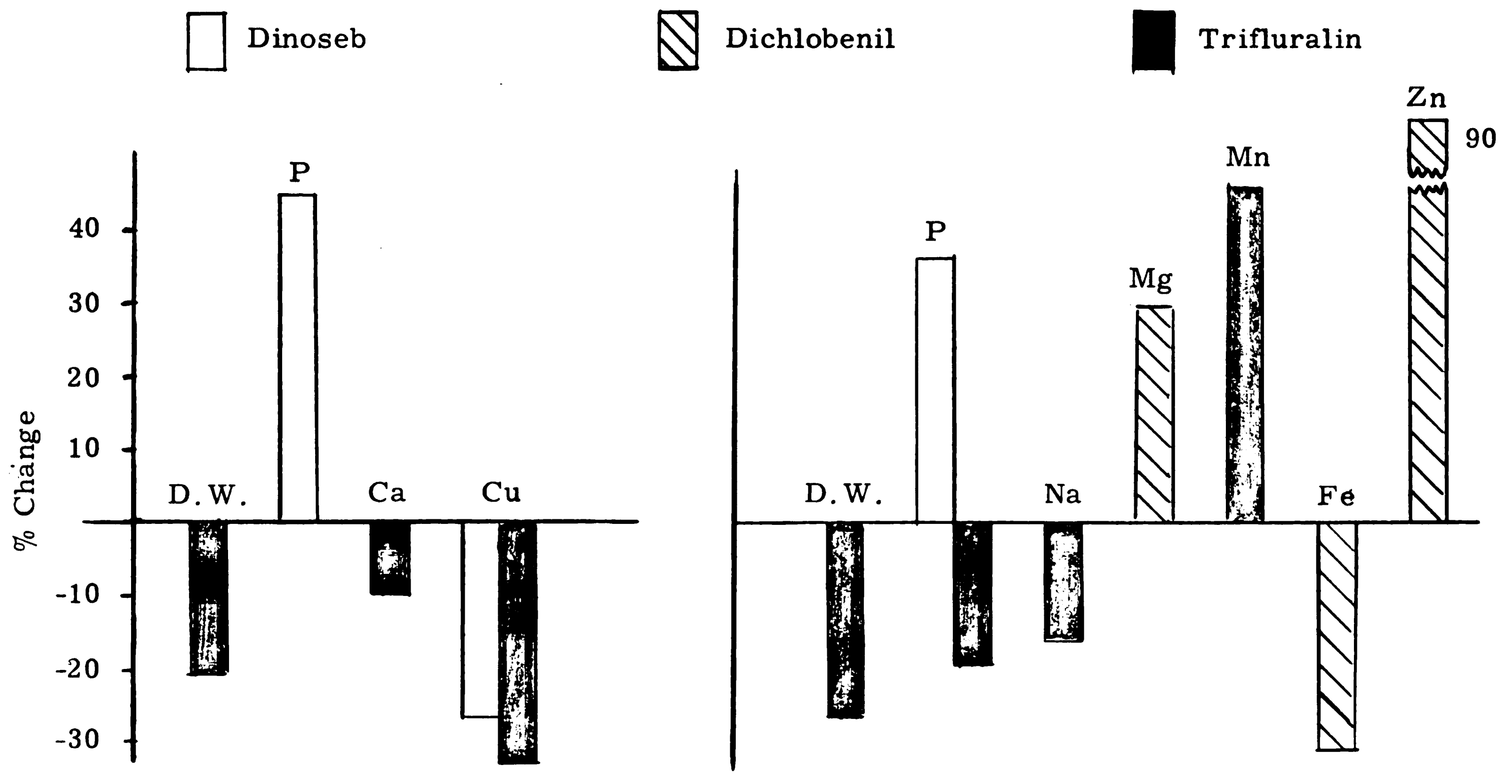

Figure 5a. --Relative effects on composition of pea of the 3 herbicides and S_1 compared with S_1 treated soils.

Figure 5b. --Relative effects on composition of pea of the 3 herbicides and S_2 compared with S_2 treated soils.

dry weight, but a 30% increase of P was observed. Dichlobenil with S_2 did not affect dry weight; however, it increased Mg 25%, Zn over 90% and reduced Fe concentration about 30%. On the other hand, trifluralin with S_2 reduced dry weight, P, and Na, but resulted in an increase of over 40% in Mn accumulation compared with plants with $simazine_2$ alone.

Combination of Herbicides and Ca Compared with Herbicides Alone

Combinations of herbicides with 100 lb/A of Ca resulted in many composition differences as compared to herbicides alone but did not influence dry weight (Figure 6). Dinoseb with Ca increased Zn, Mn and Cu from 30 to 60%. The combination of dichlobenil and Ca increased Ca 12%, Na 30%, Mn 50%, B 50% and Zn about 60%. Trifluralin and Ca promoted P and Fe accumulation when compared to trifluralin alone.

Combination of Herbicides and $Simazine_1$ Compared with Herbicides Alone

$Simazine_1$ did not significantly alter dry weight production with any of the three herbicides as compared to the herbicides alone (Figure 7a). In combination with Dinoseb, an increase of 30% in Fe was observed; and with dichlobenil, increases of 40% in Na, 15% in

