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Growth and Yield Responses of Selected Crops to Peroxyacetyl Nitrate

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Abstract. **Greenhouse-grown root, foliage, fruit, and seed crops were exposed to peroxyacetyl nitrate (PAN) at 0, 5, 10, 20, and 40 ppb, 4 hours per day, twice per week, from germination to maturity of harvestable product. A response of PAN dose and growth or yield parameters was significant only for lettuce (*Lactuca sativa* L. cv. Empire) and Swiss chard (*Beta vulgaris* L. var. *cicla*, cv. Fordhook). Leaf fresh weight was reduced by 13% in 'Empire' lettuce and by 23% in chard in the 40 ppb PAN treatments relative to 0 ppb PAN controls. Peroxyacetyl nitrate at 10 ppb appeared to stimulate the growth of most crops. The threshold for inhibition of growth by PAN, under conditions of 2 exposures per week, appeared to be between 10 and 20 ppb. These results suggest that PAN, at concentrations below the threshold for visible injury, can alter the growth of plants, but that significant reductions in growth or yield may occur only in highly susceptible cultivars of leafy crops.**

Peroxyacetyl nitrate (PAN) is part of the photochemical oxidant complex produced by the action of sunlight on hydrocarbons and oxides of nitrogen in the atmosphere. Although ozone (O_3) is the most abundant photochemical oxidant and is the major cause of vegetation injury (8), PAN has been detected in most parts of the United States (6, 18, 23), western Canada (12), Europe (3, 13), and Japan (5). During the summer months in southern California, monthly mean PAN concentrations can approach 10 ppb, daily means can exceed 20 ppb, and hourly means can exceed 40–50 ppb (18). High O_3 concentrations normally are present during these episodes, but occasionally PAN can exceed 20 ppb when O_3 is low or absent (19). These periods, when PAN is the only or major photochemical oxidant present in the atmosphere, frequently occur in the morning hours when PAN has persisted overnight but O_3 has not had sufficient time to accumulate from precursors (18). Plants have been shown to be more susceptible to PAN injury in the morning, compared with mid- or late afternoon exposures (14, 18).

Visible symptoms of injury induced by PAN have been well-characterized (2, 20). Abaxial glazing and bronzing and transverse bands of chlorotic or necrotic tissue produced by PAN on susceptible crops and ornamentals such as lettuce (*Lactuca sativa*) and petunia (*Petunia hybrida* Vilm.) can reduce greatly the market values of these crops. Severe economic losses to growers have resulted from PAN injury to susceptible species (11, 18). However, little is known of the long-term effects of PAN on growth and yield of crops. Thompson and Katz (22) reported a trend toward increased leaf and fruit drop in navel orange (*Citrus sinensis* Osb.) trees exposed to ambient concentrations of PAN compared with filtered-air controls, but data were not significant statistically. Oshima (10) exposed sweet corn (*Zea mays* L. cv. Golden Jubilee), tomato (*Lycopersicon esculentum* Mill. cv. H-11), carrot (*Daucus carota* L. cv. Emperator), cabbage (*Brassica oleracea* L. var. *capitata* cv. Copenhagen), strawberry (*Fragaria* X *ananassa* cv. Tioga), and lettuce ('Boston' and 'Prizehead') to 20 or 40 ppb PAN intermittently throughout the growing season and found no effects of either treatment on plant weight, although foliar injury symptoms on 'Boston' lettuce reduced crop marketability. Posthumus (14) found reductions in growth of nettle (*Urtica urens* L.) after exposure to 25 ppb PAN, 3 hr per day for 7 days, which caused significant foliar injury on this susceptible species. The objective of the present study was to characterize growth and yield responses of foliage, root, fruit, and seed crops to intermittent exposure to PAN over the growing season of the crop.

