Reprint from Vol. 103(3), May 1978
Journal of the American Society for Horticultural Science
Mount Vernon, Virginia 22121 USA

1661-J

J. Amer. Soc. Hort. Sci. 103(3):351–355. 1978.

The Effects of Wind and Wind-Plus-Sand on Tomato Plants[1]

Robert Precheur[2], J. K. Greig[3], and D. V. Armbrust[4]
Department of Horticulture, Kansas State University, Manhattan, KS 66506

Additional index words. Lycopersicon esculentum, plant anatomy, photosynthesis, respiration

Abstract. **Seedlings of tomato (*Lycopersicon esculentum* Mill.) were exposed to winds of 1,340 cm/sec (for 10 and 20 minutes) and wind-plus-sand (10 and 20 minutes; abrasive flux rate, 6 g/cm per minute). Exposing plants to wind alone for 10 and 20 minutes had no effect on stem or leaf anatomy, although 20 minute winds caused desiccated lesions on leaves. Tomatoes, sandblasted for 10 or 20 minutes, developed a secondary endodermis under wounded tissue with wound periderm developing 2 days after wind treatment. Leaf, palisade cell, and leaf midrib thicknesses in plants exposed to 20 minutes of wind-plus-sand were greater than those of the controls. Stems of plants sandblasted for 20 minutes developed an elongated layer of chlorenchyma below the epidermis 21 days after exposure; the layer was doubled that of the controls. Dry weight and net photosynthetic rates were reduced significantly in all plants by all treatments compared with controls except on day 1 after plants were exposed to wind for 10 minutes. Net photosynthetic rates were not significantly different 5 days after treatment, and net respiration rates were not significantly different on either day 1 or 5.**

Wind alone and wind-plus-sand can severely damage many vegetable crops, especially tomatoes. Plants exposed to wind for long period have thicker leaves with brown lesions and a more extensively developed vascular system (11, 16). In green beans and tomatoes, yield and fruit quality are reduced significantly (3, 9, 12). Tomato plants exposed to a 1,340 cm/sec (30 mph) wind at a sand-flux rate of 25 g/cm width per min had narrower stems reduced cambial activity, and a peripheral endodermis with casparian strips 4 days after treatment (8). In exposed plants, leaf thickness, leaf midrib thickness, palasade cell-length, and the no. of stomates per mm^2 were double those in control plants. Wind and sandblast damage also affected photosynthesis and respiration rates. When exposed to winds of 3.5 m/sec and greater, beans, corn, wheat, and other species all had 20 to 40% increase in respiration as windspeed increased (13). Wind and sandblast damaged winter wheat plants had reduced dry wt production and dry wt accumulation with increased plant injury; growth was reduced due to loss of leaf area, reduced photosynthesis, and increased respiration (2). Wind alone, at 3.5 m/sec, on tall fescue after 0, 2, 5, 7, and 9 days reduced rates of photosynthesis, but had no significant effect on respiration (8).

This study reports the effects of short exposures of wind and wind-plus-sand on tomato plant anatomy and plant recovery after 2, 7 and 21 days and the effects of wind and wind-plus-sand on net photosynthesis and net respiration rates.

Materials and Methods

Expt. I. Plant anatomy. 'Jet Star Hybrid' and 'Park's Whopper Hybrid' tomato plants were germinated in vermiculite and transplanted to 11.5 cm plastic pots containing 1 soil: 1 peat moss: 1 perlite, supplemented with lime, triple superphosphate (ON-19P-OK), and osmocote (14N-6P-11.6K). Plants were placed in a growth chamber with a barrierless lamp canopy with 65% input wattage of cool-white fluorescent and 35% input wattage of incandescent light. The radiant flux distribution at the top of the plant canopy was 110 $\mu w/cm^2$ at 525 nm, 970 $\mu w/cm^2$ at 570 nm, 208 $\mu w/cm^2$ at 650 nm, and 10 $\mu w/cm^2$ at 750 nm, as measured by a spectroradiometer (ISCA Model SR). The photoperiod was 12 hr day and night, with an abrupt change. Air temp was 26°C ± 1° (day), and 10°, 15.5°, and 21°C ± 1° (night) as measured by a thermocouple. Night temp was varied for a catfacing experiment. Relative humidity was 60 or ± 5%, day and night. Air movement in the chamber was upward with fresh air provided.