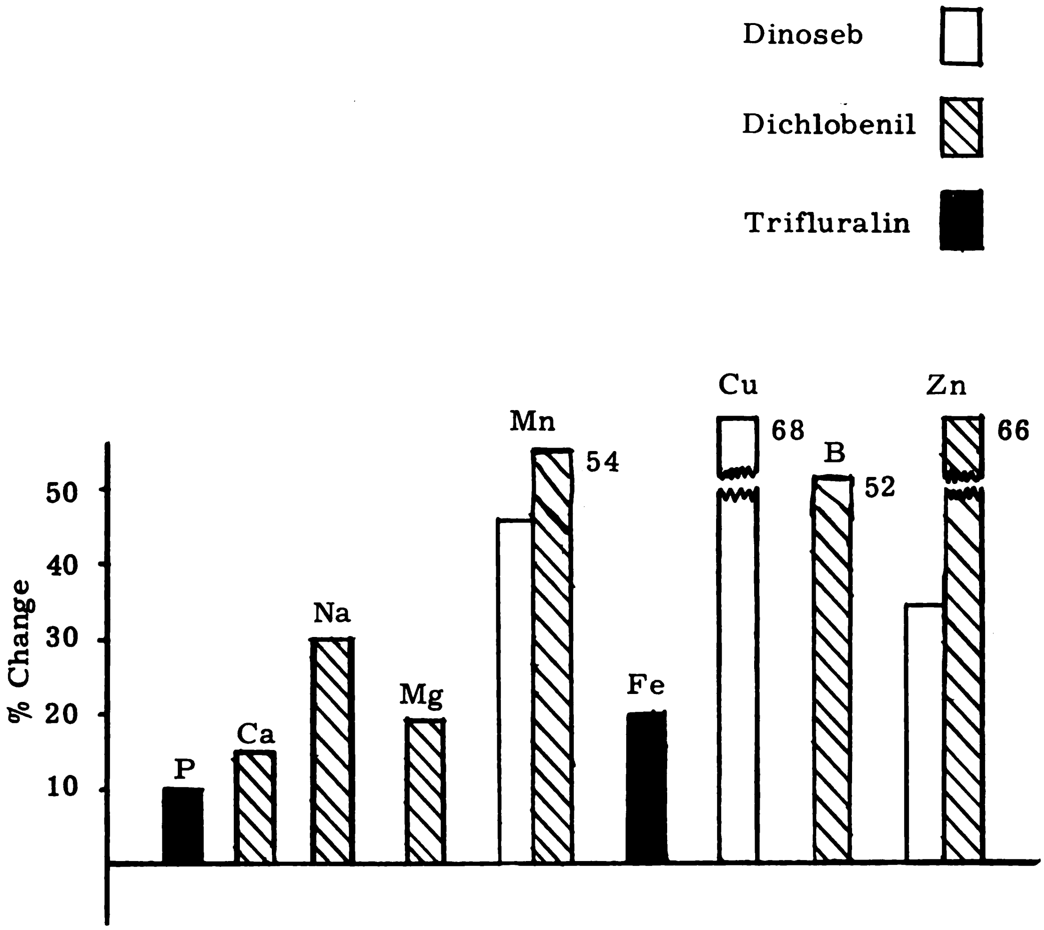

Figure 6. --Relative effects on composition of pea of Ca on herbicide treated soils compared to herbicide treated soils.

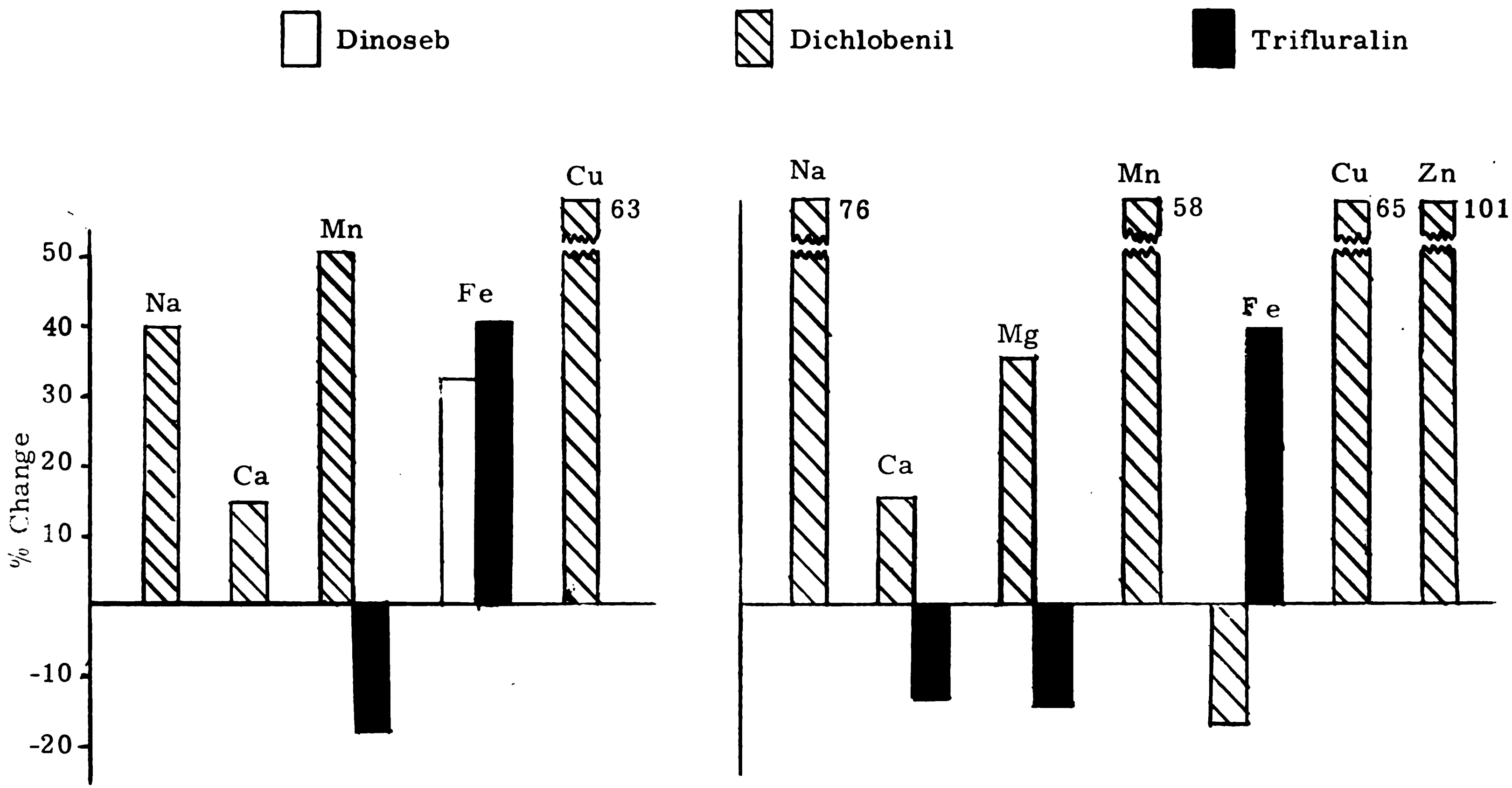

Figure 7a. --Relative effects on composition of pea of S_1 on herbicide treated soils compared to herbicide treated soils alone.