Crop species selected for treatment were chosen on the basis of: 1) importance as a cash crop; 2) known susceptibility to PAN; 3) amenability to growth under greenhouse conditions; and 4) representative of root, foliage, fruit, or seed crops. We used radish (*Raphanus sativus* L. cv. Cherry Belle), beet (*Beta vulgaris* cv. Detroit Dark Red), head lettuce ('Empire'), leaf lettuce ('Romaine'), chard (*B. vulgaris* L. var. *cicla* cv. Fordhook), tomato (*Lycopersicon esculentum* cv. Patio), pinto bean (*Phaseolus vulgaris* L. cv. U.I. 111), oat (*Avena sativa* L. cv. Sequoia), and barley (*Hordeum vulgare* L. cv. CM67).

Single seedlings of each dicot and 6 each of the monocots were transplanted into 3.8-liter (1-gal), plastic pots containing a soil medium composed of equal parts sandy loam, peat, and redwood shavings (by volume). Plants were watered automatically twice daily with ¼-strength Hoagland's nutrient solution and fertilized with full-strength Hoagland's solution or $Ca(NO_3)_2$ intermittently as needed. All plants regularly were relocated randomly on greenhouse benches to decrease variations due to positional effects. Greenhouse temperatures ranged from 20° to 35°C day and 20° to 25° night. Relative humidity ranged from 40–70% day and night. Plants were raised and exposed to PAN under natural light conditions at the season of year in which they are grown normally in southern California. Photoperiod ranged from 10 hours of daylight in December to 15 hours in June. Photosynthetically active photon flux density inside exposure chambers ranged from 200–1000 $\mu mol\ s^{-1}m^{-2}$, depending upon meteorological conditions and time of day.

Plants were exposed to PAN in continuously stirred tank reactor chambers (15) located inside a greenhouse equipped with charcoal air filters. Synthesis and analysis of PAN followed the methods of Stephens (16, 17). Plants were exposed to 0, 5, 10, 20, or 40 ppb PAN for 4 hr per day, twice each week from 7 days after germination until maturity of harvestable product. Twelve pots of each species were included in each treatment. Fresh and dry weights of roots, stems, leaves, or seeds were determined for each plant at harvest. Data were analyzed by one-way analysis of variance and regression analysis (9).

'Empire' lettuce and 'Fordhook' chard exposed to 40 ppb PAN under the conditions of this experiment had significantly lower leaf weight than 0 ppb PAN controls. 'Empire' lettuce averaged 13% lower fresh leaf weight and chard averaged 23% less leaf

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Table 1. Harvest weight or organ number of selected crop plants exposed to PAN, 4 hr per day, twice per week from seedling to maturity.

Species	Total exposure period (hr)	Parameter	PAN 0 ppb	5 ppb	10 ppb	20 ppb	40 ppb	Regression[z]
Radish	32	Radish fresh wt (g)	16.7[y]	13.5	15.8	17.3	15.4	NS
Radish	48	Radish fresh wt (g)	12.9	14.5	15.5	12.7	14.5	NS
Lettuce, cv. Empire	60	Leaf fresh wt (g)	244	258	279	206	213	$Y = 264 - 1.44 X$ $r = 0.36, F = 7.90^{**}$
cv. Romaine	72	Leaf fresh wt (g)	177	184	194	191	195	NS
Chard	128	Leaf fresh wt (g)	243	251	262	230	187	$Y = 252 - 0.041 X^2$ $r = 0.64; F = 40.65^{***}$
Oat	120	Stalk dry wt (g)	66.7	65.7	67.3	68.7	65.2	NS
		100 seed wt (g)	3.11	3.16	3.10	3.12	3.11	NS
Tomato	92	Fruit fresh wt (g)	335	303	358	355	313	NS
		No. fruit/plant	7	6	8	7	7	NS
Pinto bean	72	Pod fresh wt (g)	44.3	35.7	36.8	48.8	35.5	NS
		Seed fresh wt (g)	23.8	23.5	26.7	28.7	24.3	NS
		No. beans/plant	60	54	56	59	51	NS
Beet	100	Beet fresh wt (g)	58.3	62.0	65.1	62.5	77.7	NS
		Leaf fresh wt (g)	75.1	65.8	63.4	68.3	83.0	NS
Barley	136	100 seed wt (g)	3.09	2.66	3.33	2.98	2.89	NS

[z] Best-fit regression equation, based on linear, polynomial, or exponential models; regression significant at 1% (**), 0.1% (***), or nonsignificant (NS).

