Table 1. **Fruitworm** damage ratings for the tomato accessions in the lowest and highest damage groups, 1973.

Accession[z]	% Fruits damaged[y]
Lowest damage	
Tiny Tim	13.1 a
P. I. 128230 (Species type)	21.1 ab
N. S. S. L. 27260 (Watanabes)	27.1 ab
P. I. 97538 (Species type)	28.0 ab
P. I. 193415 (Pennorange E160A)	29.7 b
TF-2[x]	30.9 b
P. I. 120272 (Species type)	31.7 b
P. I. 102717 (Species type)	32.7 b
P. I. 303787 (Santa Catalina)	34.8 bh
N. S. S. L. 26876 (Abundance)	35.2 bh
Yellow Pear	36.2 bh
Highest damage	
Walter[w]	52.4 hl
KC 146	52.6 hl
P. I. 258481 (Rick LA 405)	53.6 hl
Marion	54.0 hl
N. S. S. L. 27381 (Livingston's Magnus)	56.8 l
P. I. 209974 (Peron)	57.0 l
P. I. 128293 (Assumed cultivar)	58.2 l
P. I. 270177 (Comet)	62.2 lm
N. S. S. L. 27243 (Thick Skinned)	64.1 lm
N. S. S. L. 26979 (E. Z. Peeling Salad)	70.6 lm
Parker[v]	77.3 m

[z]Names of cultivars with Plant Introduction (P. I.) or National Seed Storage Laboratory (N. S. S. L.) numbers enclosed in parentheses. Non-cultivar accessions are classified as either species type or assumed cultivar.

[y]Mean separation by Duncan's multiple-range test, 5% level (only letters pertinent to the extracted means shown).

[x]Resistant control (selection from STEP 494).

[w]Commercial control.

[v]Susceptible control.

operating. 'Tiny Tim', the most resistant accession, is a small-vined dwarf cultivar. The favorable rating of this cultivar obviously was not caused by a vine-size factor.

Though our data are possibly confounded by vine-size effects, 2 general conclusions with reference to fruitworm resistance in the tomato are possible. First, there is no immunity to the tomato fruitworm within the tomato cultivar germplasm searched. If immunity to this pest exists within the genus *Lycopersicon,* it must be found in unadapted *L. esculentum*-type material or in the related species. Second, there is a large amount of variability in fruitworm resistance within cultivar germplasm, and much of it may have potential usefulness in developing less susceptible cultivars. A tomato cultivar with even partial resistance to the fruitworm would be of considerable value in an integrated control program.

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Effect of Herbicides on Weed Control and Nitrate Accumulation in Spinach[1]

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Abstract. **Three herbicides, cycloate, alachlor and lenacil, gave acceptable weed control in spinach (*Spinacia oleracea* L.), while 7 other herbicide combinations did not. Cycloate, alachlor, lenacil, prometryne and chlorpropham + PPG 124 significantly increased the NO_3-N concentration of both spinach blades and petioles by as much as 3-4 times over weeded and non-weeded checks. DCPA significantly increased NO_3 in the petioles. Cycloate, alachlor and lenacil significantly increased total N concentration in the petioles, while none of the herbicide treatments affected total N in the blades. Lenacil significantly increased fresh weight of blades and petioles compared to a weeded check, while plant fresh and dry weights from cycloate and alachlor treatments were not less than the checks.**

Effective weed control in spinach is necessary for high yield, a high quality product and easier harvesting of the crop. Because of high labor costs and sometimes relatively low returns per acre the cost of a weed control program on spinach must be kept as low as possible. Hence, chemical weed control appears to be the answer to this production problem.

Chlorophenoxy and triazine herbicides have been shown to increase NO_3 in crops and several broadleaf weed species (1, 2, 3, 8, 9, 11, 12, 13, 17, 18, 21, 22, 25, 26). In some cases, the quantities of NO_3 found were high enough to be toxic to cattle (14, 21). Sublethal doses of herbicides, most notably triazines, can be beneficial by increasing the protein content in both vegetative and seed plant parts (8, 9, 11, 13, 14, 17, 18, 19, 20). However, in many cases, NO_3 accumulation occurred. Hiranpradit et al. (13) reported significant increase in the content of both protein and NO_3-N when atrazine was applied to corn. Fedtke (9) reported that the photosynthetic inhibitor herbicides, metribuzine and methabenzthizuron, enhanced nitrate reductase activity and increased NO_3 concn in potato and wheat up to 10,000%. The same results were obtained by growing the plants under low light intensity. Lowered light intensity has been shown to increase NO_3 concn in many plant species including spinach (5, 10). This can be related to the energy need of nitrate reductase that is derived from photosynthesis (24).