Figure 7b. --Relative effects on composition of pea of S_2 on herbicide treated soils compared to herbicide treated soils.

Ca, 45% in Mn and over 60% in Cu were observed from the application of S_1 compared to the herbicides alone. $Simazine_1$ applied with trifluralin resulted in a decrease in Mn of 20% and an increase of Fe of over 40% compared to trifluralin alone.

Combination of Herbicides and $Simazine_2$ Compared with Herbicides Alone

The combinations of the three herbicides with S_2 resulted in significant differences in the mineral composition of pea plants, but no differences in dry weight compared with plots that received the herbicide only (Figure 7b).

The combination of dinoseb and S_2 did not influence composition; but dichlobenil applied with S_2 increased Na about 60%, Mg about 30% and Zn and Cu from 40-90% and reduced Fe over 20%. The effect of trifluralin with S_2 was to increase Fe over 40% and to decrease Ca and Mg as compared to trifluralin alone.

Influence of Herbicides and Irrigation on the Mineral Nutrition of Pea Plants on Organic and Mineral Soil

The influences of dinoseb and irrigation on organic soil and dinoseb and trifluralin on mineral soil on the mineral composition of pea plants are indicated in Tables 9 and 10 (Appendix).

Organic Soil

The significant effects of dinoseb at 1.5 lbs/A on growth and mineral nutrition of pea plants under two systems of irrigation on muck soil are indicated in Part I of Figure 8a. Dinoseb resulted in a 20% increase in dry weight of plants and an increase of over 25% in Ca, with either conventional or mist irrigation, compared to that of plants from plots with conventional irrigation. Also, under mist irrigation Na was increased, probably related to the Na content of the irrigation water.

Effects of dinoseb on micro-nutrient accumulation are indicated in the analysis found in Appendix Table 10, but they were too variable to be significant in most cases. The overall effect of mist versus conventional irrigation is shown in Part II of Figure 8a. Mist irrigation increased P, Na, and B significantly, but reduced the dry weight and the accumulation of K.

The combination of dinoseb and Ca resulted in an increase of P compared with that found in plants from plots with Ca only. Under mist also, there was an increase of P and Na (Part I, Figure 8b). The combination of dinoseb and Ca increased P content under the two systems of irrigation compared with the plot with dinoseb alone (Part II, Figure 8b).

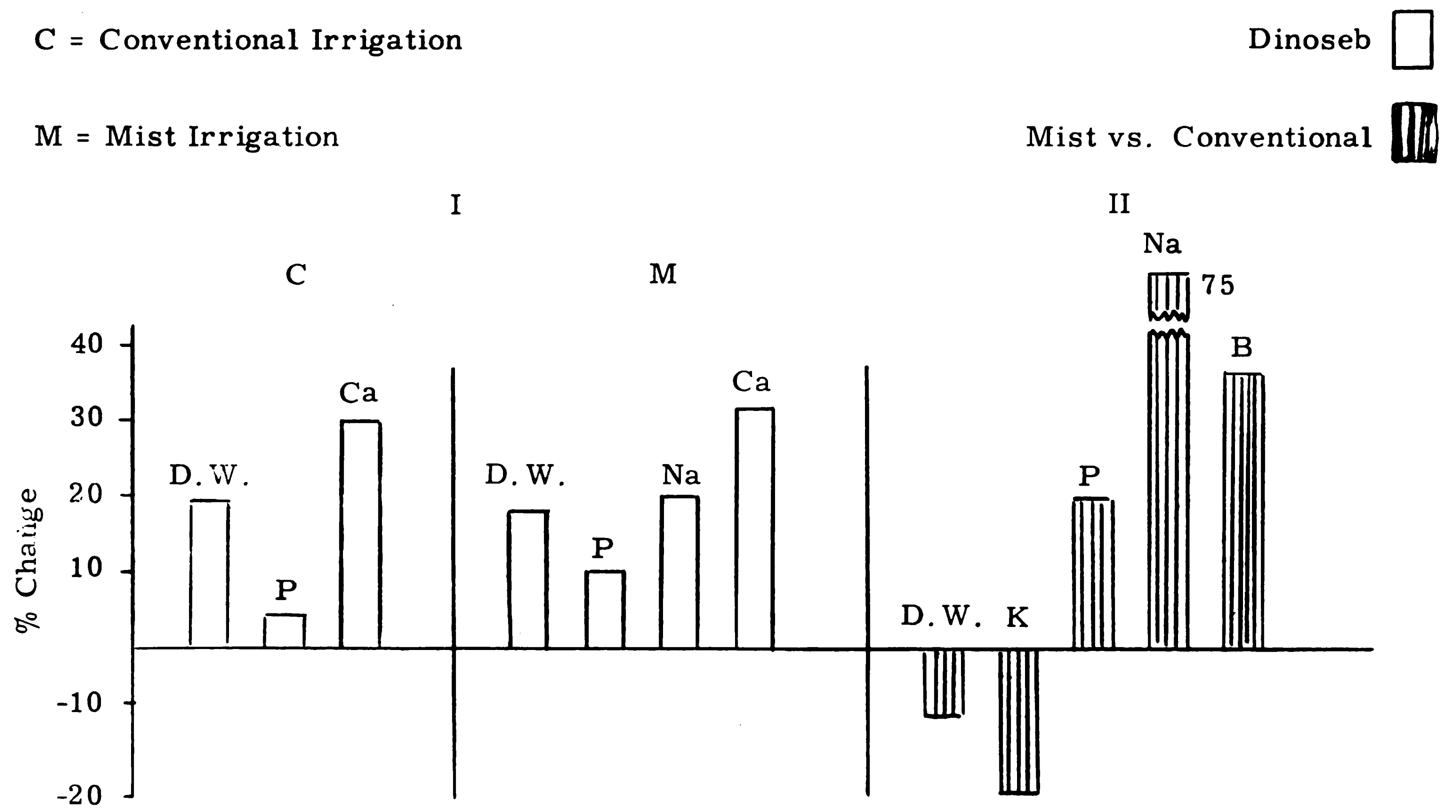

Figure 8a.--I. Relative effects on organic soils of dinoseb on pea composition under mist and conventional irrigation,
II. and of mist versus conventional irrigation.