At treatment, plants averaged 11 cm high, with flower buds less than 1 mm long. Treatments consisted of no wind, wind at 1,340 cm/sec (30 mph) for 10 and 20 min; and wind-plus-sand (0.297 – 0.42 mm) at an abrasive flux rate of 6 gm/cm width per min for 10 or 20 min. The experiment was a completely randomized block with 5 exposure treatments, 3 night temp, 2 cultivars, and 2 replications. Six plants were randomly selected from each treatment; 3 plants of each treatment and cultivar were used for anatomical study.

Uniform leaf and stem sections at leaf 5, the most recently matured, were taken from control and exposed plants at 2, 7 and 21 days after wind treatment. Tissue was fixed in Nawaschin (Craf V), dehydrated in TBA, embedded in paraplast, and sectioned at 15 μm. Selected specimens were passed through a graded series of xylene and iso-amyl acetate, critical point dried, mounted, and plated with gold palladium for scanning electron microscope analysis (ETEC).

We determined leaf thickness, leaf midrib thickness, palisade cell length, and diam of largest phloem in midrib; on stems we measured cortex thickness measured from the primary xylem to the outer edge of secondary phloem, diam of xylem vessels greater than 9.5 μm, and diam of largest phloem elements.

Expt. II. Photosynthesis and respiration. 'Park's Whopper Hybrid' was grown in the growth chamber as in Expt. I Temp were 26.5°C (day) and 15.5°C ± 1°C (night). The experiment was completely randomized with 6 replications per treatment. Exposure treatments and time of application were the same as those in Expt. I. After exposure, the plants were returned to the growth chamber. Net photosynthesis in light and net respiration in the dark were measured for half of the replicates on day 1 and for the remaining half on day 5 after treatment. Rates of CO_2 exchange were measured by a Beckman Model 215A infrared gas analyzer using a closed system. The plant chamber (plexiglass, 60 × 30 cm) was removable to permit exchange of plants. Air in the chamber was moved upward at 2.8 m/sec by a fan in the heat exchanger. Temp was 25°C ± 3°. Radiant flux density at the top of the plant canopy was 1.5 $\mu w/cm^2$ at 450 nm, 20 $\mu w/cm^2$ at 475 nm, 120 $\mu w/cm^2$ at 550 nm, 246 $\mu w/cm^2$ at 600 nm, 350 $\mu w/cm^2$ at 650 nm, 393 $\mu w/cm^2$ at 700 nm, and 360 $\mu w/cm^2$ at 750 nm, as supplied by four 300-watt, cool-beam medium spotlights.

Net photosynthesis was recorded as the time required for CO_2 to be lowered 100 to 150 ppm in a range from 400 to

[1]Received for publication May 17, 1977. Contribution No. 605-j, Department of Horticulture and No. 1661-j, Department of Agronomy, Agricultural Research Service, USDA, NCR, in cooperation with Agriculture Experiment Station, Kansas State University, Manhattan 66506.

[2]Former Graduate Research Assistant. Present address: Vegetable Crop Extension Specialist, University of Massachusetts, Amherst, MA 01002.
[3]Research Horticulturist.
[4]Soil Scientist, ARS, USDA, NCR.

200 ppm with the lights on. The time for CO_2 to increase was taken as dark respiration. Readings, begun at 1800 hr, were completed in 16 hr.

Rates of net photosynthesis and respiration are reported as mg of CO_2/plant per hr. Leaf area was not measured because wind had severely distorted and caused necrotic areas within the leaves. Plant dry wt was determined.

Results and Discussion

Expt. I. Anatomical study. Exposing tomato plants to a 1,340 cm/sec wind for 10 and 20 min resulted in no anatomical changes of either stem or leaf tissue, although the 20 min wind did cause leaf dehydration and development of necrotic areas (Fig. 1 and 2).

Sandblast damage to stem and leaves was extensive (Fig. 1). Exposing plants to 10 min of wind-plus-sand destroyed epidermal and underlying collenchyma tissue. Plants developed a secondary epidermis and extensive wound callus, 21 days after exposure. Radial growth was not restricted; treated plants had only slightly larger vessels than did control plants after 21 days (Table 1).