[y] Mean of 12 replicates.

weight at 40 ppb PAN relative to 0 PAN controls. Regression between reduction in growth and increasing concentration of PAN was highly significant for both species (Table 1). The best-fit regression model for 'Empire' lettuce was linear, although the regression equation accounted for only 13% of the variation in leaf weight. The best-fit regression model for the chard data was quadratic, and the equation accounted for 41% of the variation in leaf weight. Mean leaf weight for both 'Empire' lettuce and chard was higher in 5 and 10 ppb PAN treatments than in 0 ppb PAN controls, suggesting that the threshold for adverse effects of PAN on plant growth in these experiments was between 10 and 20 ppb.

No visible symptoms of foliar injury developed on lettuce or chard beyond the seedling stage of growth. Pinto bean was the only crop to show significant foliar injury. Severe undersurface glazing and bronzing developed on rapidly expanding 6- to 8-day-old, unifoliolate leaves and trifoliolates after exposure to 40 ppb PAN for 4 hr. Susceptibility to PAN persisted throughout the developmental cycle of pinto beans up to and including ripening of seed pods. In contrast, both 'Empire' and 'Romaine' lettuce and Swiss chard became more resistant to PAN injury after about 2 weeks of growth (data not shown). Despite occasional severe foliar injury, pinto bean growth and pod development were not reduced significantly by exposure to PAN. None of the other crops tested showed significant regression between concentration of PAN and reductions in growth and yield (Table 1).

Plants exposed to 10 ppb PAN had the highest or 2nd highest mean biomass of all treatments, including controls, for most parameters (Table 1). Although means within individual crops were generally not different significantly ($\alpha = 0.05$), pooled data from the 10 trials had a frequency distribution significantly different from that expected by random assortment ($\chi^2 = 11.85^*$, 4 df; $P < 0.025$). This trend to stimulation of growth by PAN in the 10 ppb treatments had no obvious explanation. Bennett et al. (1) reported apparent stimulation of growth of various plant species by low concentrations of ozone (0.03 ppm) relative to ozone-free controls. They suggested that plants may be "adapted" to the low amounts of ozone normally present in the lower atmosphere. However, PAN is of entirely anthropogenic origin and background concentrations are 1 ppb or less (21), so adaptation to 10 ppb PAN seems unlikely. Numerous physiological and biochemical changes have been reported in plants in response to PAN and other photochemical oxidants (7, 8). These alterations in normal metabolism usually have been interpreted in terms of impairment of physiological responses, leading to foliar injury or reductions in growth (4). Mechanisms by which photochemical oxidants such as PAN can stimulate plant growth have not been reported.

PAN alone did not appear to inhibit growth of various root, fruit, or seed crops under the conditions of these experiments. PAN did inhibit growth of foliar crops such as chard and 'Empire' lettuce, but not 'Romaine' lettuce. These results are consistent with the few previous studies of effects of PAN on plant growth which showed no statistically significant effects of ambient concentrations of PAN on growth of carrots, cabbage, strawberry, maize, tomato (10), or navel oranges (22), and severe foliar injury on one cultivar of lettuce ('Boston') but not another ('Prizehead') (10). High dosages of PAN did reduce growth of *U. urens*, a plant highly susceptible to PAN injury (14). PAN by itself, and in combination with O_3, altered growth of 4 cultivars of tomato but had little effect on lettuce and chard (unpublished).