C = Conventional Irrigation

M = Mist Irrigation

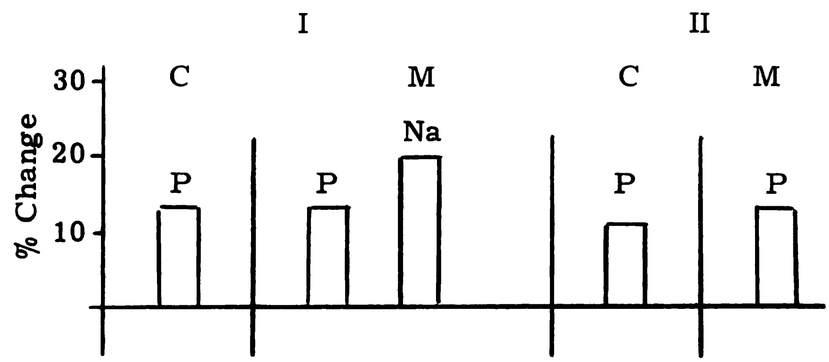

Figure 8b. --I. Relative effects on organic soils of dinoseb and Ca on pea composition compared with Ca alone,
II. and of dinoseb and Ca compared with dinoseb alone.

Mineral Soil

The relative effects of dinoseb at 4 lb/A and trifluralin at 1 lb/A on the mineral accumulation of pea plants on mineral soil under field conditions are shown in Figure 9a. Dinoseb resulted in a relative increase in P and Ca and a marked reduction in Mg and particularly Na as compared to the concentration observed in plants from control plots. On the other hand, trifluralin resulted in a relative increase in P of 20% and K of 40%, but drastic reductions in dry weight of 50%, Na 60%, and Ca 40%, 30% in Mg and 21% in B as compared to the values observed in plants from control plots.

The effects of Ca and dinoseb applied preemergence as compared to Ca alone resulted in pronounced increases in K and Mn of about 60%, and in P of over 20%, with reductions in Na of over 50% and Ca and Mg of about 20% (Part I, Figure 9b). In similar comparisons, trifluralin with Ca compared to Ca alone resulted in reductions of over 50% in dry weight, 75% in Na, 40% in Ca, 30% in Mg and about 25% in B, but in increases of over 50% in K and P in pea plants. The effects of dinoseb and Ca compared to dinoseb alone resulted in an increase in K and a decrease in Ca (Part II, Figure 9b), but no influence on Na, Mg, or Mn, as indicated in Part I. Calcium addition to trifluralin treated soil had no significant influence on pea composition. These differences between the influence of the two