Treating plants with wind-plus-sand for 20 min caused more extensive damage. Wounds extended into the vascular cambium and in some extreme cases into the pith (Fig. 3). Two days after wind treatment, wound periderm had started to form in the layer of cells subtending wounded tissue (Fig. 4).

Twenty-one days after the 20 min wind-plus sand treatment, radial growth was less at 21°C (night) than in control plants but equal to or greater than that in plants at 10 and 15°C nights. In contrast, Greig et al. (9) noted narrower stems under similar conditions but they had used an abrasive flux rate 4 times greater than those used in this experiment.

Damaged stems had a developed layer of elongated chlorenchyma cells immediately below the epidermis (Fig. 5). The layer averaged 85-μm as compared to a 35 μm average in control plants. The enlarged portion of the chlorenchyma layer generally was on one side or at different locations around the stem.

Most leaves were destroyed when plants were exposed to 20 min of wind-plus-sand. Leaf, midrib, and palisade cell thickness were considerably greater than those of control plants (Table 1).

Results of this study agreed with previous work that indicated long exposure to wind alone (2 to 40 days) is necessary to cause anatomical changes (6, 16, 17, 18). Brown lesions that formed on tomato leaves from 20-min wind treatments were also reported by Mackerron (11) on wind-damaged strawberry leaves.

Wound periderm formation 2 days after the 20 min wind-plus-sand treatments, indicated that nucleic acids and ATP needed to initiate cell division probably was produced immediately after wounding (see Expt. I).