Accumulation of NO_3 is undesirable since it can be reduced to NO_2 a form of N which can be toxic to humans, especially infants. Also, high NO_3 in processed products have been connected with detinning of cans. Spinach and similar leafy vegetables can accumulate high levels of NO_3 (4, 6). Our objective was to find effective herbicides for weed control in spinach and to determine what effect the chemicals had on NO_3 accumulation.

'America' spinach was seeded on April 27, 1972, on a sandy loam soil. Rows were spaced 1 m apart and plants 10 cm apart in the row. Individual plots were 3 rows 3 m long. There were 4 replications of each treatment. Fertilizer as 10N-4.3P-8.3K at a rate of 420 kg/ha was broadcast and disked in before planting. After the crop emerged N as as NH_4NO_3 was sidedressed at 224 kg/ha to give a total fertilizer N rate of 117 kg/ha.

Treatments included chlorpropham (isopropyl *m*-chlorocarbanilate), chlorpropham + PPG 124 (p-chlorophenyl-N-methyl carbamate). cycloate (S-ethyl N-ethylthiocyclohexanecarbamate), endothall (7-oxabicyclo[2,2,1] heptane-2, 3-dicarboxylic acid), alachlor (2-chloro-2', 6'-diethyl-N-(methoxymethyl) acentanilide), lenacil (3-cyclohexyl-6,7-dihydro-1H-cyclopentapyrimideine-2,4 (3H,5H)-dione), DCPA (dimethyl tetrachloroterephtalate), CDEC (2-chloroallyl diethyldithiocarbamate), trifluralin (α α α-trifluro-2, 6-dinitro-N,N-dipropyl-p-toluidine), prometryne (2,4-bis(isopropylamino)-6-(methylthio)-*s*-triazine), and weeded and non-weeded checks. Weeded checks were maintained weed free throughout the growing season. The

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Table 1. Effect of several herbicides on weed control and yield of spinach.

Treatment	Rate (kg/ha)	Time of application[z]	No. weeds/930 sq cm							Yield (kg/ha)
			Lambs quarter	Red root pigwood	Ragweed	Shepherds purse	Total broadleaf weeds	Crab grass	Total grass	
Chlorpropham	1.12	pre	3a[y]	1a	3a	3abc	12abc	2a	6a	2060abcdef
Chlorpropham	2.24	pre	7bcd	2a	3a	0a	12abc	6a	8a	2017abcdef
Chlorpropham + PPG 124	1.12+0.28	pre	6abc	3ab	2a	1ab	14abc	9a	10a	2062bcdefg
Chlorpropham + PPG 124	2.24+0.56	pre	5abc	2a	4a	1ab	11ab	5a	7a	1084abcde
Cycloate	3.36	ppi	0a	0a	2a	0a	2a	0a	1a	4048g
Cycloate	4.48	ppi	3abc	0a	1a	0a	4a	1a	2a	2006abcdef
Endothall	1.12	pre	3abc	2a	2a	4bc	14abc	20a	23a	3025defg
Endothall	2.24	pre	2abc	1a	1a	4bc	10ab	10a	11a	3059efg
Alachlor	2.24	pre	1ab	0a	3a	0a	5a	2a	4a	3025defg
Alachlor	4.48	pre	1ab	0a	3a	0a	4a	0a	0a	2091cdefg
Lenacil	1.12	pre	0a	1a	4a	0a	12abc	2a	3a	3070fg
Lenacil	2.24	pre	1ab	1a	1a	0a	3a	2a	3a	3074fg
DCPA	4.48	pre	1ab	2a	2a	6cd	15abc	2a	5a	1022abc
DCPA	6.72	pre	1ab	1a	3a	4bc	11ab	0a	4a	1001ab
CDEC	2.24	pre	13d	3ab	5a	5cd	28c	10a	12a	2013abcdef
CDEC	3.36	pre	3abc	2a	3a	6cd	16abc	5a	8a	2062bcdefg
Trifluralin	0.56	ppi	1ab	0a	3a	6cd	13abc	0a	2a	1068abcd
Prometryne	1.12	pre	2abc	1a	4a	3abc	12abc	1a	3a	71a
Weeded check			0a	0a	0a	0a	0a	0a	0a	2080cdefg
Non-weeded check			8cd	5b	3a	8d	24bc	3a	5a	3048efg

[z]ppi (preplant incorporated treatments) – applied immediately before seeding.
pre (preemergence treatments) – applied immediately after seeding.
[y]Mean separation in columns by Duncan's multiple range test, 5% level.

rate and time of application can be found in the tables. Preplant incorporated (ppi) treatments were applied immediately before seeding while preemergence (pre) treatments were applied immediately after seeding. The treatments were applied with an Oxford Precision Sprayer at a rate of 280 liter/ha at 2 kg/cm^2 pressure.