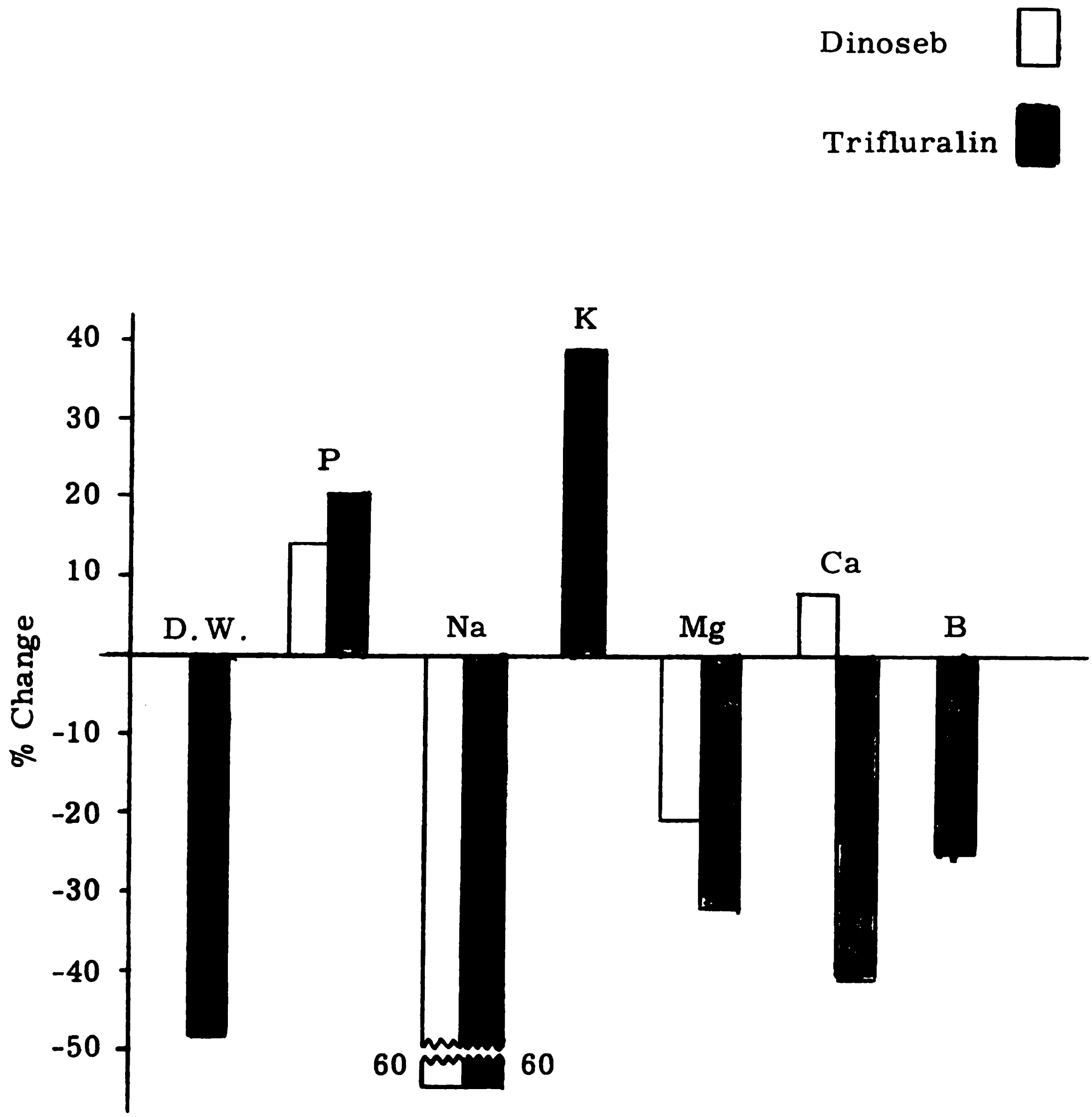

Figure 9a. --Relative effects on mineral soil of dinoseb and trifluralin on pea composition compared with the control.

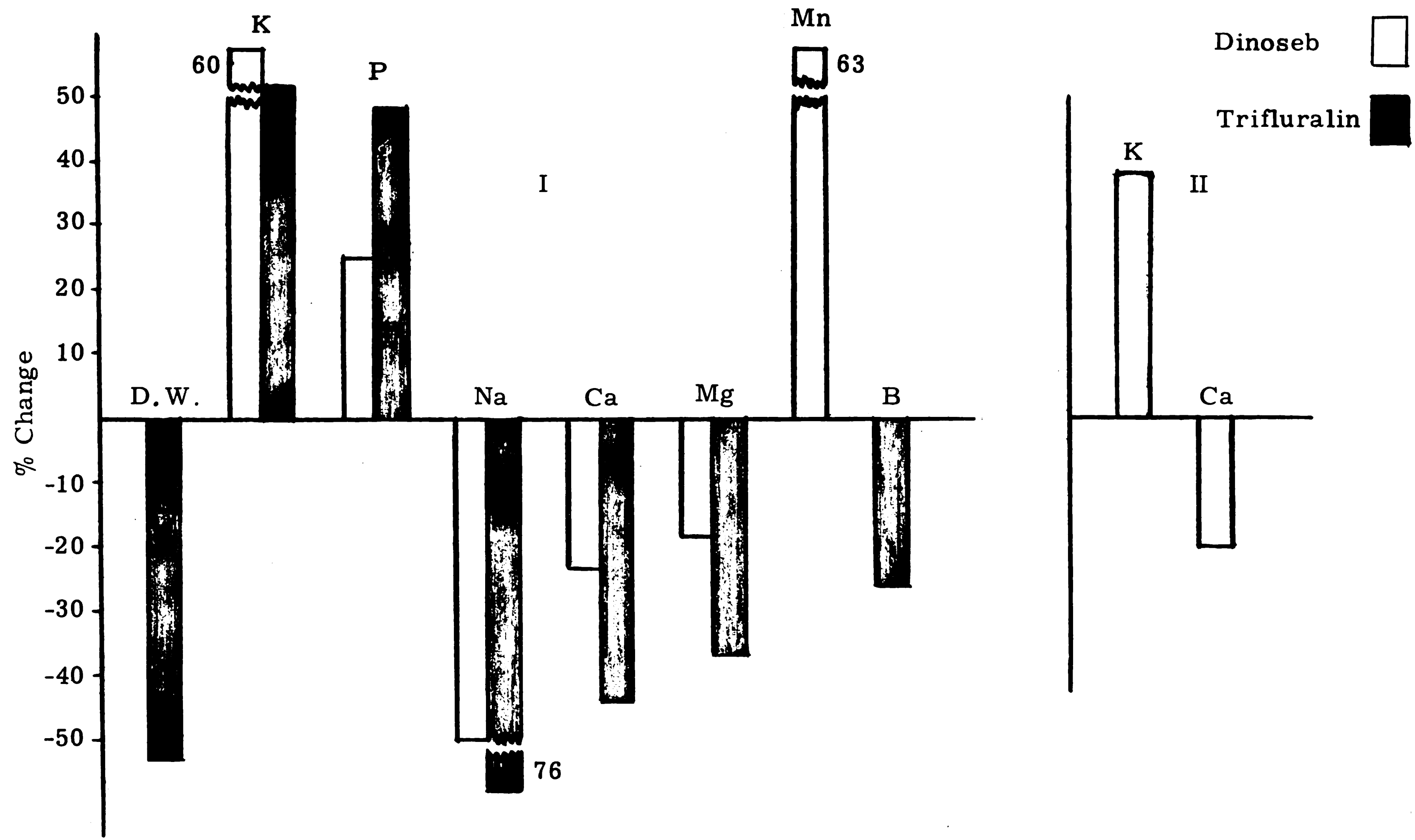

Figure 9b. --I. Relative effects on mineral soil of dinoseb and trifluralin with Ca on composition of pea compared with Ca alone,
II. and of the 2 herbicides and Ca compared with the herbicides alone.

herbicides in the two comparisons indicate that they alter some aspects of the absorption or transport mechanisms in a profoundly different manner in relation to Ca.

SUMMARY OF RESULTS

Comparative relative significant changes in dry weight and mineral concentration attributable to various herbicide-calcium applications are summarized in Table 5. Calcium, dinoseb and simazine application alone resulted in increases in dry weight compared to the controls. Dichlobenil had no effect and trifluralin at the rate applied resulted in marked reduction in dry weight. A synergic effect of calcium with dinoseb or simazine on phosphorus accumulation was observed. The increase in phosphorus accumulation from trifluralin application on field mineral soils might be related to the reduced growth of the plants. Simazine and dinoseb with calcium in certain comparisons apparently enhanced potassium accumulation.

As might be expected, calcium application resulted in calcium accumulation; however, dinoseb application had an influence of about the same magnitude on calcium accumulation, and simazine had some influence. Both dichlobenil and trifluralin application resulted in a reduction in calcium accumulation; trifluralin on mineral field soil, where dry weight was reduced over 50%.