The elongated chlorenchyma cells were possibly caused by

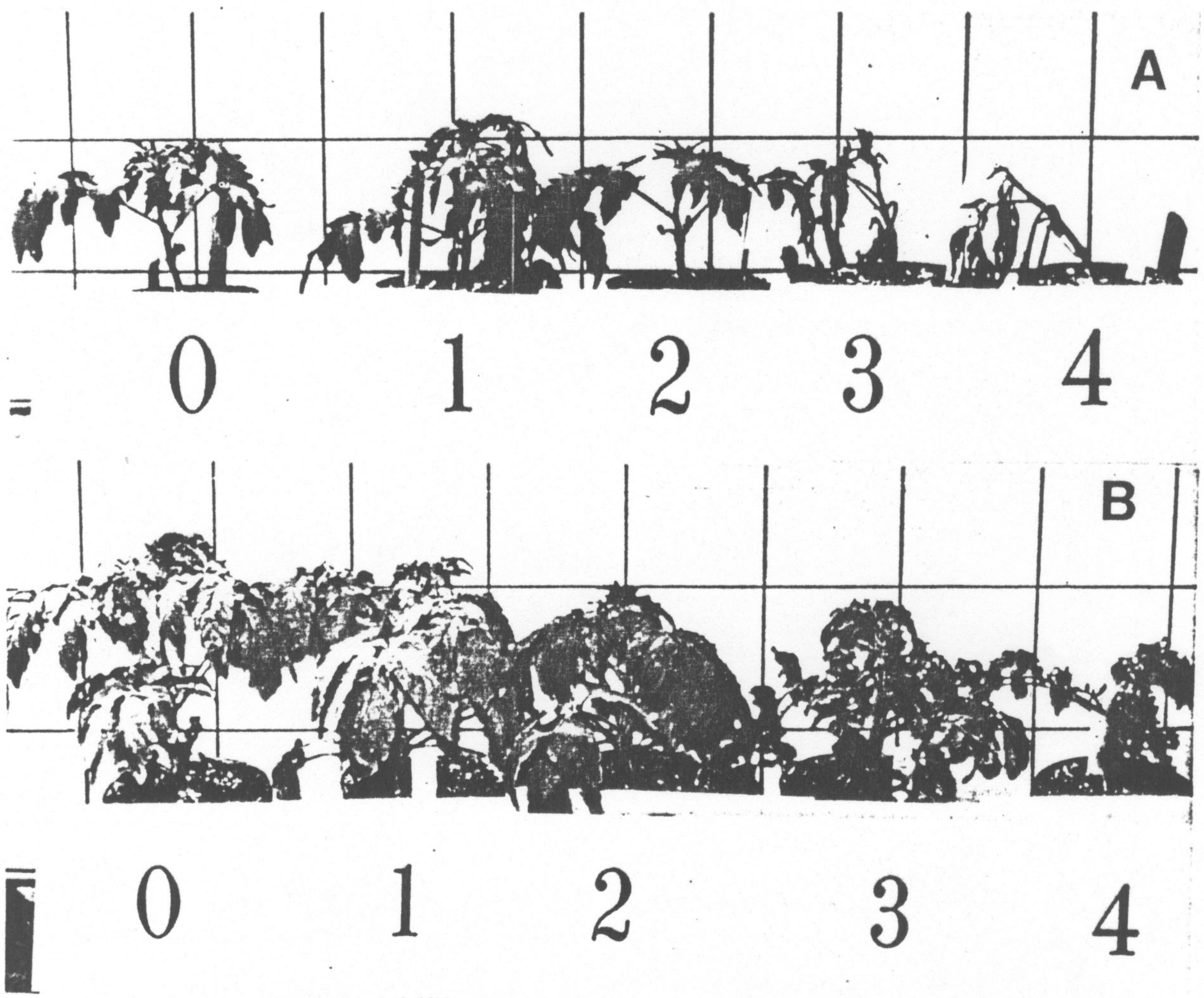

Fig. 1. Tomato plants grown at: (A) 21°C (night immediately after wind and wind-plus-sand treatments showing severe wilting and sandblast damage; (B) 15.5°C (night) 7 days after wind and wind-plus-sand treatments, showing severe leaf curling. Treatments: 0 = Control, no wind; 1 = 10 min wind at 1,340 cm/sec, 2 = 20 min wind, 3 = 10 min of wind-plus-sand, 4 = 20 min of wind-plus-sand.

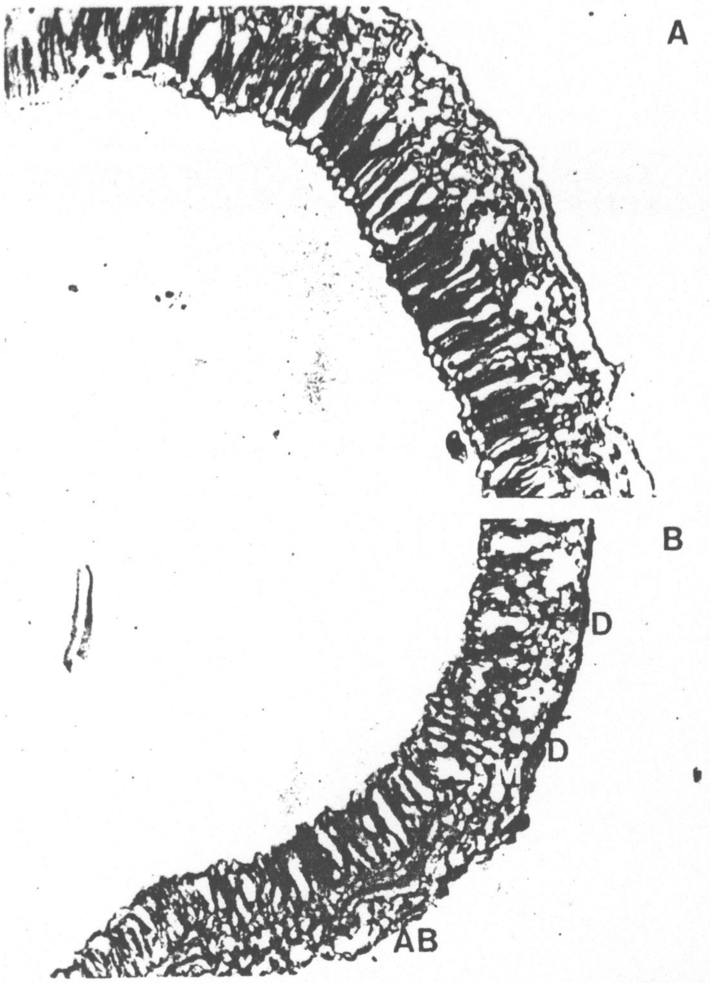

Fig. 2. Cross section of tomato leaf from: (A) no wind, control plant at same age as exposed plants; (B) tomato plant 7 days after exposure to wind alone for 20 min, showing desiccation of epidermis and spongy mesophyll on the abaxial surface (× 265). AB = abaxial surface, M = spongy mesophyll, D = desiccated area