Weeds per 930 sq cm were counted after the crop was well established. The primary weeds present were lambs-quarters (*Chenopodium album* L). ragweed (*Ambrosia artemisiifolia* L.), redroot pigweed (*Amaranthus retroflexus* L.) shepherds purse (*Capsella bursa-pastoris* L.), and crabgrass (*Digitaria sanguinalis* L.).

Plants from the center of each plot were harvested 37 days after emergence. The plants were washed in distilled water, separated into leaf blades and petioles then dried at 70°C for 48 hr. The tissue was ground in a Wiley mill and NO_3 then determined using an Orion nitrate ion electrode (7). A portion of the tissue was acid digested and total N was determined by nesslerizing an aliquot of the digested sample (16). The remainder of the plants were harvested and weighed on the same day.

Cycloate and alachlor at either rate and lenacil at 2.24 kg/ha gave the best overall weed control of broadleaf weeds and grasses (Table 1). All 3 compounds gave excellent control of lambs-quarters, redroot pigweed and shepherds purse. None of these 3 herbicides had an adverse affect on spinach yields. Prometryne and DCPA significantly reduced yield (Table 1) through 75% reduction in germination by prometryne and a 50% reduction by DCPA. None of the other herbicides tested gave satisfactory weed control. The same 10 herbicides were tested under similar conditions again in 1973 and weed control from all treatments was similar to that obtained in 1972. However, in 1973, prometryne prevented spinach germination entirely.

All 3 herbicides that gave satisfactory weed control, cycloate, alachlor and lenacil, significantly increased NO_3-N in the blades and petioles at either rate applied (Table 2). Other herbicides that increased NO_3 in the blades and petioles were prometryne and chlorpropham + PPG 124 at the lower rate. None of these compounds are chemically related. DCPA at both rates significantly increased NO_3 in the petioles. None of the herbicide treatments significantly reduced the NO_3-N concn of the spinach. Although non-significant, there was a lower NO_3-N concn in the blades and petioles of the non-weeded check compared to the weeded. This was probably the result of competition for soil NO_3 by weeds and spinach in the non-weeded check.

Herbicide treatments did not increase the total N concn in the blades compared to the checks, but cycloate, alachlor and lenacil did increase total N in the petioles.

Fresh wt of the blades were significantly increased over the checks only by lenacil, while blade dry wt appeared essentially unaffected by herbicides. Blade wt of the weeded and non-weeded checks were equal, however petiole fresh wt of the non-weeded check were significantly more than those of the weeded check. This was probably due to weed-crop competition for light, causing elongation of the spinach petioles. Petiole fresh wt of the plants treated with 2.24 kg/ha endothall or either rate of lenacil were significantly more than the weeded check, but none of the herbicide treated petioles were more than the non-weeded check. This fresh wt difference between lenacil and check plants was the same in 1973.

Herbicides, predominately chlorophenoxy and triazine herbicides, have given increased NO_3 concns in various plant species (2, 3, 9, 11, 13, 17, 21, 22). This increase in NO_3 can result from at least 2 causes; increased plant uptake of NO_3 from the soil, or lowered nitrate reductase activity (2). Since the total N concn of both the spinach blades and petioles did not increase dramatically it appears that the herbicides, especially cycloate, alachlor, prometryne and lenacil, are increasing NO_3 accumulation through a decrease in some phase of nitrate reduction. The mode of action has not been specifically determined for any of these herbicides although they have been linked to a disruption in protein synthesis and enzyme activity while prometryne is thought to be a photosynthetic inhibitor (1). Some uracil derivatives similar to lenacil have been shown to inhibit the induction of nitrate reductase by NO_3 and Mo in leaf tissue (12).

Nitrate reductase activity has been reported to increase in plants treated with simazine but only when plants were grown on a media containing NO_3 (17). This may have been in response to higher NO_3 concn in the tissue.

Recently, Klepper (15) reported that the lethal action of photosynthetic herbicides including triazines is directly linked to inhibition of nitrite reductase. Nitrite accumulates in the plant and

Table 2. Effect of several herbicides on NO_3-N, total N and weights of spinach blades and petioles.