Table 5. --Summary of significant effects from treatment comparisons on dry weight and mineral accumulation of pea (based on dry weight concentration).

Comparison	Dry Wt.	P	K	Ca	Mg	Na	Fe	Mn	Cu	Zn	B
Greenhouse Experiment											
Ca/Control	++			++							
Din/Control	++			++							
Din + Ca/Ca	--	++				++		++	++	++	
Din + Ca/Din								++	++	++	
Din + S_1/S_1		++							--		
Din + S_2/S_2		++									
Din + S_1/Din							++				
Din + S_2/Din											
Dic/Control											
Dic + Ca/Ca				--							
Dic + Ca/Dic				+	+	++		++			++
Dic + S_1/S_1											
Dic + S_2/S_2					++		--			*	
Dic + S_1/Dic				+	++			++	*		
Dic + S_2/Dic				+	++	*	-	++	*	*	
Trif/Control	--	--		+	+			*			
Trif + Ca/Ca	--			-				*			
Trif + Ca/Trif		+					+				
Trif + S_1/S_1	--			-					--		
Trif + S_2/S_2	--	-				-		++			
Trif + S_1/Trif							++	-			
Trif + S_2/Trif				-	-		++				
S_1/Control	++		+	+	+			++			
S_2/Control	++					+	+				
S_1 + Ca/Control	+		+	+	+						
S_2 + Ca/Control	+		+	+	+						
S_1 + Ca/Ca	-			-	+						
S_2 + Ca/Ca	-			-	+						
S_1 + Ca/S_1	-		-	+	-						
S_2 + Ca/S_2	-			+	+						

Table 5. --Continued.

Comparison	Dry Wt.	P	K	Ca	Mg	Na	Fe	Mn	Cu	Zn	B
Muck Soil Experiment											
Mist/Control		+	--			*					++
Ca/Control				++							
Din/Control	++	+		++							
Din + M/M	++	+		++		+					
Ca + M/M				+							
Din + Ca/Ca		+									
Din + M + Ca/Ca + M		+				+					
Din + Ca/Din		+									
Din + Ca + M/Din		+									
Mineral Soil Experiment											
Ca/Control				+							
Din/Control		+			--	d*					
Trif/Control	d*	++	++	--	--	d*					--
Din + Ca/Ca		++	++	-	-	d*		*			
Trif + Ca/Ca	d*	++	++	--	--	d*					--
Din + Ca/Din			++	+							
Trif + Ca/Trif											

Key:

Treatments	Greenhouse	Muck Soil	Mineral Soil
Din = Dinoseb	3 lbs/A postemergence	1.5 lbs/A postemergence	4 lbs/A preemergence
Dic = Dichlobenil	1 lb/A preemergence		
Trif = Trifluralin	$\frac{1}{2}$ lb/A preemergence		1 lb/A preemergence

S_1 = Simazine $\frac{1}{8}$ lb/A
S_2 = Simazine $\frac{1}{4}$ lb/A
Ca = Calcium 100 lbs/A as $CaSO_4$
M = Mist (evaporative cooling irrigation)

Response

Dry Weight: + = increase < 10%; ++ 10 to 25%
- = reduction < 10%; -- 10 to 25%; d* > 50%

Mineral Accumulation: + = increase < 25%; ++ 25 to 50%; * > 50%
- = reduction < 25%; -- 25 to 50%; d* > 50%

Magnesium accumulation by pea plants was enhanced by dichlobenil with calcium or simazine, or by simazine alone, but markedly reduced by trifluralin or dinoseb in the mineral soil field test.

Either dinoseb or dichlobenil enhanced sodium accumulation when applied with calcium, but both dinoseb and trifluralin applied to mineral field soil drastically reduced the sodium content of the plant, irrespective of their influence on growth or whether or not they were applied with calcium. The sodium content was also increased on pea plants by mist irrigation, which can probably be related to the sodium content of the applied water.

All four herbicides in combination with calcium or simazine markedly increased Mn accumulation, with an increase of 70% observed with trifluralin. Possibly the application of these herbicides could result in either a toxicity in some situations or correct a deficiency in others. Simazine enhanced iron accumulation in combination with dinoseb or trifluralin, depressed it in combination with dichlobenil.

The accumulation of copper and zinc was increased by a dinoseb with calcium application, and markedly increased by over 60% by dichlobenil in combination with either calcium or simazine. However, trifluralin when applied to simazine treated soils reduced copper accumulation. Except for the marked reduction in dry weight associated and a pronounced increase in manganese accumulation with the application of trifluralin, the wide variation in heavy metal micronutrient contents associated with herbicide application had little influence on the dry weight of the pea plant. It is possible that with other species or under other edaphic conditions growth might be more markedly influenced.

Either dichlobenil or mist irrigation resulted in an increase in boron accumulation, and trifluralin decreased boron uptake of peas grown on the mineral soil.

DISCUSSION AND SUMMARY

The original objective of this phase of the investigation was to study the influence of selected herbicides on the mineral content of peas, with special attention to their influence on calcium accumulation. A review of the literature indicated limited available information on the influence of herbicides on mineral accumulation by plants. A series of comparisons of an exploratory nature were conducted in the greenhouse and the field with herbicides to determine their beneficial or detrimental effects on mineral element accumulation by pea plants.

The deficiency of calcium in plants has been shown to be related to or associated with many physiological disorders (85, 24). Data from this investigation indicate that calcium accumulation is markedly influenced in some comparisons by herbicide application. The use of herbicide chemicals, not only as weed killers but also as physiological agents that may modify mineral absorption patterns, is a relatively unexplored field. It is quite possible that some herbicides might be used to alleviate a physiological disorder by increasing calcium accumulation by plants or to correct a nutrient deficiency.