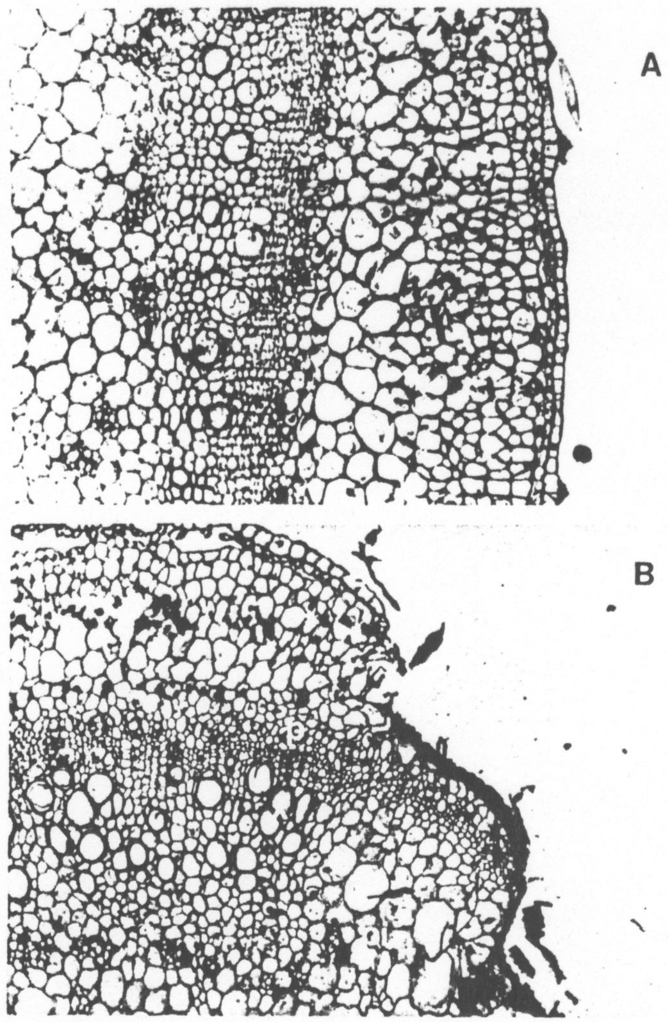

Fig. 3. Cross section of tomato stem: (A) no wind, control plant at same age as exposed plants; (B) 2 days after being exposed to 20 min of wind-plus-sand, showing extensive erosion through the cortex and vascular tissue into the pith (× 265). e = epidermis, p = phloem, x = xylem, c = cortex, pi = pith

ethylene produced from wounded cells. Ethylene has been shown to cause cell and stem swelling (10). Normally old tomato stems develop an extensive layer of chlorenchyma, but those cells remain almost circular in cross section and are not appreciably elongated. Additional chloroplasts in this layer might have helped to compensate for the loss of viable photosynthetic leaf area 7 to 21 days after exposure to wind-plus-sand.

Expt. II. Photosynthesis and respiration. All wind and

Table 1. The effect of no wind (control), wind-plus-sand, and night temp on tomato leaf anatomy at 3 stages after treatment.

		Control				Wind-plus-sand (20 min)			
Night temp (°C)	Days post treatment	Leaf thickness (μm)	Midrib thickness (μm)	Palisade layer thickness (μm)	Max diam of phloem (μm)	Leaf thickness (μm)	Midrib thickness (μm)	Palisade layer thickness (μm)	Max diam of phloem (μm)
21	2	218[z]	750	98	8	185	855	83	9
	7	160	680	100	11	190	705	92	9
	21	245	650	135	8	200	560	100	9
15.5	2	210	560	103	8	225	775	113	7
	7	218	568	104	18	271	705	133	10
	21	343	963	138	11	438	1075	190	8
10	2	380	900	130	10	300	1000	150	9
	7	250	875	120	13	330	1025	148	10
	21	250	1250	110	13	475	1730	175	10

[z]All means are a minimum of 3 samples.