The inhibition of growth of 'Empire' lettuce and chard in these experiments was consistent with the extreme susceptibility of these species to foliar injury induced by PAN (20), although growth reduction occurred without the production of foliar injury symptoms. Conversely, pinto bean exhibited severe foliar injury on young leaves but had no reduction of growth at 40 ppb PAN. The results of these experiments suggest that ambient concentrations of PAN, present during episodes of photochemical oxidant pollution in southern California, can affect plant growth in the absence of visible injury symptoms. However, significant reduction in growth or yield of crops may occur only in highly susceptible cultivars of leafy crops such as lettuce or chard.

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Water Retention of Container Soils Transplanted into Ground Beds

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Abstract. **Water stress resulting from inadequate soil water retention following transplanting is a major cause of container-grown transplant failure. The relatively small water supply contained in the soil containers used in nursery and bedding plant production is reduced further by enhanced drainage following transplanting. This drainage phenomenon, which has received little previous attention, was investigated under controlled laboratory conditions. Samples of 2 suitable container soils were embedded in simulated ground bed soil and retained in a container; water retention of the embedded soil, surrounding ground bed soil, and contained soil was monitored simultaneously to determine if the embedded soil (analogous to a container-grown transplant's soil) retained less water than the contained soil. The embedded soils lost 30% to 85% of their estimated available water within a few hours, whereas contained soils lost the same quantity only after 3 or 4 days of surface evaporation. A simultaneous increase in water content in the surrounding ground bed soil indicated that the rapid water loss from the embedded soil was due to water movement into the surrounding soil. A similar water loss following subsequent irrigation of the embedded and ground bed soils indicated that this embedded soil water loss is primarily a drainage phenomenon. This effect was concluded to be a potentially significant factor affecting transplant survival.**

Water stress is considered the most important cause of losses of transplanted, container-grown plants (3). ("Container soil" herein refers to any soil or soil-like porous medium physically suitable for container plant production. "Contained soil" refers to such a soil still in a container and "transplanted container soil" is a container soil which has been embedded in bulk into a ground bed soil so that their top surfaces coincide. "Transplant's soil" refers to the container soil mass accompanying a transplant during transplanting.) Until its root system extends into the surrounding soil, the transplant depends on the one- or 2-day water supply (3) retained in the accompanying container soil mass (4) and therefore must be irrigated frequently to avoid water stress. Unfortunately this is often impractical and the amount of water retained by the transplanted container soil may be the key factor in determining the transplant's survival.

The water supply in container soils apparently is often reduced further by water movement into the surrounding ground bed soil following transplanting (3, 5). Container soils are designed to provide adequate aeration under the perched water table conditions occurring in containers (11, 13, 14). However, the perched water table is eliminated by contact with the ground bed soil at transplanting and the transplant's soil is subjected to much greater drainage pressures resulting in its retention of less water than when in the container.

This potentially harmful drainage phenomenon has received little attention from individuals concerned with transplant production and apparently is seldom considered in the design of container soils. The results of laboratory experiments confirming this drainage phenomenon are reported in this paper.

Samples of 2 soils were embedded in bulk in simulated ground bed soil and retained in a container. The water retention of the embedded soil, surrounding ground bed soil,

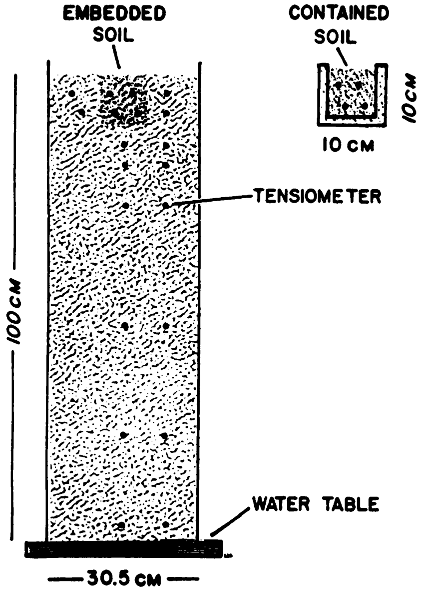

Fig. 1. Diagram of soil column (simulated ground bed soil), embedded soil (simulated transplanted container soil), and contained soil indicating tensiometer locations (dots).

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