The investigations conducted with pea plants indicated that dinoseb increased the Ca concentration and total content per plant and improved growth under both greenhouse and field conditions. Nasked and Ilwicki (1968) reported that Ca was increased in soybean, corn and crabgrass grown for a short period in water cultures by the addition of Linuron. When Ca interacted with dinoseb, compared with the effect of Ca alone, the herbicide reduced growth, but increased P, Na and trace elements. These data suggest that the herbicide induced greater accumulation of Ca when this element was at a lower level in the soil. This effect is quite similar to that described for simazine (65, 66, 67) with nitrogen. It has been recognized for many years that Ca sulfate may increase growth and does increase Ca accumulation in plants (13). With dinoseb under field conditions the total Ca and Mg accumulation in the plant was decreased but P and K were increased. Na was considerably reduced in the field and increased in the greenhouse by the interaction of dinoseb plus Ca. Probably this is the result of the different rates of herbicide used and the type of application, foliar postemergence versus preemergence on the soil. The addition of the lower level of simazine as an interacting factor with dinoseb markedly increased P and Fe.

Trifluralin was also used under greenhouse and field conditions on mineral soil. This herbicide resulted in a sharp increase in Mn. However, the yield of plant material was reduced both in the greenhouse and field. The drastic reduction in growth in the field is probably related to the increased rate of application, and in the greenhouse reduced growth may be related to Mn toxicity. The addition of Ca neither reduced the toxicity of Mn nor improved the growth compared with plots with calcium alone. Trifluralin with simazine increased Fe accumulation similarly to dinoseb if the interaction is compared with plots with the herbicide alone.

Simazine application was associated with increased dry weight production. Simazine at the rate of $\frac{1}{8}$ lb/A resulted in greater accumulation of four elements, at the rate of $\frac{1}{4}$ lb/A only of two. The interactions of simazine with Ca resulted in a detrimental effect on growth compared with plots with calcium or simazine alone. Adams (1) in experiments on soil found that simazine interacted with P, increased the accumulation of K, Mn, Fe and Si. These results are in agreement with the results obtained by Adams, although the present study did not involve the application of P. Previous investigations have also indicated that simazine increased dry weight (51). Similar results to those found in peas in this study were obtained with corn (27) relative to the influence of simazine on the accumulation of Mg and K.

At the rate used, dichlobenil had no effect on the accumulation of any element when applied alone. However, interacting with

Ca and compared with dichlobenil alone, pea concentrations of Na, Ca, Mg, Mn and B were significantly increased. Also, the interaction with either rate of simazine resulted in a significant increase of Ca, Mg, Mn and Cu, and with the higher level of simazine Zn and Na.

Herbicide treatment combinations that increase the accumulation of nutrients or additional fertilizer should be evaluated in practice when the use of a particular herbicide that promotes deficiencies is required for weed control.

Data obtained from the application of mist irrigation to pea plants treated with dinoseb showed a considerable increase of Ca due to this practice. Total dry weight and K were lower in plants under mist; however, P, Na and B were increased significantly. Na was increased more than 150% and B by 35%, which probably indicates salt in the water.

Evidence is incomplete to make a more critical interpretation of some of the significant interactions. It is suggested that further studies, with different herbicide rates and subrates, are warranted. The influence of herbicides on membrane permeability, absorption and transport of minerals should be investigated. Significant variations in response to herbicide treatment among varieties may be related to effects on nutrition. Differences in mineral accumulation from application of the chemical to the soil and by foliar spray should add to our knowledge of herbicide action and nutrient transport. The influence of time of application and environmental parameters in relation to mineral accumulation and herbicide action may add useful knowledge in the area of plant nutrition and herbicide physiology.

Plants are complex in respect to their mineral nutrition. It has been shown, in this exploratory investigation, that plants may be influenced markedly by herbicides, to their advantage or disadvantage, depending on the level of soil nutrients. This investigation suggests some possible new techniques of studying some physiological abnormalities, caused by shortages of essential elements in plants.

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APPENDIX

Table 6. --Effect of dinoseb, calcium and simazine on the mineral nutrition of pea plants under greenhouse conditions (average of 3 replicates).

Treatments	D.W.[a]	Percent Dry Wt.					ppm Dry Wt.				
		K	P	Na	Ca	Mg	Mn	Fe	Cu	B	Zn
Control	4.16	3.76	0.24	0.15	2.63	0.78	75	81	21	34	49
Ca	5.60	3.80	0.22	0.14	3.55	0.90	72	86	20	31	43
S_1	4.83	4.28	0.18	0.20	3.15	0.98	107	88	26	31	61
S_1 + Ca	4.73	3.83	0.25	0.20	3.10	0.82	121	97	18	34	54
S_2	5.27	3.94	0.19	0.16	3.29	0.91	88	95	25	31	50
S_2 + Ca	4.73	3.73	0.22	0.20	3.07	0.90	78	92	20	34	47
Din[b]	4.73	3.63	0.27	0.17	3.44	0.85	70	79	17	27	45
Din + Ca	4.93	3.70	0.30	0.18	3.50	0.88	104	93	29	33	63
Din + S_1	5.06	3.93	0.26	0.21	3.35	0.93	95	105	19	34	47
Din + S_1 + Ca	4.63	4.12	0.18	0.14	3.34	0.92	96	103	23	24	52
Din + S_2	5.00	3.94	0.26	0.16	3.06	0.89	82	92	19	33	52
Din + S_2 + Ca	4.93	3.76	0.21	0.16	3.28	0.99	93	105	24	36	64
Tukey's Test 5%	0.5	0.37	0.06	0.03	0.34	0.15	28	22	7	7	14
Tukey's Test 1%	0.6	0.44	0.07	0.04	0.41	0.18	34	26	10	9	17

[a]Dry weight: grams/plant.

[b]Dinoseb 3 lbs/A postemergence.

Table 7. --Effect of dichlobenil, calcium and simazine on the mineral nutrition of pea plants under greenhouse conditions (average of 3 replicates).