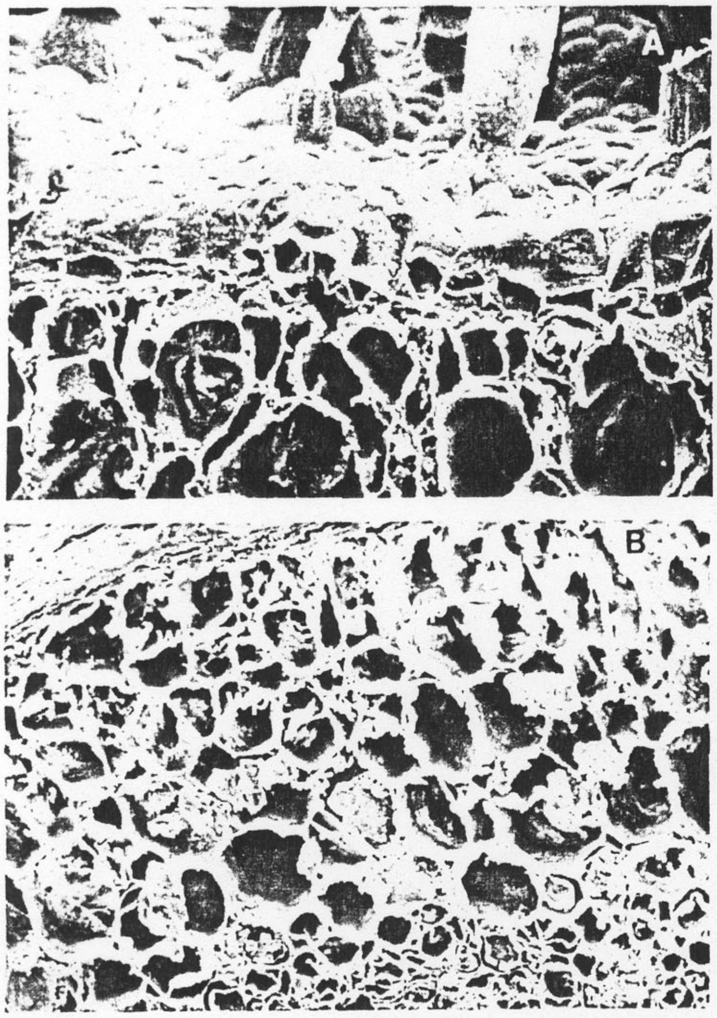

Fig. 4. SEM micrograph of a tomato stem cross section: (A) no wind, control plant at same age as exposed plants; (B) 2 days after exposure to 20 min of wind-plus-sand, showing initiation of wound periderm and newly formed cell walls (× 300). wp = wound periderm