Treatment	Rate (kg/ha)	Time of application[z]	% (dry wt basis)				Wt/plant (g)			
			NO_3-N		Total N		Fresh		Dry	
			Blades	Petioles	Blades	Petioles	Blades	Petioles	Blades	Petioles
Chlorpropham	1.12	pre	.15abc[y]	0.93abcd	5.41abc	3.14abcd	44.7abc	19.1abcdef	3.6abc	1.2abcdef
Chlorpropham	2.24	pre	.22abcdef	1.30bcdef	5.43abc	3.44bcde	50.6abcde	18.3abcdef	3.4abc	1.0abcd
Chlorpropham + PPG 124	1.12+0.28	pre	.33efgh	1.61defgh	5.67bc	3.54bcde	55.7bcde	17.3abcdef	4.6abc	1.2abcdef
Chlorpropham + PPG 124	2.24+0.56	pre	.26bcdefg	1.33bcdefgh	5.71bc	3.42bcde	51.4abcde	19.2abcdef	4.1abc	1.2abcdef
Cycloate	3.36	ppi	.44h	2.02gh	6.04c	3.59cde	68.5cde	25.7defg	4.8bc	1.4bcdef
Cycloate	4.48	ppi	.43h	2.07h	5.57bc	3.77de	48.0abcd	18.0abcdef	3.6abc	1.1abcdef
Endothall	1.12	pre	.11a	1.02abcd	5.64bc	3.22abcd	55.8bcde	23.7cdefg	5.2c	1.5cdef
Endothall	2.24	pre	.19abcde	1.43bcdefgh	4.92a	3.47bcde	67.4cde	26.6efg	4.5bc	1.5cdef
Alachlor	2.24	pre	.33efgh	1.78efgh	5.50abc	4.09e	57.7bcde	22.0abcdefg	4.4bc	1.3bcdef
Alachlor	4.48	pre	.37fgh	1.95fgh	5.33ab	3.54bcde	63.7bcde	23.3bcdefg	5.0c	1.4bcdef
Lenacil	1.12	pre	.35fgh	1.54cdefgh	5.79bc	3.67de	74.9de	30.1g	5.3c	1.7f
Lenacil	2.24	pre	.45h	1.83fgh	5.38abc	3.67de	78.3e	28.4fg	5.0c	1.6ef
DCPA	4.48	pre	.31defgh	1.57defgh	5.58bc	3.32bcd	4.44abc	17.3abcde	3.5abc	1.1abcdef
DCPA	6.72	pre	.30cdefgh	1.89fgh	5.63bc	3.48bcde	38.9ab	13.8ab	3.1ab	0.9abc
CDEC	2.24	pre	.11a	0.60a	5.76bc	3.12abcd	29.5a	14.3abc	2.5a	0.9abc
CDEC	3.36	pre	.17abcd	1.08abcde	5.55abc	2.90abc	47.2abcd	21.1abcdefg	3.8abc	1.2abcdef
Trifluralin	0.56	ppi	.17abcd	0.80ab	5.73bc	3.20abcd	48.3abcd	17.1abcde	3.6abc	1.1abcdef
Prometryne	1.12	pre	.39gh	1.76efgh	5.81bc	3.52bcde	40.7abc	13.0a	3.1ab	0.7a
Weeded check			.16abcd	0.87abc	5.44abc	2.61a	38.2ab	15.8abcd	3.4abc	1.1abcdef
Non-weeded check			.12ab	0.60a	5.83bc	2.84ab	44.4abc	26.1efg	3.5abc	1.5cdef

[z]ppi (preplant incorporated treatments) – applied immediately before seeding.
pre (preemergence treatments) – applied immediately after seeding.

[y]Mean separation in columns by Duncan's multiple range test, 5% level.

becomes toxic. He found little influence of these herbicides on NO_3 accumulation or nitrate reductase activity. Klepper was working with lethal herbicide doses over short incubation times. On the other hand, other researchers (9, 17, 18, 23), using sublethal doses of various photosynthetic or triazine herbicides, have reported increases in nitrate reductase activity and nitrate accumulation. The difference appears to be partially due to the concn of herbicide used. In our work, we were looking at the effects of the herbicide for approx 37 days after it was applied. The herbicides were most likely, if at all, present at very low concn in the plants at harvest time. Hence the effects of the herbicides on nitrate accumulation complimented that of sublethal dose rate. Swanson and Shaw (22) reported that the NO_3 concn of Sudan grass sprayed with 2,4-D varied according to the time after herbicide application.

Although we have shown that herbicides can cause nitrate to accumulate in spinach, there should be little concern for nitrate poisoning to occur. Toxicity can occur if a 70 kg adult ingests approx 0.7 g NO_3-N (4). If we consider the cycloate treated plants in our experiment a person would have to ingest 554 g of fresh petioles or 2273 g of fresh leaf tissue to get a toxic dose of NO_3. This would have to be eaten raw and essentially at one meal. It is unlikely that any human could do this.

Total N was significantly increased in petioles of the promising herbicide treatments, which suggests that N fertilizer may be more efficiently used. Possibly lower rates of N fertilizer may be used if cycloate, alachlor or lenacil are used as a herbicide for spinach.

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