Treatments	D.W.[a]	Percent Dry Wt.					ppm Dry Wt.				
		K	P	Na	Ca	Mg	Mn	Fe	Cu	B	Zn
Control	4.53	3.50	0.28	0.15	2.68	0.77	75	96	21	28	44
Ca	5.20	3.68	0.24	0.17	3.61	0.74	86	106	20	37	45
S_1	5.36	3.79	0.24	0.14	2.97	0.80	78	109	17	38	49
S_1 + Ca	4.53	3.70	0.26	0.21	3.33	0.86	76	97	16	33	50
S_2	5.30	3.92	0.24	0.18	2.63	0.67	81	94	18	34	40
S_2 + Ca	4.63	3.92	0.23	0.21	3.12	1.00	78	123	17	31	45
Dic[b]	3.93	3.80	0.26	0.13	2.34	0.65	61	81	14	27	38
Dic + Ca	4.80	3.98	0.23	0.17	2.70	0.78	93	87	18	41	63
Dic + S_1	4.06	3.93	0.26	0.18	2.67	0.54	92	98	24	32	45
Dic + S_1 + Ca	4.60	3.83	0.30	0.15	2.47	0.95	88	85	19	33	55
Dic + S_2	4.67	3.63	0.25	0.23	2.71	0.87	97	65	24	33	76
Dic + S_2 + Ca	3.33	3.96	0.26	0.16	2.89	0.91	69	69	17	25	45
Tukey's Test 5%	1.07	0.62	0.06	0.04	0.29	0.18	26	24	7	6	19
Tukey's Test 1%	1.28	0.74	0.07	0.05	0.34	0.21	31	29	8	7	22

[a]Dry weight: grams/plant.

[b]Dichlobenil 1 lb/A (preemergence).

Table 8. --Effect of trifluralin, calcium and simazine on the mineral nutrition of peas under greenhouse conditions (means of 3 replicates).

Treatments	D.W.[a]	Percent Dry Wt.					ppm Dry Wt.				
		K	P	Na	Ca	Mg	Mn	Fe	Cu	B	Zn
Control	4.33	3.60	0.26	0.15	2.87	0.76	74	83	22	31	47
Ca	5.36	3.80	0.22	0.15	3.55	0.82	69	88	21	32	40
S_1	4.80	4.07	0.18	0.18	3.13	0.98	96	89	26	32	62
S_1 + Ca	4.70	3.78	0.26	0.18	3.38	0.87	78	106	18	34	50
S_2	5.20	3.83	0.25	0.18	2.75	0.72	82	109	19	35	44
S_2 + Ca	4.96	3.97	0.21	0.21	3.17	0.88	81	100	19	33	50
Trif[b]	3.70	3.70	0.19	0.15	3.09	0.92	125	69	20	31	43
Trif + Ca	4.03	3.72	0.21	0.16	3.25	0.86	113	83	17	30	47
Trif + S_1	3.80	3.76	0.18	0.17	2.83	0.97	103	96	17	34	50
Trif + S_1 + Ca	3.93	3.93	0.21	0.16	3.08	0.85	107	123	19	31	38
Trif + S_2	3.80	3.80	0.20	0.15	2.68	0.79	120	98	20	31	49
Trif + S_2 + Ca	3.80	3.86	0.20	0.17	3.02	0.95	115	86	18	35	44
Tukey's Test 5%	0.37	0.32	0.03	0.02	0.16	0.09	18	15	4	NS	12
Tukey's Test 1%	0.44	0.38	0.04	0.03	0.19	0.11	22	18	5		14

[a]Dry weight: grams/plant.

[b]Trifluralin ½ lb/A (preemergence)

Table 9. --Effect of DNBP, calcium and trifluralin on the mineral nutrition of pea plants in mineral soil (means from three replications).

Treatments	D.W.[a]	Percent Dry Wt.					ppm Dry Wt.				
		K	P	Na	Ca	Mg	Mn	Fe	Cu	B	Zn
Control	1302	1.63	0.28	0.08	2.23	0.29	59	171	7	35	25
Calcium	1125	1.63	0.25	0.08	2.50	0.29	66	129	8	35	26
Din[b]	1336	1.93	0.32	0.03	2.41	0.23	84	175	8	35	30
Din + Ca	1144	2.61	0.31	0.04	1.93	0.24	108	179	8	34	32
Trif[c]	668	2.28	0.34	0.03	1.33	0.20	65	152	9	26	30
Trif + Ca	519	2.48	0.37	0.02	1.42	0.19	66	182	6	27	25
Tukey's Test 5%	340	0.35	0.04	0.02	0.20	0.05	29	NS	NS	7	NS
Tukey's Test 1%	446	0.46	0.05	0.03	0.27	0.07	38			9	

[a]Total grams (dry weight).

[b]Dinoseb 4 lbs/A (preemergence).

[c]Trifluralin 1 lb/A (preemergence).

Table 10. --Effect of DNBP and calcium on the mineral nutrition of pea plants under mist and conventional sprinkler irrigation in muck soil (means from two replications).

Treatments	D.W.[a]	Percent Dry Wt.					ppm Dry Wt.				
		K	P	Na	Ca	Mg	Mn	Fe	Cu	B	Zn
Control + C[b]	1744	3.31	0.42	0.02	1.36	0.18	24	50	8	23	22
Calcium + C[c]	1994	3.42	0.43	0.02	1.73	0.20	26	59	10	25	25
Din + C[d]	2078	3.26	0.44	0.02	1.77	0.19	17	60	8	25	25
Din + Ca + C	1962	3.48	0.49	0.02	1.56	0.19	23	84	9	29	28
Control + M[e]	1614	2.53	0.48	0.05	1.47	0.19	16	53	27	33	27
Calcium + M	1792	2.68	0.53	0.05	1.76	0.21	21	78	9	35	33
Din + M	1920	3.01	0.53	0.06	1.95	0.23	23	86	10	34	32
Din + Ca + M	1782	2.78	0.60	0.06	1.83	0.22	21	125	11	36	30
Tukey's Test 5%	285	0.51	0.02	0.01	0.28	NS	NS	49	NS	8	11
Tukey's Test 1%	394	0.69	0.03	0.02	0.38			66		11	15

[a]Dry weight: total in grams.

[b]Conventional irrigation.

[c]Ca 100 lbs/A (as $CaSO_4$).

[d]Dinoseb 1.5 lbs/A (postemergence).

[e]Mist irrigation.