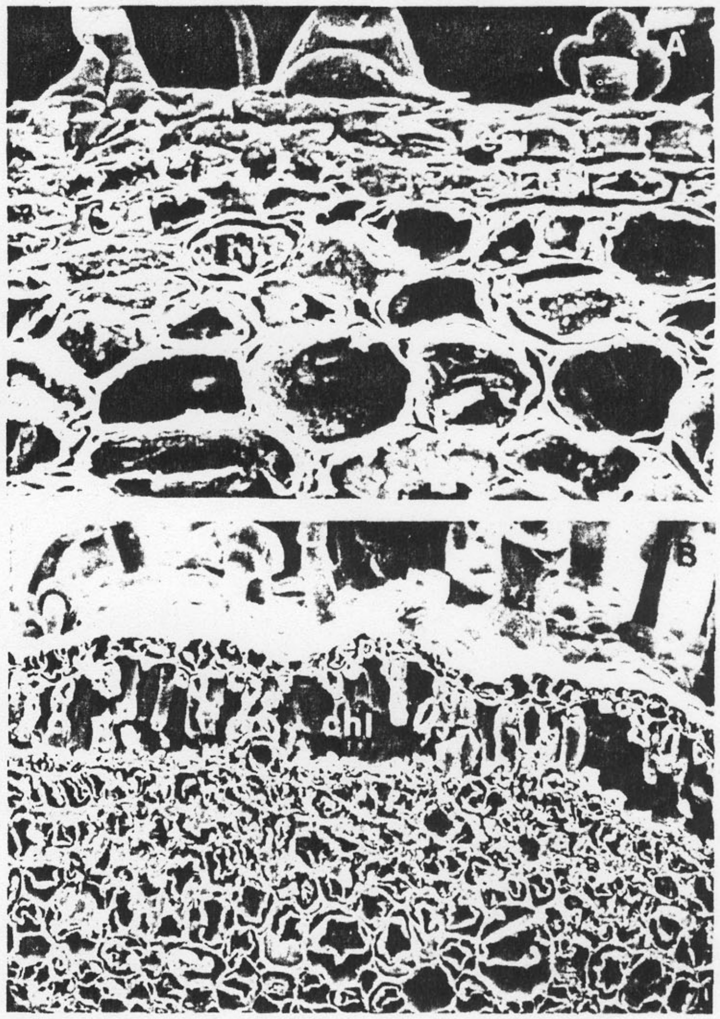

Fig. 5. SEM micrograph of a tomato stem cross section: (A) no wind, control plant at same age as exposed plants; (B) 21 days after exposure to 20 min of wind-plus-sand showing an extensive layer of elongated chlorenchyma immediately below the epidermis (× 200). epi = epidermis, chi = chlorenchyma

wind-plus-sand treatments reduced dry wt and net photosynthetic rates (mg CO_2/plant per hr) significantly, as compared with control plants, except for plants exposed to wind alone for 10 min on day 1 (Table 2). Plants exposed to wind and to wind-plus-sand for 20 min had significantly lower photosynthetic rates than plants exposed to wind alone for 10 min. Five days after exposure, differences among treatments were not significant.

On day 5, there was no significant difference in dry wt among treatments or in dry wt accumulated between day 1 and 5. The growth rate of damaged plants equaled that of controls.

Net respiration rates of the tomatoes were not significantly different on either day 1 or 5.

Dry wt and net photosynthetic rate reduction with increasing wind speed and/or plant damage reported here closely agreed with previous work (7, 9, 12, 16, 17, 18). By day 5, net photosynthetic rates indicated that the plants were compensating for loss of viable leaf area. Expt. I showed that 7 or 21 days after treatment leaf and palisade cell thickness were greater in severely damaged plants than in controls and at 21 days, plants treated with wind-plus-sand for 20 min had an enlarged layer of chlorenchyma cells. Armbrust (2) indicated that damaged wheat plants increased net photosynthesis (calculated on a live leaf-area basis). Chlorophyll also increased when 26% of the leaf area was killed (2). In our study, this probably explained why on day 5 there were no significant difference in net photosynthesis.

The effect of wind and wind-plus-sand treatments on net respiration rates in our study did not agree with previous work (2, 13), which indicates that as wind speed or sand damage

Table 2. The effect of no wind (control), wind, and wind-plus-sand on dry weight, photosynthesis, and respiration of tomato plants 1 day and 5 days after treatment.

	Dry wt (g)		Photosynthesis (mg CO_2/plant per hr)		Respiration (mg CO_2/plant per hr)	
Treatments	Day 1	Day 5	Day 1	Day 5	Day 1	Day 5
Control	3.6	3.3	42.6	60.3	67.7	61.2
Wind, 10 min	2.9	4.4	54.8	77.6	41.8	83.10
Wind, 20 min	2.3	3.1	23.2	47.8	53.5	70.3
Wind-plus-sand 10 min	1.3	3.1	26.7	48.1	63.4	80.6
Wind-plus-sand 20 min	2.2	2.8	11.8	45.0	46.1	58.3
LSD 5%	.7	N.S.	16.7	N.S.	N.S.	N.S.

increased, plant respiration increased. Considering the reduction in plant sizes, dry wt, or wounding in itself, severely damaged plants probably had increased respiration to compensate for injury. The anatomical study showed that by day 2 the process of wound healing (cell division) had begun. The respiration needed to initiate wound healing was not measurable in this experiment. Todd and Saren (6, 13) reported that increased respiration rates in plants exposed to wind treatments decreased rapidly after exposure.

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